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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~~ 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 to −40°C. The precision is stated for temperatures from -34 to -15°C.

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

1.3 ~~This test method uses the millipascal (mPa·s), as the unit of viscosity. For information, the equivalent centipoise unit is shown in parentheses.~~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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E1137 Specification for Industrial Platinum Resistance Thermometers

3. Terminology

3.1 *Definitions:*

3.1.1 *apparent ~~viscosity—~~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, or display of the temperature, or both. This device is sometimes referred to as a *digital thermometer*.

3.1.3 *Newtonian oil or ~~fluid—~~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—~~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 *shear ~~rate—~~rate, n—*the velocity gradient in fluid flow. 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 being described), and ignoring any end effects, the shear rate is given as follows:

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

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

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

where:

G_r = shear rate at the surface of the rotor in reciprocal seconds, s^{-1},
Ω = angular velocity, rad/s,
R_s = stator radius, mm,
R_r = rotor radius, mm, and
t = time in seconds for one revolution of the rotor.

For the specific apparatus being described in ~~5.1.1~~6.1.1,

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

3.1.6 *shear ~~stress—~~stress, n—*the motivating force per unit area for fluid flow. Area is the area under shear. For the rotary viscometer being described, the rotor surface is the area under shear.

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

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

where:

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

For the dimensions given in ~~5.1.1~~6.1.1,

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

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

3.1.7 *~~viscosity—~~viscosity, n—*the ratio between the applied shear stress and rate of shear. It is sometimes called the coefficient of dynamic viscosity. This value is thus a measure of the resistance to flow of the liquid. The SI unit of viscosity is the pascal second (Pa·s). ~~The centipoise (cP) is one millipascal second (mPa·s) and is often used.~~

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *borderline pumping ~~temperature—~~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—~~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. Calibration oils, which are essentially Newtonian fluids, are available commercially, and have an approximate viscosity of 30 000 mPa·s (30 000 cP) at −20°C.[2,2]

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

3.2.6 *yield ~~stress—~~stress, n—*the shear stress required to initiate flow. For all Newtonian fluids and some non-Newtonian fluids, yield stress is zero. Some engine oils have a yield stress that is a function of their low-temperature cooling rate, soak time, and temperature.

[2] 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.

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,*[2]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	17.0 mm
Length of rotor	20.0 mm
Inside of diameter of cup	19.0 mm
Radius of shaft	3.18 mm
Radius of string	0.1 mm

6.2 ~~*Thermometers,*~~*Temperature Measuring Device*—Use either a calibrated DCT described in 6.2.1 or liquid-in-glass thermometers as described in 6.2.2~~for measuring temperature of the block. Two are required, one graduated from at least +70 to 90°C in 1°C subdivisions, the other with a scale from at least −36 to +5°C in 0.2°C subdivisions.~~. The DCT or the calibrated low temperature liquid-in-glass thermometer shall be used as the thermometer for temperature measurement 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.

6.2.1 A DCT shall meet the following:

(1) A range from -45 to 100°C with a display resolution to at least 0.01 °C.

(2) The only acceptable sensors are a resistance temperature device (RTD), such as a platinum resistance thermometer (PRT) or a thermistor that are either glass or metal sheathed.

(3) For metal sheathed probe, use a 3 mm diameter probe with a sensing element that is less than 30 mm in length; a metal sheathed probe requires a thermowell sleeve measuring 6 mm outside diameter by 58 mm long with a hole in the center to accommodate the probe. For a glass sheathed probe, use a probe 6 mm in diameter containing a sensing element less than 12 mm in length.

(4) A combined (display and probe) minimum accuracy of ±50 mK (0.05°C).

(5) A response time of less than or equal to 25 s as defined in Specification E1137.

(6) A drift of less than 50 mK (0.05°C) per year.

(7) Error of less than 50 mK (0.05°C) over the range of intended use.

(8) The DCT shall have a report of temperature calibration from a calibration laboratory with demonstrated competency in temperature calibration which is traceable to a national calibration laboratory or metrology standards body.

(9) The DCT shall be calibrated over a range from -40 to 85°C with at least 4 data points evenly distributed over the range of -40 to -1°C. The test report shall include the calibration data.

