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Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)¹

This standard is issued under the fixed designation D 445; 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 is also a standard of the Institute of Petroleum issued under the fixed designation IP 71. The final number indicates the year of last revision.

This test method has been approved by the sponsoring committee and accepted by the Cooperating Societies in accordance with established procedures.

This standard has been approved for use by agencies of the Department of Defense and replaces Method 305.6 of Federal Test Method Standard 791b. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers the determination of the kinematic viscosity of liquid petroleum products (Note 1), both transparent and opaque, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer. The dynamic viscosity can be obtained by multiplying the measured kinematic viscosity by the density of the liquid.

NOTE 1—For the measurement of the viscosity of bitumens, see also Test Method D 2170 and Test Method D 2171.

1.2 This test method is intended primarily for application to liquids for which the shear stress and shear rates are proportional.

1.2.1 This test method depends on the behavior of the sample, and ideally the coefficient of viscosity should be independent of the rate of shear (this is commonly called Newtonian flow behavior). If, however, the coefficient of viscosity varies significantly with the rate of shear, different results may be obtained from viscometers of different capillary diameters.

1.3 This test method also includes the determination of the kinematic viscosity of fuel oils which often exhibit non-Newtonian properties.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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:

- D 446 Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers²
- D 2170 Test Method for Kinematic Viscosity of Asphalts (Bitumens)³
- D 2171 Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer³
- E 1 Specification for ASTM Thermometers⁴
- E 77 Method for Verification and Calibration of Liquid-in-Glass Thermometers⁵

3. Terminology

3.1 Definitions:

3.1.1 *kinematic viscosity*—a measure of the resistive flow of a fluid under gravity, the pressure head being proportional to the density, ρ , of the fluid: for gravity flow under a given hydrostatic head, the pressure head of a liquid is proportional to its density, ρ . For any particular viscometer, the time of flow of a fixed volume of fluid is directly proportional to its kinematic viscosity, $\nu = \eta/\rho$, where η is the dynamic viscosity coefficient. The kinematic viscosity coefficient has the dimension L^2/T , where L is a length, and T is a time. The cgs unit of kinematic viscosity is one centimetre squared per second and is called one stokes (symbol St). The SI unit of kinematic viscosity is one metre squared per second and is equivalent to 10^4 St. Frequently, the centistokes (symbol cSt) is used ($1 \text{ cSt} = 10^{-2} \text{ St} = 1 \text{ mm}^2/\text{s}$).

3.1.2 *density*—the mass per unit volume of the fluid. The dimension of density is M/L^3 , where M is a mass. The cgs unit of density (ρ) is one gram per millilitre, and the SI unit of density is one kilogram per cubic metre.

3.1.3 *dynamic viscosity* (coefficient of)—the ratio between the applied shear stress and rate of shear. This coefficient, η , is thus a measure of the resistance to flow of the fluid; it is commonly called the viscosity of the liquid. The dimension of the coefficient of dynamic viscosity is $M/LT = FT/L^2$

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In the IP, this test method is under the jurisdiction of the Standardization Committee.

² Annual Book of ASTM Standards, Vol 05.01.

³ Annual Book of ASTM Standards, Vol 04.03.

⁴ Annual Book of ASTM Standards, Vols 05.01 and 14.03.

⁵ Annual Book of ASTM Standards, Vol 14.01.

TABLE 1 Viscometer Types

Viscometer Identification	Range, cSt (mm ² /s) ^A
A. Ostwald Types for Transparent Liquids:	
1. Cannon Fenske Routine ^C	0.5 ^B to 20 000
2. Zeitfuchs ^C	0.6 to 3 000
3. SIL ^C	0.6 to 10 000
4. Cannon-Manning Semi-micro ^C	0.4 to 20 000
5. BS/IP U-tube ^D	0.9 ^B to 10 000
6. BS/IP U-tube Miniature ^D	0.2 to 100
7. Pinkevitch	0.6 ^B to 17 000
B. Suspended-Level Types for Transparent Liquids:	
1. Ubbelohde ^C	0.3 ^B to 100 000
2. FitzSimons ^C	0.6 to 1 200
3. Atlantic ^C	0.75 ^B to 5 000
4. Cannon-Ubbelohde, Cannon-Ubbelohde Dilution ^C	0.5 ^B to 100 000
5. Cannon-Ubbelohde Semi-micro ^C	0.4 to 20 000
6. BS/IP Suspended Level ^D	3.5 ^B to 100 000
7. BS/IP Suspended Level, Shortened Form ^D	1.05 ^B to 10 000
8. BS/IP Miniature Suspended Level ^D	0.6 to 3 000
C. Reverse-Flow Types for Transparent and Opaque Liquids:	
1. Zeitfuchs Cross-Arm ^C	0.6 to 100 000
2. Cannon-Fenske Opaque ^C	0.4 to 20 000
3. Lantz-Zeitfuchs ^C	60 to 100 000
4. BS/IP U-tube Reverse Flow ^D	0.6 to 300 000

^A Each range quoted requires a series of viscometers. To avoid the necessity of making a kinetic energy correction, these viscometers are designed for a flow time in excess of 200 s except where noted in Table 4.

