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.

Designation: D3829 – 20a

Standard Test Method for Predicting the Borderline Pumping Temperature of Engine Oil[1]

This standard is issued under the fixed designation D3829; 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 prediction of the borderline pumping temperature (BPT) of engine oils through the use of a 16 h cooling cycle over the temperature range from 0 °C to −40 °C. The precision is stated for temperatures from –34 °C to –15 °C.

1.2 Applicability to petroleum products other than engine oils has not been determined.

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

1.3.1 *Exception*—This test method uses the SI based unit of milliPascal second (mPa·s) for viscosity, which is equivalent to centipoise (cP).

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

1.5 *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:*

D8278 Specification for Digital Contact Thermometers for Test Methods Measuring Flow Properties of Fuels and Lubricants

E563 Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature

2.2 *ISO Standards:*[2]

ISO 17025 General requirements for the competence of testing and calibration laboratories

ISO Guide 34 General requirements for the competence of reference material producers

3. Terminology

3.1 *Definitions:*

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

3.1.2 *digital contact thermometer (DCT), n*—an electronic device consisting of a digital display and associated temperature sensing probe.

3.1.2.1 *Discussion*—This device consists of a temperature sensor connected to a measuring instrument; this instrument measures the temperature-dependent quantity of the sensor, computes the temperature from the measured quantity, and provides a digital output. This digital output goes to a digital display and/or recording device that may be internal or external to the device.

3.1.2.2 *Discussion*—The devices are often referred to as a "digital thermometers," however the term includes devices that sense temperature by means other than being in physical contact with the media.

3.1.2.3 *Discussion*—PET is an acronym for portable electronic thermometers, a subset of digital contact thermometers (DCT).

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

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

3.1.5 *viscosity, n*—the ratio between the applied shear stress and rate of shear which is sometimes called the coefficient of dynamic viscosity and is a measure of the resistance to flow of the liquid.

3.2 *Definitions of Terms Specific to This Standard:*

[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] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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

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3.2.1 *borderline pumping temperature, n*—the maximum temperature at which the critical yield stress or critical viscosity occurs, whichever is the higher temperature.

3.2.2 *calibration oils, n*—those oils for establishing the instrument's reference framework of apparent viscosity versus speed from which the apparent viscosities of test oils are determined.

3.2.3 *critical viscosity, n*—the maximum viscosity at a defined shear rate to allow adequate flow of oil to the oil pump in an automotive engine. A higher viscosity can cause failure to maintain adequate oil pressure through the limiting of flow through the oil screen or oil inlet tubes.

3.2.4 *critical yield stress, n*—the maximum yield stress that allows oil to flow to the inlet oil screen in an automotive engine. With a higher yield stress, air may be drawn into the pump and cause failure to maintain adequate oil pressure through air-binding of the pump.

3.2.5 *shear rate, n*—the velocity gradient in fluid flow.

3.2.5.1 *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:

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

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

where:

$\dot{\gamma}$ = 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 in seconds for one revolution of the rotor.

For the specific apparatus being described in 6.1.1,

$$\dot{\gamma} = \frac{63}{t} \quad (3)$$

3.2.6 *shear stress, n*—the motivating force per unit area for fluid flow.

3.2.6.1 *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.

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

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

where:

T_r = torque applied to rotor, N·m,
M = applied mass, g,
R_o = radius of the shaft, mm,
R_t = radius of the thread, mm,
τ = shear stress at the rotor surface, Pa, and
h = height of the rotor, mm.

For the dimensions given in 6.1.1,

$$T_r = 31.7M \times 10^{-6} \quad (6)$$

$$\tau = 3.5M \quad (7)$$

3.2.7 *test oil, n*—any oil for which the apparent viscosity and yield stress are to be determined by use of the test method under description.

3.2.8 *yield stress, n*—the shear stress required to initiate flow.

3.2.8.1 *Discussion*—For all Newtonian fluids and some non-Newtonian fluids, yield stress is zero. An oil can have a yield stress that is a function of its low-temperature cooling rate, soak time, and temperature.

4. Summary of Test Method

4.1 An engine oil sample is cooled from 80 °C to the desired test temperature at a nonlinear programmed cooling rate over a 10 h period and held at the test temperature for the remainder of a 16 h period. After completion of the soak period, two standard torques of increasing severity are applied to the rotor shaft and the speed of rotation in each case is measured. From the results at three or more temperatures, the borderline pumping temperature is determined.