6.2.1.1 The DCT calibration 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 6.2.1 (6 and 7).

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.

6.2.2 Two liquid-in-glass thermometers are required. One 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. The low temperature thermometer shall have a report of calibration showing the temperature deviation at each calibrated test temperature. The second shall be a 76 mm partial immersion thermometer graduated from at least +70 to 90°C in 1°C subdivisions.

6.2.2.1 *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.

6.2.2.2 *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.

6.3 *Temperature Control System*—A means of lowering the temperature to the predetermined test temperature at a controlled, nonlinear rate.

6.4 *Circulating System,*[2]for supplying suitable liquid coolant to the block as needed. Methanol is a suitable coolant. One should observe toxicity and flammability precautions that apply to the use of methanol. The circulating system must be capable of maintaining test temperature over a 16-h test period. If methanol is leaking from the system, discontinue the test and repair the leak before continuing.

6.5 *Chart Recorder,* to verify that the correct cooling curve is being followed, it is recommended that a chart recorder be used to monitor the block temperature.

6.6 *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 ±1 mm (1.5 ±0.05 in.) 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 ±1 mm (1.10 ±0.05 in.) in diameter and the bottom half is 19 mm (0.745 in.) 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 ±1 mm (0.438 ±0.05 in.). The cap is made in two halves to facilitate placement in the top of the cell.

6.6.1 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.

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

6.7.1 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.

6.8 *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,*[2]of approximately 30 Pa·s (30 000 cP) viscosity at −20°C for calibration of the viscometric cells.

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 6.2.

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 6.6.1).

9.1.2 Place the thermometer in the thermowell. See Note 3. This thermowell should be used for all measurements.

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. For instruments using an independent temperature controller, see X2.1 for calibration guidance.

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 weight is normally used for both calibration and viscosity measurements. However, different weights may be used for calibration and viscosity measurements if the mass of the each of the two weights is certified to be 150 ± 0.1 g.

9.3 Using the steps in 10.1, prepare the cells for the calibration test cycle.

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.

9.4 Using 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 ~~Calibration~~ Place the thermometer in the thermowell at least 30 min prior to executing 9.7. See Note 3~~is required for the temperature dial on the panel.~~. The thermowell location is to be used for calibration and temperature monitoring during the test procedure.

~~8.1.1 Place calibrated thermometer in position (see assembly instructions) and turn the RESET dial fully counterclockwise.~~

~~8.1.2 Set the dial at 100 and allow to cool to control temperature. Allow approximately 30 min for temperature equilibrium to be established.~~

~~8.1.3 Record the temperature.~~

~~8.1.4 Repeat 8.1.3 and 8.1.4 for dial settings of 200, 300, 500, 700, and 900 or until –37°C has been reached.~~

~~8.1.5 On one- or two-cycle semilog graph paper, plot log (reading) versus temperature (°C) to establish calibration curve. See Fig. 1.~~

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, follow this procedure for each cell in turn.

9.7.1 Align the pulley wheel with the rotor shaft for the cell to be tested.

9.7.2 Hang the string over the timing wheel.

9.7.3 Suspend the weight holder plus a 10-g weight (total mass 20 g) from string.

9.7.4 Disengage the locking pin.

9.7.5 As soon as the crossbar is clear of the locking pin, reengage the locking pin. This will stop the rotation at approximately one half revolution.

9.7.6 Remove weight holder and 10-g weight from the string.

9.7.7 Suspend the 150-g weight from the string.

9.7.8 Disengage the locking pin and simultaneously start timing as soon as the rotor is released.

9.7.9 Determine the time for exactly three revolutions of the rotor.

NOTE 6—For some instruments, the timing may be done automatically.

9.7.10 After three revolutions, reengage the locking pin and remove the weight from the string.

9.7.11 Record the time for three revolutions and the cell number.

9.8 Repeat 9.7.1–9.7.11 for each of the remaining cells in numerical order.

9.9 ~~The calibration of each viscometric cell (viscometer constants) can be determined with the viscosity standard and the following procedure~~ Calculate the viscometer constant for each cell (rotor/stator combination) with the following equation:

$$C = \frac{\eta_o}{M \cdot t} \tag{8}$$

~~at –20~~

where:

η_o = viscosity of the standard oil, mPa·s at -20°C,
C = cell constant, Pa,
M = applied mass, g, and
t = time in seconds for one revolution.

