



# Standard Test Method for Estimating Apparent Vapor Pressures and Molecular Weights of Lubricating Oils<sup>1</sup>

This standard is issued under the fixed designation D2878; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers a calculation procedure for converting data obtained by Test Method D972 to apparent vapor pressures and molecular weights. It has been demonstrated to be applicable to petroleum-based and synthetic ester lubricating oils,<sup>2</sup> at temperatures of 395 K to 535 K (250 °F to 500 °F). However, its applicability to lubricating greases has not been established.

NOTE 1—Most lubricants boil over a fairly wide temperature range, a fact recognized in discussion of their vapor pressures. For example, the apparent vapor pressure over the range 0 % to 0.1 % evaporated may be as much as 100 times that over the range 4.9 % to 5.0 % evaporated.

1.2 The values stated in SI units are to be regarded as the standard. In cases in which materials, products, or equipment are available in inch-pound units only, SI units are omitted.

1.3 **WARNING**—Mercury has been designated by many regulatory agencies as a hazardous material that can cause central nervous system, kidney and liver damage. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Material Safety Data Sheet (MSDS) for details and EPA's website—<http://www.epa.gov/mercury/faq.htm>—for additional information. Users should be aware that selling mercury or mercury containing products into your state or country may be prohibited by law.

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 or regulatory limitations prior to use.* For specific warning statements, see 6.2, 7.1, 8.2, and Annex A2.

<sup>1</sup> This test method is under the jurisdiction of Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.L0.07 on Engineering Sciences of High Performance Fluids and Solids (Formally D02.1100).

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<sup>2</sup> Coburn, J. F., "Lubricant Vapor Pressure Derived from Evaporation Loss," *Transactions, American Society of Lubricating Engineers, ASLTA*, Vol 12, 1969, pp. 129–134.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

- A240/A240M Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
- D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
- D972 Test Method for Evaporation Loss of Lubricating Greases and Oils
- D2503 Test Method for Relative Molecular Mass (Molecular Weight) of Hydrocarbons by Thermoelectric Measurement of Vapor Pressure
- D2595 Test Method for Evaporation Loss of Lubricating Greases Over Wide-Temperature Range
- D2883 Test Method for Reaction Threshold Temperature of Liquid and Solid Materials
- E659 Test Method for Autoignition Temperature of Chemicals

## 3. Terminology

### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *apparent vapor pressure* ( $p$ ),  $n$ —the time-averaged value of the vapor pressure from the start to the end of the evaporation test.

3.1.1.1 *Discussion*—While this may include some effects of differences in nonideality of the vapor, heat of vaporization, surface tension, and viscosity between the  $m$ -terphenyl and the lubricating oil, these factors have been demonstrated to be negligible. Unless stated, this average shall cover the range 0 to  $5 \pm 1$  %.

3.1.2 *cell constant* ( $k$ ),  $n$ —the ratio of the amount of  $m$ -terphenyl or lubricating oil carried off per unit volume of gas to that predicted by Dalton's law.

$$k = 22.41 PW/VpM \quad (1)$$

where:

$k$  = call constant

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- P* = ambient atmospheric pressure, torr  
*W* = mass of lubricant evaporated, g  
*V* = volume of gas passed through all litres at 273 K and 101.3 kPa (760 torr)  
*p* = apparent vapor pressure, torr  
*M* = mole average molecular weight of lubricant vapor, g/mole  
*T* = test temperature, K

It has been empirically determined that for *m*-terphenyl in air

$$k = 0.1266 - 12.60/(T - 273) \quad (2)$$

and that the cell constant is independent of the composition of the lubricant.

3.1.3 Test Method **D972** is normally run with air, which may cause changes in easily oxidized fluids. In such cases, use of common reactive gas nitrogen and recalibration to obtain a slightly different cell constant (*k'*) is mandatory.

#### 4. Summary of Test Method

4.1 The test is run at the selected temperature for a sufficient time to give the selected amount of evaporation, which is 5 % ± 1 % unless otherwise specified. This evaporation rate is compared with a standard value for pure *m*-terphenyl to yield the apparent vapor pressure and molecular weight of the lubricating oil as defined in Section 3.

#### 5. Significance and Use

5.1 The vapor pressure of a substance as determined by measurement of evaporation reflects a property of the bulk sample. Little weight is given by the procedure to the presence of low concentrations of volatile impurities.

