

British Standard Methods of test for
Petroleum and its products

**Part 71. Kinematic viscosity of transparent and opaque liquids and
calculation of dynamic viscosity**

(Identical with IP 71/80)

Méthodes d'essai pour le pétrole et les produits pétroliers
Partie 71. Viscosité cinématique des liquides opaques et transparents
et calcul de la viscosité dynamique

Prüfmethoden für Erdöl und Erdölprodukte
Teil 71. Kinematische Viskosität von transparenten und trüben
Flüssigkeiten, und Berechnung der dynamischen Viskosität

Foreword

BS 2000 comprises a series of test methods for petroleum and its products that have been published previously by the Institute of Petroleum (IP) and have been accorded the status of British Standards. Each method should be read in conjunction with BS 2000 : Part 0 'General introduction', which gives details of the BSI/IP agreement for publication of the series, lists more than 50 methods scheduled to be published in this way in 1982, and provides general information on safety precautions, sampling and other matters.

The numbering of the other Parts follows that of the corresponding methods published in 'IP Standards for petroleum and its products, Part 1 Methods for analysis and testing'. BS 2000 : Part 71 is thus identical with IP 71/80. IP 71/66 was previously published in A5 format as BS 4708* which has now been re-numbered and issued in the BS 2000 series. It is intended to issue further revisions when necessary in line with changes that may be made in subsequent editions of the IP method.

Related International Standards are ISO 3104 and ISO 3105.

Caution. Attention is drawn to the safety precautions mentioned in Part 0 of this British Standard. In particular attention is drawn to the use of chromic acid (see 8.2) and of diethyl ether (see C.3.2).

Chromic acid is potentially hazardous in contact with organic materials and it is toxic and highly corrosive. If used, wear approved full face-shield and full-length protective clothing including gloves.

Diethyl ether is highly flammable and gives a harmful vapour; inhalation of the vapour should be avoided and other suitable precautions taken.

NOTE. The titles of the standards publications referred to in this Part of this British Standard are listed on the inside back cover.

WITHDRAWN

*Now withdrawn.

Method (identical with IP 71/80¹)**1. SCOPE**

1.1. This method describes a procedure for the determination of the kinematic viscosity of liquid petroleum products (see 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 ASTM Method D2170/IP 319, Kinematic Viscosity Asphalts (Bitumens)², and D2171/IP 222 Viscosity of Asphalts.²

1.2. The method is intended for application to liquid for which the ratio of shear stress to shear rate is the same for different viscometers (Newtonian flow, see Note 2).

NOTE 2: The method depends on the behaviour of the sample, and ideally the coefficient of viscosity should be independent of the rate of shear (this is commonly called Newtonian flow behaviour). If, however, the coefficient of viscosity varies significantly with the rate of shear, different results may be obtained from viscometers of different capillary diameters.

2. SUMMARY OF METHOD

2.1. 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.

3. DEFINITIONS

3.1. *Kinematic Viscosity* is a measure of the resistance to gravity flow of a fluid, the pressure head being 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 (abbreviated 1 St). The SI unit of kinematic viscosity is one metre squared per second and is equivalent to 10^4 St. Frequently, the centistokes (abbreviated 1 cSt) is used ($1 \text{ cSt} = 10^{-2} \text{ St}$).

3.2. Density is 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 cubic centimetre, and the SI unit of density is one kilogram per cubic metre.

3.3. *Dynamic Viscosity* is the ratio between the applied shear stress and rate of shear and is called the coefficient of dynamic viscosity η . This coefficient is thus a measure of the resistance to flow of the liquid; it is commonly called the viscosity of the liquid. The dimension of the coefficient of dynamic viscosity is $M/LT = FT/L^2$ depending on whether the dimension of viscosity is based on the $M-L-T$ system or on the $F-L-T$ system (here 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 (abbreviated 1 P). The SI unit of dynamic viscosity is one newton-second per metre squared and is equivalent to 10 poises. Frequently, the centipoise (abbreviated 1 cP) is used ($1 \text{ cP} = 10^{-2} \text{ P}$).