4.2 Alternatively, for some specification or classification purposes it may be sufficient to determine that the BPT is less than a certain specified temperature.

5. Significance and Use

5.1 Borderline pumping temperature is a measure of the lowest temperature at which an engine oil can be continuously and adequately supplied to the oil pump inlet of an automotive engine.

6. Apparatus

6.1 *Mini-Rotary Viscometer,*[3] consisting of one or more viscometric cells including a calibrated rotor-stator assembly, which are contained in a temperature-controlled aluminum block.

6.1.1 The viscometric cell has the following nominal dimensions:

Diameter of rotor	17.06 mm ± 0.08 mm
Length of rotor	20.00 mm ± 0.14 mm
Inside of diameter of cup	19.07 mm ± 0.08 mm
Radius of shaft	3.18 mm ± 0.13 mm
Radius of string	0.1 mm

6.2 *Weights:*

6.2.1 *Yield Stress Measurement*—A set of nine disks and a disk holder, each with a mass of 10 g ± 0.1 g.

6.2.2 *Viscosity Measurement*—Weight with mass of 150 g ± 1.0 g.

6.3 *Temperature Measuring Device*—Use either a DCT meeting the requirements described in 6.3.1 or liquid-in-glass thermometers as described in 6.3.2. A calibrated DCT or

[3] The sole source of supply of the apparatus known to the committee at this time is Cannon Instrument Co., P.O. Box 16, State College, PA 16801. 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.

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ASTM D3829-20a
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calibrated low temperature liquid-in-glass thermometer shall be used as the thermometer for temperature measurement below 25 °C independent of the instrument's temperature control, and shall be located in the thermowell.

NOTE 1—The display device and sensor must be correctly paired. Incorrect pairing will result in temperature measurement errors and possibly irreversible damage to the electronics of the display.

6.3.1 *Digital Contact Thermometer*—Use D02-DCT14 listed in Specification D8278. As an alternative to the 3 mm metal sheathed probe noted in Specification D8278, a glass sheathed DCT probe with a 6 mm O.D. is acceptable provided it meets the other requirements shown for D02-DCT14 in Specification D8278. A DCT display resolution of 0.01 C is preferable. If thermowell ID is larger than the probe OD, then a metallic sleeve must be used to fill the gap between the probe OD and thermowell ID with a length of 58 mm.

6.3.1.1 The DCT calibration drift shall be checked at least annually by either measuring the ice point or against a reference thermometer in a constant temperature bath at the prescribed immersion depth to ensure compliance with 6.3.1. With respect to an ice bath, Practice E563 provides guidance on the preparation and use of an ice bath. However, for this use, variance from the specific steps, such as water source, is permitted provided preparation is consistent. The basis for the variance is due to the reference being used to track change in calibration not verification.

NOTE 2—When a DCT's calibration drifts in one direction over several calibration checks, that is, ice point, it may be an indication of deterioration of the DCT.

6.3.2 For liquid-in-glass, LiG, thermometers, two are required. One LiG shall be a calibrated 76 mm partial immersion thermometer with a scale from +5 °C to 1 degree less than the lowest test temperature in 0.2 °C subdivisions. This low temperature LiG thermometer shall have a report of calibration showing the temperature deviation at each calibrated test temperature. The second LiG thermometer shall be a 76 mm partial immersion thermometer graduated from at least +70 °C to 90 °C in 1 °C subdivisions, which is used to verify the preheat temperature.

6.3.2.1 *Calibration Check*—Verify the low temperature thermometer at least annually against a reference thermometer in a constant temperature bath or an ice bath. The thermometer is to be inserted to its immersion depth. If using an ice bath, the ice point reading is to be taken within 60 min after the thermometer has been at test temperature for at least 3 min. If the corrected temperature reading deviates from the reference thermometer or the ice point then repeat this calibration check. If the thermometer deviates from the reference value on two successive checks then a full thermometer recalibration is needed.

6.3.2.2 *Recalibration*—A complete recalibration of the liquid-in-glass thermometer, while permitted, is not necessary in order to meet the accuracy ascribed to liquid-in-glass thermometer's design until the thermometers corrected measured temperature deviates from the reference thermometer or ice point by one scale division, or until five years has elapsed since the last full calibration.

6.4 *Temperature Control System*—Regulates the mini-rotary viscometer block temperature in accordance with the temperature requirements described in Table X1.1.