5.2 Vapor pressure, *per se*, is a thermodynamic property that is dependent only upon composition and temperature for stable systems. In the present method, composition changes occur during the course of the test so that the contribution of minor amounts of volatile impurities is minimized.

#### 6. Apparatus

6.1 *Evaporation Cell*, as described in **Annex A1**.

6.2 *Air Supply System*, capable of supplying to the cell the required flow of air free of entrained particles (**Warning**—Compressed gas under high pressure. Use with extreme caution in the presence of combustible material, since the autoignition temperatures of most organic compounds in air are drastically reduced at elevated pressures. See **Annex A2.1**.) A 410 mm (16 in.) length of 1 in. diameter pipe packed with glass wool has been found satisfactory for filtering the air.

6.3 *Oil Bath*, as described in **Annex A1**.

NOTE 2—Other constant-temperature baths may be used if the exit air passing over the grease sample is at the test temperature (±0.5 K (1 °F)).

6.4 *Temperature Measuring Devices*—Resistance thermometers, thermocouples, or liquid-in-glass thermometers calibrated to accuracy within ±0.5 °C (±1.0 °F) may be used. The use of mercury-in-glass thermometers of equal accuracy is permitted, although it is discouraged.

6.5 *Flowmeter*<sup>4</sup>—A rotameter calibrated to deliver air at a rate of 2.583 g/min ± 0.02 g/min between 289 K and 302 K (60 °F and 85 °F) (2 L/min at standard temperature and pressure). It shall be furnished with a needle valve and mounted as shown in **Fig. 1**.

6.6 *Oil Sample Cup*, as described in **Fig. 1** and **A1.1.2**.

#### 7. Calibration of Equipment

7.1 It is assumed that equipment conforming to Test Method **D972** in design and installation needs no calibration. If questions arise, carry out the procedure using *m*-terphenyl (**Warning**—Harmful or fatal if swallowed. See **A2.2**.) of good commercial quality. The following two points shall be determined:

K	Temperature °F	Time, h	Evaporation to Conform to Eq 2, g
395	250	22	0.267 ± 0.027
420	300	6.5	0.503 ± 0.050

If the data do not fall within the above ranges, check flow rate and temperature. If these are correct, prepare a substitute equation for *k'* similar to **Eq 2** and use it in Section 10. When use of nonreactive gas is required, this calibration is necessary as standard cell constants are not valid for gases other than air.

7.2 If the apparatus specified in Test Method **D2595** is to be used, it shall be calibrated as described in 7.1.

#### 8. Procedure

8.1 Weigh the clean test specimen cup and hood to the nearest 1 mg. Transfer, by means of a pipet, 10.00 g ± 0.05 g of test specimen to the cup. Assemble the cup and hood, being careful not to splash oil on the underside of the hood. Weigh the assembly and record the net test specimen weight to the nearest 1 mg.

8.2 With cover in place, but without the hood and test specimen cup attached, allow the evaporation cell to acquire the temperature of the bath (controlled to ±0.5 K (±1 °F)) at which the test is to be made by immersing the cell in it, as shown in **Fig. 1**. Allow the cell to remain in the bath at least ½ h before beginning the test. During this period, allow clean air (**Warning**—Compressed gas under high pressure. Use with extreme caution in the presence of combustible material, since the autoignition temperatures of most organic compounds in air are drastically reduced at elevated pressures. See **Annex A2.1**.) to flow through the cell at the prescribed rate, 2.583 g/min ± 0.02 g/min (2 L/min at standard temperature and pressure), as indicated by the rotameter. Then remove the cover, thread and weighed hood and sample cup into place, and replace the cover. Tighten the three knurled cover-tightening screws securely to prevent air leakage under the cover. Pass clean air through the cell for the required period. (**Warning**—Do not perform this test with air at temperatures in excess of the autoignition

<sup>4</sup> The sole source of supply of the apparatus known to the committee at this time is Flowrater meter, Fisher and Porter Co., Hatboro, PA. 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,<sup>1</sup> which you may attend.