4. APPARATUS

4.1. *Viscometers* – of the glass capillary type, calibrated and capable of measuring kinematic viscosity within the limits of precision given in Section 10, are acceptable. The viscometers listed in Table 1, whose specifications are given in BS 188 Appendix A, in ASTM D446 and in ISO 3105, meet these requirements. It is not intended to restrict this Standard either to the use of only those viscometers listed in Table 1 or to the use of U-tube viscometers.

4.1.1. Automated assemblies which perform as herein required are considered suitable alternatives.

4.2. *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.

¹ Under the standardization procedure of ASTM, this method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants.

In the IP, this method is under the jurisdiction of the Standardization Committee. In 1972, the method was editorially revised in a significant manner to bring it into line with recommendation to ISO TC/28 on Petroleum Products.

² 1974 *Annual Book of ASTM Standards*, Part 15

NOTE to note 1. It is not at present intended to include either IP 222 or IP 319 in the BS 2000 series.

NOTE to 3.1. $1 \text{ cSt} = 1 \text{ mm}^2/\text{s}$

NOTE to 3.3. $1 \text{ cP} = 1 \text{ mPa s}$

4.3. *Viscometer Thermostat and Bath* – Any transparent liquid or vapour 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 2 cm below the surface of the bath liquid or less than 2 cm above the bottom of the bath.

TABLE 1. Viscometer types

Test viscometers	Range ⁽¹⁾ cSt	
A. Ostwald Types for Transparent Liquids:		
1. Cannon Fenske routine ⁽³⁾	0.5 ⁽²⁾	to 20,000
2. Zeitfuchs ⁽³⁾	0.6	to 3,000
3. SII ⁽³⁾	0.6	to 10,000
4. Cannon–Manning semi-micro ⁽³⁾	0.4	to 20,000
5. BS/IP U-tube ⁽⁴⁾	0.9 ⁽²⁾	to 10,000
6. BS/IP U-tube miniature ⁽⁴⁾	0.2	to 20,000
7. Pinkevitch ⁽³⁾	0.6 ⁽²⁾	to 17,000
B. Suspended Level Types for Transparent Liquids:		
1. Ubbelohde ⁽³⁾	0.3 ⁽²⁾	to 100,000
2. FitzSimons ⁽³⁾	0.6	to 1,200
3. Atlantic ⁽³⁾	0.75 ⁽²⁾	to 5,000
4. Cannon–Ubbelohde, Cannon–Ubbelohde dilution ⁽³⁾	0.5 ⁽²⁾	to 100,000
5. Cannon–Ubbelohde semi-micro ⁽³⁾	0.4	to 20,000
6. BS/IP suspended level ⁽⁴⁾	3.5 ⁽²⁾	to 100,000
7. BS/IP suspended level, shortened form ⁽⁴⁾	1.05 ⁽²⁾	to 10,000
8. BS/IP miniature suspended level ⁽⁴⁾	0.6	to 3,000
C. Other Types for Transparent and Opaque Liquids:		
1. Zeitfuchs Cross-Arm ⁽³⁾	0.6	to 100,000
2. Cannon–Fenske opaque ⁽³⁾	0.4	to 20,000
3. Lantz–Zeitfuchs ⁽³⁾	60	to 100,000
4. BS/IP U-tube viscometer for opaque liquids ⁽⁵⁾	0.6	to 300,000

⁽¹⁾ 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 sec except where noted.

⁽²⁾ In each of these series, the minimum flow time for the viscometers with the lowest constant exceeds 200 sec.

⁽³⁾ Specifications and operating instructions for these viscometers are given in ASTM D446.

⁽⁴⁾ Specifications and operating instructions for these viscometers are given in BS 188 and for B 6, 7 and 8 also in Appendix B.

⁽⁵⁾ Specifications and operating instructions for these viscometers are given in Appendix C.

4.3.1. The temperature control of the bath fluid must be such that within the range 15 to 100°C (60 to 212°F) the temperature over the length of the viscometer or between viscometers is maintained within $\pm 0.01^\circ\text{C}$ ($\pm 0.02^\circ\text{F}$) of the selected temperature. For temperatures outside the range 15 to 100°C, the deviation from the desired temperature must not exceed 0.03°C (0.05°F).