~~± 0.2°C.~~

~~8.2.1 Use steps 9.1.1-9.1.5.~~

~~8.2.2 Set the temperature-control, ten-turn dial to correspond to –20°C and turn switch to cool.~~

8.2.3 Allow to soak at −20 ± 0.2°C for at least 1 h, making small temperature adjustments, if necessary, to maintain the test temperature.

8.2.4 At the end of the soak period record the temperature reading (test temperature), and remove the cover of the viscometer cell.

8.2.5 Proceed to steps 9.2.1-9.2.3.

8.2.6 Place a 150-g mass on the string in accordance with instructions in 9.3.1.

8.2.7 Repeat 8.2.5 and 8.2.6 for each of the remaining cells, taking the cells in order from left to right.

8.2.8 Calculate the viscometer constant for each cell (rotor/stator combination) with the following equation:

$$C = \frac{\eta_o}{Mt} \quad (8)$$

where:

η_o = viscosity of the standard oil, mPa·s (cP) at −20°C,
C = cell constant, Pa (N/m^2 g),
M = applied mass, g, and
t = time in seconds for one revolution.

8.3 It is essential that the ice point of the calibrated thermometer be measured initially and periodically thereafter, and that the corrections be adjusted to conform with any change in the ice point.

9.10 Check the rate of cooling periodically to ensure a standard cool down rate. The reset knob should rotate one complete revolution each hour for 10 h, but must not turn during the final 6-h soak period. The approximate temperature of the thermometer at hourly intervals is shown in If corrected values for the instrument's temperature control and thermometer deviate by more than Table 1 for cooling to a final temperature of −20°C, and should be attained within the limits shown in the table. A chartthe tolerance (±0.1°C), use the procedure in X2.1 recorder may be used to monitor the temperature cool down rate.to assist in determining the cause and correction.

10. Yield Stress and Viscosity Measurement Procedure

10.1 *Test Sample and Viscometric Cell Preparation:*

10.1.1 WithIf the viscometric cells clean and at ambient temperature,cells are not clean, see 10.7 removefor the nine rotors.cleaning procedure.

10.1.2 Place a 10 ± 1 mL oil sample in each cup. ±0.2 mL of test oil samples into the clean cells.

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 *Loading Cells with Test Oils*—Place each rotor and test oil in its cell, and place upper pivot pin in position, including any unused cells. See Note 5.

10.1.4 Install the rotors in the proper stators and install the upper pivots.If available for instrument, install a cell cap on all cells, including any unused cells.

10.1.5 Place one of the loops in the For each cell, except any unused ones, place a loop of the nominal 700-mm long string over the crossarm at the top of the rotor shaft and wind all but 200 mm of the length of 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. Loopshaft until the remaining end of the string over the top bearing cover. Make sure that the marked (red) end of the crossarm at the top of the rotor shaft points to the rear of the viscometer unit.end is about 100 mm below the wheel. Do not overlap windings.

NOTE 7—The strings can be pre-wound around the shafts before they are installed in 10.1.3.

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

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

10.1.5.3 Repeat 10.1.5–10.1.5.2 until all cells with samples to be measured are prepared.

10.1.6 Place the housing cover in place to minimize the formation of frost on the cold metal parts exposed to air. If frost formation persists, a small container of a desiccant such as Drierite may be placed under the cover to absorb excess moisture.over the viscometric cells.

10.1.7 Turn the switch to HEAT to preheat the oil sample to 80 ±Connect the dry gas supply to the housing cover, as noted in 6.73°C. The rate of increase of temperature is approximately 3°C/min. Hold the temperature of the oil at this temperature for 2 h to allow solution of any material not in true solution at room temperature. . 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.

9.1.7 Set the temperature control ten-turn dial to the test temperature desired (see Section 8), turn the reset knob to the extreme clockwise position, turn the switch to COOL, and record the time as start of 16-h conditioning period.