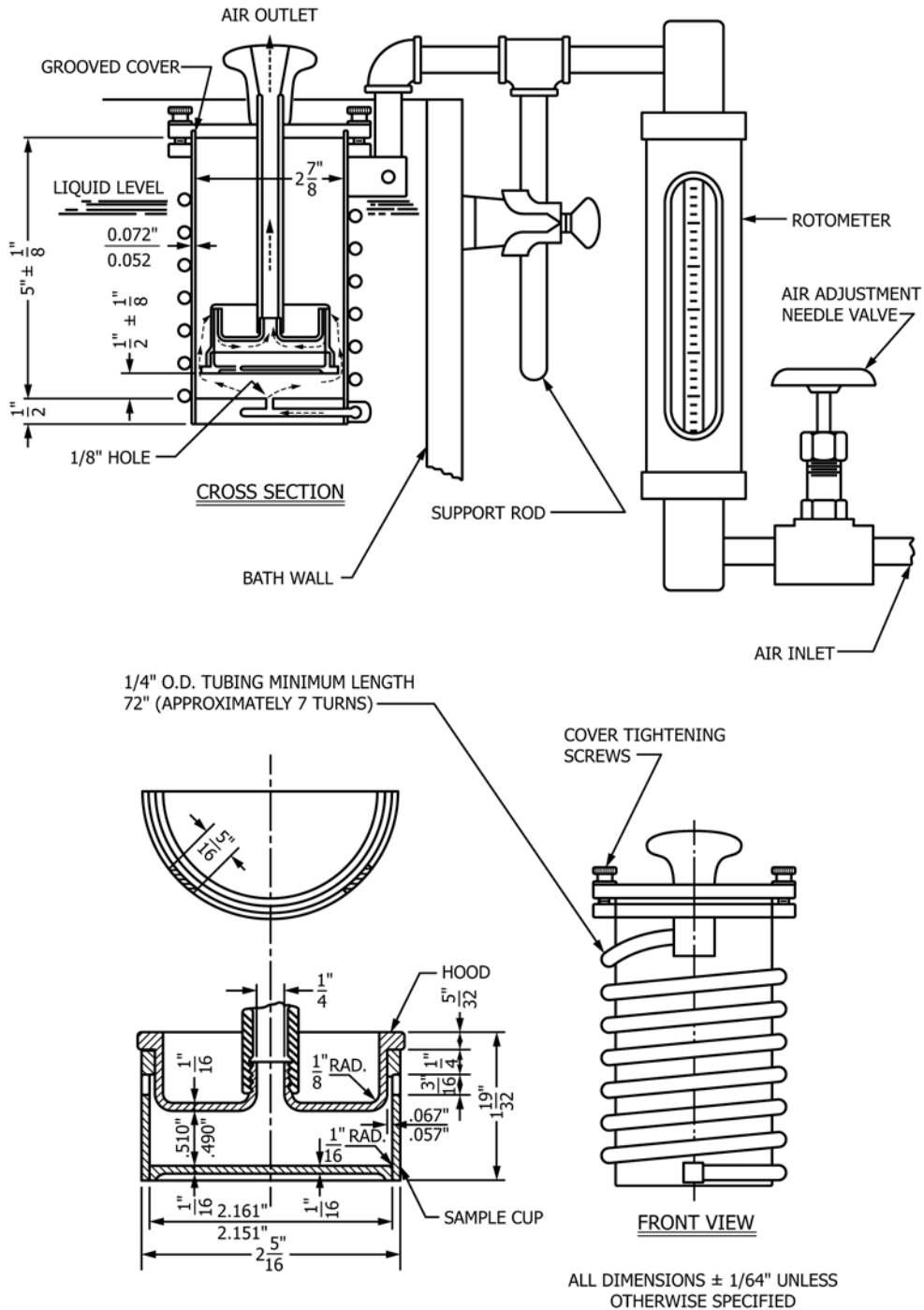


FIG. 1 Evaporation Test Cell

temperature of the test specimen as determined by Test Method E659 or Test Method D2883, or both.)

8.3 At the end of the test period, remove the assembled test specimen cup and hood from the cell, and allow to cool to room temperature. Determine the net weight of the sample to the nearest 1 mg.

### 9. Determination of Molecular Weight and Apparent Vapor Pressure

9.1 If a value of  $M$  is already available from Test Method D2503 or equivalent, 9.2 – 9.4 and 10.1 may be omitted, even

though this value is for the whole lubricant instead of the part vaporized, as the calculation is not very sensitive to  $M$  error.