4.4. *Temperature Measuring Device* – a thermometric device which, when used in the manner described in its certificate of calibration, will enable the temperature of the bath adjacent to the sample to be read to 0.01°C in the range 15 to 100°C, and to 0.03°C outside that range. Currently, the accuracy of calibration of 'kinematic viscosity thermometers' is deemed to be $\pm 0.02^\circ\text{C}$ (see Appendix A, 'IP Standard Thermometers' – 'Notes on care and use of liquid-in-glass thermometers', pp. AP-A49 to AP-A51).

4.5. *Timing Device* – Any timing device may be used provided that the readings can be taken with a discrimination of 0.2 sec or better, and that it has an accuracy within $\pm 0.07\%$ when tested over intervals of 15 min.

4.5.1. Electrical timing devices may be used if the current frequency is controlled to an accuracy of 0.05% or better. Alternating currents, as provided by some public power systems, are intermittently rather than continuously controlled. When used to actuate electrical timing devices, such control can cause large errors in viscosity flow measurements.

5. CALIBRATION

5.1. See Appendix A.

6. PROCEDURE FOR KINEMATIC VISCOSITY

6.1. The specific details of operation vary for the different types of viscometers listed in Table 1. In all cases, however, proceed in accordance with 6.2 through 6.6.

NOTE to 4.4. BS 2000 : Part 0 : Addendum 1 is identical with Appendix A of 'IP Standards for petroleum and its products' Part 1.

6.2. Maintain the bath at the test temperature within the limits given in 4.3.1 taking account of the precautions given in Appendix A2.2 and of the correction supplied on the certificate of calibration.

6.2.1 In order to obtain the most reliable temperature measurement it is recommended that two thermometers with valid calibration certificates be used. The thermometers should be held in an upright position under the same conditions of immersion as when calibrated. They should be viewed with a lens assembly giving about 5 times magnification and which should be arranged to eliminate parallax errors.

6.2.2. Select a clean dry, calibrated viscometer having a range covering the estimated viscosity (i.e. a wide capillary for a very viscous liquid and a narrower capillary for a more fluid liquid). The flow time should not be less than 200 sec.

6.2.3. When the temperature of the test is below the dew point, fit loosely packed drying tubes on to the open ends of the viscometer to prevent water condensation. Drying tubes must fit the design of the viscometer and not restrict the flow of the sample under test by pressures created in the instrument. At temperatures below 0°C (32°F), it may be advisable to charge the sample into the viscometer at ambient temperature; allow the viscometer to cool to bath temperature, keeping sample in the working capillary to prevent slight accumulation of frost on the walls of the capillary.

6.2.4. Viscometers used for silicone fluids, fluoro-carbons, and other liquids which are difficult to remove by the use of a cleaning agent, should be reserved for the exclusive use of those fluids except when calibrating. Such viscometers should be subjected to calibration checks at frequent intervals.

6.3. Charge the viscometer in the manner dictated by the design of the instrument, this operation being in conformity with that employed when the instrument was calibrated. Should the sample contain solid particles, filter during charging through a No. 200 (75 µm) sieve.

NOTE to 6.3. A sieve complying with BS 410 is suitable.

6.3.1. With certain products which exhibit 'gel-like' behaviour, take care that measurements are made at sufficiently high temperatures for such materials to flow freely so that similar results will be obtained in viscometers of different capillary diameters.

6.3.2. The viscosity of steam-refined cylinder oils, black lubricating oils, residual fuel oils, and similar waxy products can be affected by the previous thermal history. The following preheating procedure should be followed to obtain uniform results for viscosities below 95°C (200°F).

6.3.2.1. To obtain a representative sample, heat in the original container to about 50°C (122°F) with stirring and shaking. Probe the bottom of the container with a rod to be certain that all waxy materials are in solution. Pour 100 ml into a 125-ml flask. Stopper loosely with a cork or rubber stopper. Immerse the flask in a bath of boiling water for 30 min. Mix well, remove the sample from the bath, and strain it through a No. 200 (75 µm) screen directly into the viscometer already in the thermostatted bath. Complete the viscosity test within 1 h after preheating.

NOTE to 6.3. A conical flask complying with BS 2734 is suitable.