6.5 *Cell Cap*—A cover inserted into the top of the viscometer cell to minimize room air circulation into the cells is required for thermoelectrically cooled instruments. The cell cap is a stepped cylinder 38 mm ± 1 mm in length made of a low thermal conductivity material, for example, thermoplastic such as acetyl copolymers that have known solvent resistivity and are suitable for use between the temperature ranges of this test method. The top half is 28 mm ± 1 mm in diameter and the bottom half is 19 mm in diameter with a tolerance consistent with the cell diameter. The tolerance on the bottom half is such that it will easily fit into cell but not allow the cap to contact the rotor shaft. The piece has a center bore of 11 mm ± 1 mm. The cap is made in two halves to facilitate placement in the top of the cell.

6.5.1 Cell caps shall not be used in the direct refrigeration instruments, since such use would block the flow of cold, dry air into the stators to keep them frost-free.

6.6 *Supply of Dry Gas*—A supply of dry filtered dry gas to minimize moisture condensation on the upper portions of the instrument.

6.6.1 For thermoelectric cooled instruments, which use cell caps, the dry gas supply is connected to the housing cover. The supply of dry gas is discontinued when the cover is removed for the measurement phase of the test.

6.7 *Locking Pin*—A device to keep the rotor from turning prematurely and able to stop the rotor at the nearest half revolution by interaction with the rotor crossbar.

7. Reagents and Materials

7.1 *Low Cloud-Point, Newtonian Oil,*[3] a calibration oil of approximately 30 Pa·s viscosity at −20 °C for calibration of the viscometric cells. The calibration oil shall be obtained from suppliers complying with ISO Guide 34 and ISO 17025 with traceability to a national metrology institute (NMI).

7.2 *Methanol,* commercial or technical grade of dry methanol is suitable for the cooling bath.

7.3 *Oil Solvent,* commercial heptanes or similar solvent is suitable.

7.4 *Acetone,* technical grade of acetone is suitable provided it does not leave a residue upon evaporation.

8. Sampling

8.1 A representative sample of test oil free from suspended solid material and water is necessary to obtain valid results. If the sample in its container is received below the dew-point temperature of the room, allow to warm to room temperature before opening.

9. Calibration and Standardization

9.1 *Temperature Control Calibration Procedure*—Calibrate the MRV temperature control by comparing the instruments displayed temperature against a thermometer in the thermowell. The thermometer used shall meet the requirements in 6.3.

9.1.1 Place 10 mL of a typical test fluid and rotor in each cell. If required, place cell caps over each cell then place cover on instrument. Cell caps shall not be used on direct refrigeration instruments (see 6.5.1).

9.1.2 Place the thermometer in the thermowell. See Note 3. This thermowell is to be used for all temperature measurements below 25 °C.

NOTE 3—Prior to inserting the thermometer or DCT probe in the thermowell, place several drops (~3) of a heat transfer fluid such as 50/50 water/ethylene glycol mix, CCS reference oil CL100 or a dewaxed low viscosity mineral oil in the thermowell.

9.1.3 Make the temperature measurements at 80 °C then at least three measurements that are 5 °C apart from –5 °C to the lowest test temperature used including both end points to establish a calibration curve for this combination of thermometer and the instrument's temperature control. Make at least two temperature measurements at every calibration temperature with at least 10 min between observations.

NOTE 4—All temperatures in this test method refer to the actual temperature and not necessarily the indicated temperature.

9.1.4 Follow the instrument manufacturers instructions for correcting the instrument's measured temperature. Alternatively, establish a correction equation between thermometer and instrument's measured temperature then adjust each temperature of the cooling program by the offset determined with the correction equation.

9.2 *Viscometer Cell Calibration*—The calibration constant of each rotor/stator combination is determined at –20 °C using a viscometric standard as a test sample.

9.2.1 The same 150 g mass is normally used for both calibration and viscosity measurements. However, different weights may be used for calibration and viscosity measurements provided they are certified to be 150 g ± 0.1 g.

9.3 Following the steps in 10.1, prepare the cells for calibration using the calibration oil as the sample.

9.4 Use the calibration temperature profile or the cooling program for –20 °C test temperature, follow the owner's manual instructions for the instrument to initiate the cooling profile program.