9.2 Conduct a test on the sample in accordance with the procedure in Section 7, at 477 K (400 °F). The proper test time to evaporate 5% (0.500 g) may be estimated from the flash point of the lubricant as measured by Test Method D92, from Table 1.

NOTE 3—The need for a run at 477 K (400 °F) is, created by lack of exact values for the first two constants in Eq 3, Eq 4, and Eq 5 for other temperatures.

**TABLE 1 Estimated Time to Evaporate 5 %, h<sup>A</sup>**

Flash Point		Test Temperature, K (°F)					
K	°F	394 (250)	422 (300)	450 (350)	477 (400)	505 (450)	533 (500)
422	300	2.7	0.9	0.3	0.1	...	...
450	350	8.1	2.7	0.9	0.3	0.1	...
477	400	24.3	8.1	2.7	0.9	0.3	0.1
505	450	72.9	24.3	8.1	2.7	0.9	0.3
533	500	...	72.9	24.3	8.1	2.7	0.9
561	550	...	...	72.9	24.3	8.1	2.7
589	600	...	...	...	72.9	24.3	8.1

<sup>A</sup> This table may be extended by means of equation:  
 Estimated Hours =  $0.9 \log^{-1} [0.0095(F - 1.87 + 460)]$

9.3 For synthetic and redistilled petroleum oils, the variation of  $W/t$  with  $W$  is not great, and the 5 % point shall be approximated by linear interpolation of two points taken at different  $W$  values. For single-distilled petroleum or unknown oils, three points shall be plotted, representing the estimated time and also half and twice that time. These readings may all be obtained on one sample by stop and start operation of the apparatus.

9.4 When a single data point that does not fall within the 5 % ± 1 % evaporated range is used (as is often justifiable on synthetic oils) or the evaporation is measured at some other level of  $W$ , this fact shall be reported in Section 11.

9.5 The test for apparent vapor pressure is conducted in accordance with Section 8 for the estimated time at the selected temperature. If the 5 ± 1 % criterion is not met, proceed as in 9.3.

## 10. Calculations

### 10.1 Calculation of Molecular Weight:

10.1.1 Use the evaporation time,  $t$ , (in seconds) obtained in 9.3 to evaporate 5 % ± 1 %.

10.1.2 Calculate the molecular weights of lubricants in general as follows:

$$\log M = 3.028 - 0.164 \log(10\ 335\ PW/t) \quad (3)$$

10.1.3 For lubricants of known composition, slightly greater accuracy is obtained with special equations:

10.1.3.1 For polyol esters:

$$\log M = 3.181 - 0.207 \log(10\ 335\ PW/t) \quad (4)$$

10.1.3.2 For dibasic esters:

$$\log M = 3.089 - 0.190 \log(10\ 335\ PW/t) \quad (5)$$

10.1.3.3 For mineral oils:

$$\log M = 2.848 - 0.106 \log(10\ 335\ PW/t) \quad (6)$$

10.1.4 The molecular weight equations all contain the standard value of  $k$  at 477K (400°F) from Table 2. If a change greater than ±3 % in this value is caused by the calibration in Section 7, adjustments shall be made in the constant 10 335 by multiplying it by the factor ( $k/k'$ ).

### 10.2 Calculation of Apparent Vapor Pressure:

10.2.1 Use the molecular weight,  $M$ , as calculated in 10.1 or predetermined in 9.1 to calculate the vapor pressure as follows:

$$p = 672\ PW/tkM \quad (7)$$

**TABLE 2 Standard Cell Constants**

Temperature		Cell Constant <sup>2</sup>
K	°F	
394	250	0.02247
422	300	0.04204
450	350	0.05540
477	400	0.06483
505	450	0.07229
533	500	0.07814

where  $k$  is obtained from Table 2. Use Eq 2 to extend this table. If a special equation was required in 7.1, use it rather than Table 2 or Eq 2.

10.2.2 For the special case of lubricants run at 477 K (400 °F) for 6.5 h as required in several military aircraft engine oil specifications, with  $P = 760$  torr:

$$\log p = 1.164 \log(10W) - 1.255 \quad (8)$$

where  $10W$  = percent evaporated from a 10 g sample.