^B In each of these series, the minimum flow time for the viscometers with the lowest constant exceeds 200 s.

^C Specifications and operating instructions for these viscometers have been assembled in Specifications and Operating Instructions D 446.

^D Specifications for these are given in Appendixes to IP 71.

depending on whether the dimension of viscosity is based on the *M-L-T* system or the *F-L-T* system (where *F* represents a force). The cgs unit of dynamic viscosity is one gram per centimetre per second = one dyne-second per centimetre squared and is called one poise (symbol P). Frequently, the centipoise (symbol cP) is used (1 cP = 10⁻² P). The SI unit of dynamic viscosity is one pascal-second; for convenience its submultiple of millipascal-second is frequently used (1 mPa·s = 1 cP).

NOTE 2—Dynamic viscosity also denotes a frequency-dependent quantity in which shear stress and shear rate have a sinusoidal time dependence; it is hoped that this dual use of the same term will not be confusing.

4. Summary of Test Method

4.1 The time is measured in seconds for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer under a reproducible driving head and at a closely controlled temperature. The kinematic viscosity is the product of the measured flow time and the calibration constant of the viscometer.

5. Significance and Use

5.1 Many petroleum products, as well as nonpetroleum materials, are used as lubricants for bearings, gears, compressor cylinders, hydraulic equipment, etc. The proper operation of the equipment depends upon the proper kinematic viscosity or viscosity (sometimes called dynamic viscosity) of the liquid. Thus, the accurate measurement of kinematic viscosity and viscosity is essential to many product specifications.

5.2 The kinematic viscosity of many petroleum fuels is important for their proper use, for example, flow of fuels through pipe lines, injection nozzles and orifices, and the determination of the temperature range for proper operation of the fuel in burners.

6. Apparatus

6.1 *Viscometers* of the glass capillary type, calibrated and capable of measuring kinematic viscosity within the limits of precision given in Section 15 are acceptable. Viscometers listed in Table 1 meet these requirements.

6.1.1 Automated assemblies that measure kinematic viscosity within the limits of precision given in Section 15 are acceptable alternatives; kinematic viscosities less than 10 cSt (mm²/s) and flow times less than 200 s may require a kinetic energy correction (see Specification D 446).

6.2 *Viscometer Holders* to enable the viscometer to be suspended in a similar position as when calibrated. The proper alignment of vertical parts may be confirmed by using a plumb line.

6.3 *Viscometer Thermostat and Bath*—Any transparent liquid or vapor bath may be used, provided that it is of sufficient depth that at no time during the measurement will any portion of the sample in the viscometer be less than 20 mm below the surface of the bath liquid or less than 20 mm above the bottom of the bath.

6.3.1 The temperature control must be such that for the range from 15 to 100°C (60 to 212°F) the temperature of the bath medium does not vary by more than 0.01°C (0.02°F) over the length of the viscometers, or between the position of each viscometer, or at the location of the thermometer. For

TABLE 2 Kinematic Viscosity Test Thermometers^A

Test Temperature ^B Scale Error ^B		Thermometer Number	
°F	°C	ASTM ^C	IP ^D
-65	-53.9	74F, C†	69F, C
-60 to -35	-51 to -35	43F	65F, C
-40	-40	73F, C	68F, C
-15	-26.1	126F, C	71F, C
	-20	127C	99C
0	-17.8	72F, C†	67F, C
32	0	128F, C	33F, C
68 and 70	20 and 21.1	44F, C	29F, C
77	25	45F, C	30F, C
86	30	118F, C	
100	37.8	28F, C	31F, C
	40	120C	92C
122	50	46F, C	66F, C
130	54.4	29F, C†	34F, C
140	60	47F, C	35F, C
	80		100C
180	82.2	48F, C	90F, C
200	93.3	129F, C	36F, C
210 and 212	98.9 and 100	30F	32F, C
	100	121C	
275	135	110F, C	

^A The smallest graduation of the Fahrenheit thermometers is 0.1°F and for the Celsius thermometers is 0.05°C except for ASTM 43F and IP 65F for which it is 0.2°F.

^B Scale error for the Fahrenheit thermometers is not to exceed ±0.2°F (except for ASTM 110F which is ±0.3°F); for the Celsius thermometers it is ±0.1°C. These scale errors are required to apply only at the given test temperature.

^C Complete construction detail is given in Specification E 1.

^D Complete construction detail is given in Part I of IP Standards for Petroleum and Its Products.

† Editorially corrected.