9.5 Place the thermometer in the thermowell at least 30 min prior to executing 9.7. See Note 3. The thermowell location is to be used for calibration and temperature monitoring during the test procedure.

9.6 At the completion of the temperature profile, check that the final test temperature is at the desired calibration temperature within ±0.1 °C. Final test temperature is to be verified independently of the instrument's temperature control with a thermometer that has been in the thermometer well for at least the time proscribed in 9.5. See Note 3.

9.7 Beginning with the cell farthest to the left facing the instrument, perform the steps in 10.6.3.

9.8 Repeat 9.7 for each of the remaining cells in numerical order.

9.9 Calculate the viscometer constant for each cell (rotor/stator combination) using Eq 8:

$$C = \eta_0 / t \quad (8)$$

where:

η_0 = viscosity of the standard oil, mPa·s at –20 °C,
C = cell constant for an applied mass of 150 g, mPa, and
t = time in seconds for three revolutions.

9.10 If corrected values for the instrument's temperature control and thermometer deviate by more than the tolerance (±0.1 °C), use the procedure in X2.1 to assist in determining the cause and correction.

10. Yield Stress and Viscosity Measurement Procedure

10.1 *Viscometric Cell Preparation:*

10.1.1 If the cells are not clean, clean according to 10.7 cleaning procedure.

10.1.2 Place 10 mL ± 0.2 mL of test oil sample into a clean cell.

10.1.2.1 All cells should contain a fluid and rotor; if there are less than a full set of samples to run, fill each of the unused cells with 10 mL of a typical test sample.

10.1.3 Repeat 10.1.2 until all test samples are in their cells.

10.1.4 Place each rotor in its cell, and place upper pivot pin in position, including those for any unused cells.

NOTE 5—Before inserting the rotors in the cells, inspect each rotor to be sure that the shaft is straight, that the rotor surface is smooth and free from dents, scratches, and other imperfections. For rotors with a bearing point at the bottom of the shaft, ensure that the point is sharp and centered on the rotor shaft. If these conditions are not met, repair or replace the rotor.

10.1.5 *Optional*—If available for instrument, install a cell cap on all cells, including any unused cells.

10.1.6 For each cell, except any unused ones, place a loop of the nominal 700 mm long string over the crossbar. Hang the string over the timing wheel with a small weight attached such as a large paper clip. Wind the string around the shaft until the end is about 100 mm below the wheel. Do not overlap windings.

NOTE 6—The strings can be pre-wound around the shafts before they are installed in 10.1.4.

10.1.6.1 Engage the locking pin to prevent the rotor from turning.

10.1.6.2 Lay the remaining string over the top of the bearing plate letting it hang over the back of the plate.

10.1.6.3 Repeat 10.1.6 until all cells with samples to be measured are prepared.

10.1.7 Place the housing cover over the viscometric cells.

10.1.8 Connect the dry gas supply to the housing cover, as noted in 6.6. Set the dry gas flow to approximately 1 L/h. Increase or decrease the flow as necessary to minimize frost or moisture condensation around the cells.

10.2 Select the cooling profile for the desired test temperature and follow the instrument instructions to initiate the program. Table X1.1 shows cooling program requirements for each test temperature.

10.3 Place the thermometer in the thermowell at least 30 min prior to completion of the test. See Note 3. The same thermowell location is to be used for all measurements and must be the same one as was used for calibration.

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ASTM D3829-20a

10.4 At the completion of the cooling profile, check the time-temperature plot for the run to ensure that the time-temperature profile is within tolerance and that the test temperature as measured in the thermowell is within ±0.2 °C of the final test temperature. Both of these checks may be done automatically by the control software incorporated in some instruments. Final test temperature is to be verified independently from the instrument's temperature control using a thermometer that has been in the thermowell for at least 30 min prior to reaching the test temperature. See Note 3. If the final test temperature is more than 0.1 °C from the set point on two consecutive runs, the instrument's temperature control must be recalibrated according to 9.1.

10.5 If the temperature profile is within tolerance, proceed with measurements. If not, then abort the test and recalibrate instrument's temperature control as in 9.1.

10.6 *Measurement of the Yield Stress and Viscosity:*

10.6.1 Immediately prior to starting measurements, take the cell housing cover off the instrument.

10.6.2 *Yield Stress Determination*—Starting with the cell farthest to the left while facing the instrument, use the following procedure for each cell in turn, bypassing the unused cells.