10.2.3 These results may be converted to SI units by the equations:

$$p' = 133.32p \text{ and } P' = 133.32P \quad (9)$$

where:

$p'$  = apparent vapor pressure, Pa

$P'$  = ambient atmospheric pressure, Pa

## 11. Report

11.1 If the results are obtained in accordance with 9.1, 9.2, 9.3, and 9.5, and calculated by Eq 3, they shall be reported as “Apparent Vapor Pressure = \_\_ torr at \_\_ °C (\_\_ °F), and Molecular Weight = \_\_.”

11.2 If the results are obtained in accordance with 9.1, 9.2, 9.3, and 9.5, and calculated by Eq 4, Eq 5, or Eq 6, they shall be reported as “Apparent Vapor Pressure = \_\_ torr at \_\_ °C (\_\_ °F), and Molecular Weight = \_\_, calculated as polyol ester,” “...diester,” or “...petroleum,” as appropriate.

11.3 If the results are obtained as indicated in 8.2 or 9.4, they shall be reported as “Apparent Vapor Pressure = \_\_ torr at \_\_ °C (\_\_ °F) and 0 to \_\_ percent evaporated.” The molecular weight shall be reported only if the test was conducted at 477 K (400 °F) or a separate test at this temperature was made.

## 12. Precision and Bias

12.1 No independent precision statement can be issued at this time. However, the statement in Test Method D972 may be

used as a guide. Applying the exponent 1.164 from Coburn's paper<sup>2</sup> to the Test Method **D972** statement results in the following criteria for apparent vapor pressure results:

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

6 %

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, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

23 %

12.2 Similarly, from Test Method **D2595**, for use with that apparatus:

12.2.1 *Repeatability*—The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

23 %

12.2.2 *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, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

35 %

12.3 *Bias*—No statement is made on bias for this test method since the results cannot be compared to an accepted reference material.

### 13. Keywords

13.1 lubricating oils; molecular weight; vapor pressure

## ANNEXES

### (Mandatory Information)

#### A1. APPARATUS

A1.1 *Evaporation Cell* and attachments conforming with the dimensional tolerances indicated in **Fig. 1** and capable of being supported upright in the oil bath. Other structural details are as follows:

A1.1.1 The body and cover of the cell shall be constructed of stainless steel and the air-heating coil of tinned copper tubing.

A1.1.2 The sample cups (recommended maximum weight 200 g each), hood, eduction tube, and orifice shall be constructed of 18 % chromium, 8 % nickel alloy steel. A suitable material is an alloy steel conforming to Grade S, Type 304, of Specification **A240/A240M**. To facilitate removal and separation of the cup and hood for inserting the sample and weighing, the sample cup shall be threaded to the hood and this in turn to the eduction tube of the cover.

A1.1.3 The cover of the cell shall be made airtight.

A1.2 *Oil Bath* of sufficient depth to allow submersion of the evaporation cell to the proper level and capable of being controlled at the desired test temperature  $\pm 0.5$  K ( $\pm 1$  °F), with a maximum variation throughout the bath of 0.5 K (1 °F). Circulation of the oil-heating medium by a pump or stirrer is recommended. Sufficient heat capacity shall be provided to return the bath to the required temperature within 60 min after immersion of the cell. The bath shall be provided with a temperature well such that the thermometer used can be inserted to its proper immersion depth. The bath shall be arranged so that there are no drafts or wide fluctuations in temperature around the evaporation cell.

## A2. WARNING STATEMENTS

### A2.1 Compressed Air

A2.1.1 **Warning**—Compressed gas under high pressure.

Use with extreme caution in the presence of combustible material, since the autoignition temperatures of most organic compounds in air are drastically reduced at elevated pressures.

Keep cylinder valve closed when not in use.

Always use a pressure regulator.

Release regulator tension before opening cylinder.

Do not transfer to cylinder other than one in which air is received.

Do not mix gases in cylinder.

Do not drop cylinder.

Make sure cylinder is supported at all times.

Stand away from cylinder outlet when opening cylinder valve.

Keep cylinder out of sun and away from heat.

Keep cylinders from corrosive environment.

Do not use cylinder without label.

Do not use dented or damaged cylinders.

For technical use only.

Do not use for inhalation purposes.

### A2.2 *m*-Terphenyl

A2.2.1 **Warning**—Harmful or fatal if swallowed.

Use only with adequate ventilation.

Avoid prolonged breathing of vapor or spray mist.

Avoid prolonged repeated contact with skin.

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