6.4. Allow the charged viscometer to remain in the bath long enough to reach the test temperature. Because this time will vary for the different instruments and for different temperatures, establish a safe temperature equilibrium time by trial (30 min should be sufficient). Where design of the viscometer requires it, adjust the volume of the test sample after the sample has reached temperature equilibrium. One bath is often used to accommodate several viscometers. Never add or withdraw a viscometer while any other viscometer is in use for measuring a flow time.

6.5. Use suction (if the sample contains no volatile constituents) or pressure to adjust the head level of the test sample to a position in the capillary arm of the instrument about 5 mm ahead of the first timing mark. With the sample flowing freely, measure in seconds to within 0.2 sec (see 4.5), the time required for the meniscus to pass from the first timing mark to the second. If this flow time is less than the specified minimum (see 6.2.2), select a viscometer with a capillary of smaller diameter and repeat the operation.

6.5.1. For modified Ostwald and suspended-level types, repeat the procedure described in 6.5 to make a second measurement of the flow time. For reverse-flow viscometers, use the same or another unit and begin at 6.3 to make the second measurement.

6.6. If two measurements agree within 0.2%, use the average for calculating the reported kinematic viscosity. For the viscometers mentioned under C of Table 1, flow times should agree within 0.35%. If these agreements are not obtained, reject the test results.

7. PROCEDURE FOR DYNAMIC VISCOSITY

7.1. Determine the kinematic viscosity as described in Section 6.

7.2. Determine the density of the sample, to 0.001 g/cc at the same temperature as the viscosity, in accordance with any applicable method.

NOTE to 7.2. The symbol 'g/cc' should be replaced by 'g/ml' or 'g/cm³'.

8. CLEANING OF VISCOMETER

8.1. Between successive determinations, clean the viscometer thoroughly by several rinsings with an appropriate solvent completely miscible with the sample, followed by a completely volatile solvent. Dry the tube by passing a slow stream of filtered dry air through the viscometer for 2 min or until the last trace of solvent is removed.

8.2. Periodically clean the instrument with chromic acid to remove organic deposits, rinse thoroughly with distilled water and acetone, and dry with clean dry air (organic deposits may be removed by hydrochloric acid treatment before use of cleaning acid, particularly if barium salts are suspected).

NOTES to 8.2. Distilled water and acetone, complying respectively with BS 3978 and BS 509, are suitable.

Caution. See foreword.

9. CALCULATIONS AND REPORT

9.1. Calculate the kinematic viscosity ν from the measured flow time t and the instrument constant by means of the following equation:

$$\nu = Ct$$

where:

ν = kinematic viscosity, centistokes,

C = calibration constant of the viscometer, centistokes per second, and

t = flow times, seconds

9.2. Calculate the viscosity η from the calculated kinematic viscosity ν and the density ρ by means of the following equation:

$$\eta = \rho\nu$$

where:

η = dynamic viscosity in centipoises,

ρ = density, grams per cubic centimetre (see Note 3) at the same temperature used for measuring the flow time t , and

ν = kinematic viscosity, centistokes.

NOTE 3: It is permissible to use density values calculated in grams per millilitre units as being numerically equivalent to those in grams per cubic centimetre units.

9.3. Report test results for both the kinematic and dynamic viscosity rounded to the nearest one part per thousand of the value measured or calculated, respectively.

NOTE to 9.3. Test results should be reported as having been obtained in accordance with BS 2000 : Part 71.

10. PRECISION

10.1. The following precision applies to clean, transparent oils tested between 15° and 100°C (60° and 212°F).

10.1.1. *Repeatability* – Duplicate results by the same operator, using the same viscometer, should be considered suspect if their difference is greater than 0.35% of their mean.

10.1.2. *Reproducibility* – The results submitted by each of two laboratories should not be considered suspect unless their difference is greater than 0.7% of their mean.

APPENDIX A

CALIBRATION

A1. CALIBRATION OF VISCOMETERS

A1.1. *By using reference viscometers* – Select any petroleum product that will have a flow time at the test temperature of at least 200 sec in both the reference viscometer and the viscometer whose calibration factor is sought. Some viscometers with small calibration factors require a longer flow time in order that the kinetic energy correction will be negligible (see ASTM D446 and ISO 3105).