10.6.2.1 Align the pulley wheel with the rotor shaft of the cell to be tested.

10.6.2.2 Hang the string over the timing wheel such that the string hangs past the front of the housing. Make sure that the disk holder clears the edge of the bench during testing. (Do not allow the rotor shaft to turn.)

10.6.2.3 Suspend the disk holder from the string.

10.6.2.4 For instruments with automatic timing, start timing and then release the locking pin. For manual timing, start timing immediately after the locking pin is disengaged.

10.6.2.5 Observe whether the end of the crossbar moves more than 3 mm in 15 s. (This 3 mm is approximately twice the diameter of the crossbar.) An alternative procedure is the use of a marked rotation of the timing wheel equivalent to a crossbar movement of 3 mm.

10.6.2.6 Electronic or timing wheel motion-sensing devices, which are available on some instruments, are suitable alternatives to direct observation.

10.6.2.7 If rotor movement of more than 3 mm in 15 s is observed in 10.6.2.5, remove the disk holder from the end of the string, and proceed to 10.6.3.

10.6.2.8 If a rotor movement of less than 3 mm in 15 s is observed in 10.6.2.5, stop timing and lift the disk holder so it is not supported by the string. Then add an additional 10 g disk to disk holder.

NOTE 7—As additional disks are added to the disk holder it is necessary to suspend the holder with the additional disks from the string and restart timing without the use of the locking pin for the remainder of the yield stress assessment. When using software available for some instruments, ensure that the mass applied is the mass requested by the program.

10.6.2.9 Carefully and gently, suspend the disk holder from the string and start timing.

10.6.2.10 Repeat steps in 10.6.2.8 and 10.6.2.9 until the accumulated mass causes rotation of the rotor. At this point, remove the disk holder from the string.

10.6.2.11 If no rotation is observed with a total of 100 g, record that the yield stress is >350 Pa, and proceed with 10.6.3.

10.6.3 *Viscosity Determination:*

10.6.3.1 Gently suspend the 150 g mass from the string.

10.6.3.2 If the applied mass moves the rotor, as soon as the cross-arm is clear of the locking pin, reengage the locking pin. Allow rotation to continue until the cross-arm contacts the locking pin causing rotation to stop. If no appreciable rotation occurs, terminate the test and proceed to 10.6.3.7.

NOTE 8—Yield stresses exceeding the stress exerted by 150 g have been encountered.

10.6.3.3 When using instruments capable of timing rotation automatically, initiate viscosity measurement by starting timing, then release the locking pin. When timing manually, start timing immediately after the locking pin is disengaged.

10.6.3.4 Stop the timer after three revolutions of the rotor from point of release. When the time for one revolution is greater than 60 s, time only one revolution.

NOTE 9—The timing of three revolutions may be done automatically.

10.6.3.5 After completing three revolutions (one revolution if the time is greater than 60 s), remove mass from string.

10.6.3.6 Record both the time and the number of revolutions timed.

10.6.3.7 If no rotation occurs with the application of the 150 g mass, record the result for that sample as being "Too Viscous To Measure" (TVTM).

10.6.3.8 Repeat 10.6.2 – 10.6.3.7 for the remaining cells to be measured.

10.7 *Cleaning:*

10.7.1 When all measurements have been completed, set the instrument to warm to room temperature or somewhat above. Cleaning cells above a temperature of 55 °C is not recommended.

10.7.2 When the desired cleaning temperature is reached:

10.7.2.1 For instruments with non-removable cells, remove strings, rotors, and cell caps, when used, then proceed with 10.7.3.

10.7.2.2 For instruments with removable cells, either follow instructions for non-removable or remove cells from instrument. The removable cells are to be cleaned by generally following the instructions in 10.7.3.

10.7.3 *Cleaning Cells:*

10.7.3.1 Remove oil samples from cells by using a vacuum hose.

10.7.3.2 Using an appropriate solvent, rinse, the cells at least three times with approximately 15 mL of an appropriate solvent for each rinse. Then rinse once with acetone.

10.7.3.3 Remove traces of residual solvent by flushing cell with dry air or preferably with a vacuum hose to prevent contamination with house air. (**Warning—**When flushing cells with air, be sure that the air is clean and free from oil, water and other contaminants as these could be left in the cell. House air is frequently contaminated.)

10.7.4 Clean rotors with appropriate sample solvent, and dry.

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ASTM D3829-20a
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