

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 71/87)

Méthodes d'essai du pétrole et des produits pétroliers

Partie 71. Viscosité cinématique des liquides opaques et transparents et calcul de la viscosité dynamique

Verfahren zur Prüfung von 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, provides general information on safety precautions, sampling and other matters, and lists the methods scheduled for publication as Parts of BS 2000. When BS 2000 : Part 0 was first published in 1982, it included a list of more than 60 methods intended for publication in the first group of Parts of BS 2000; it is envisaged that Part 0 will be revised from time to time to take account of the publication of additional methods.

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', which in 1987 has been retitled by the IP as 'Standard methods for analysis and testing of petroleum and related products'. BS 2000 : Part 71 is thus identical with IP 71/87. In this present revision separate procedures are given for the transparent liquids and the opaque liquids and new precision data has been added for the latter. A safety warning has been added (see 1.4).

For fuller information on the theoretical aspects of viscosity measurement and the derivation of viscometer constants reference should be made to BS 188.

Related international standards are ISO 3104 and ISO 3105.

It is intended to issue further revisions when necessary in line with changes that may be made in subsequent editions of this IP method.

This Part of BS 2000 supersedes BS 2000 : Part 71 : 1982, which is withdrawn.

Caution. Attention is drawn to the safety precautions mentioned in Part 0 of this British Standard and 1.4. In particular attention is drawn to the use of chromic acid (see 11.2 and C3.2).

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

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

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Method (identical with IP 71/87¹)**1. SCOPE**

1.1 This method covers the determination of the kinematic viscosity ν 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 η 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 Method 319 and ASTM Method D2171/IP Method 222.

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

1.2.1. 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.

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

1.4. This method may involve hazardous materials, operations, and equipment. This method does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this method to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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. SIGNIFICANCE AND USE

3.1. Many petroleum products, as well as non-petroleum 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.

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

4. DEFINITIONS

4.1. *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 ($1 \text{ cSt} = 10^{-2} \text{ St}$).

4.2. *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.

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 clause 4. In this context precedence should be given to the SI units:

1 cSt = 1 mm²/s

1 cP = 1 mPa.s

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.

4.3. *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 ($1 \text{ cP} = 10^{-2} \text{ P}$).

5. APPARATUS

5.1. *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.

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. SIL ⁽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 of 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.

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

5.2. *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.

5.3. *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.

5.3.1. 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).

5.4. *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).

5.5. *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.

5.5.1. 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.

6. CALIBRATION

6.1. See Appendix A.

7. GENERAL PROCEDURE FOR KINEMATIC VISCOSITY

7.1. The specific details of operation vary for the different types of viscometers listed in Table 1. The operating instructions for the different types of viscometers are given in ASTM D446.

7.2. Maintain the bath at the test temperature within the limits given in 5.3.1, taking account of the precautions given in Appendix A2.2 and of the correction supplied on the certificate of calibration.

7.2.1. 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.

7.3. Select a clean dry, calibrated viscometer having a range covering the estimated viscosity (that is 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.

7.3.1. When the test temperature is below the dew point, affix loosely packed drying tubes to the open ends of the viscometer. The drying tubes must fit the design of the viscometer and not restrict the flow of the sample by pressures created in the instrument. Carefully flush the moist room air from the viscometer by applying vacuum to one of the drying tubes. Finally, before placing the viscometer in the bath, draw up the sample into the working capillary and timing bulb and allow to drain back as an additional safeguard against moisture condensing or freezing on the walls.

7.3.2. 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. Solvents which have been used to clean these viscometers should not be used for the first rough cleaning of other viscometers because of danger of contamination.

8. PROCEDURE FOR TRANSPARENT LIQUIDS

8.1. In general, the viscometers used for transparent liquids will be of the type listed in Table 1, A and B.

8.2. 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 200 mesh (75 μm) filter.

8.2.1. 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.

NOTE to 5.4. BS 2000 : Part 0 : Addendum 1 is identical with Appendix A of IP 'Standard methods for analysis and testing of petroleum and related products'.

NOTE to 7.1. There is no British Standard corresponding to ASTM D446, but operating instructions for most of these viscometers that are used in the UK are given in BS 188.

8.2.2. 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 equilibrium time by trial (30 minutes should be sufficient). 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.

8.2.3. Where the design of the viscometer requires it, adjust the volume of the sample to the mark.

8.3. 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 5.5), the time required for the meniscus to pass from the first to the second timing mark. If this flow time is less than the specified minimum (see 7.3) select a viscometer with a capillary of smaller diameter and repeat the operation.

8.3.1. Repeat the procedure described in 8.3 to make a second measurement of flow time.

8.3.2. If two measurements agree within 0.2%, use the average for calculating the kinematic viscosity to be reported. If the measurements do not agree, repeat the operations from 8.2 to 8.3.1 after thorough cleaning and drying of the viscometer and filtering of the sample.

9. PROCEDURE FOR OPAQUE LIQUIDS

9.1. In general, the viscometers used for opaque liquids will be of the reverse-flow type listed in Table C1.

9.2. For steam refined cylinder oils and black lubricating oils, proceed to section 9.4 ensuring a thoroughly representative sample is used. The viscosity of residual fuel oils and similar waxy products can be affected by the previous thermal history and the following procedure should be followed to minimize this.

9.2.1. Heat in the original container, in an oven, at $60 \pm 2^\circ\text{C}$ for one hour.

9.2.2. Thoroughly stir the sample with a non-metallic rod of sufficient length to reach the bottom of the container. Continue stirring until there is no sludge or wax adhering to the rod.

9.2.3. Recap the container tightly and shake vigorously for one minute to complete the mixing.

NOTE 2: With samples of a very waxy nature or oils of high viscosity, it may be necessary to increase the heating temperature to achieve proper mixing.

The sample should be sufficiently fluid for ease of stirring and shaking.

9.3. Immediately after completing 9.2.3, pour sufficient sample to fill two viscometers into a 100 ml glass flask and loosely stopper.

9.3.1. Immerse the flask in a bath of boiling water for 30 minutes.

NOTE 3: Caution. Vigorous boil-over may occur when opaque liquids which contain high levels of water are heated to high temperatures.

9.3.2. Remove the flask from the water, stopper tightly and shake for one minute.

9.4. Charge two viscometers in the manner dictated by the design of the instrument. For example, for the BS U-Tube viscometers for opaque liquids or the cross-arm viscometers, filter the sample through a 200 mesh (75 μm) filter into two viscometers previously placed in the bath. For samples subjected to heat treatment, use a preheated filter to prevent the sample coagulating during the filtration. Viscometers which are charged before being inserted into the bath may need to be preheated in an oven prior to charging the sample to ensure the sample will not be cooled below the test temperature.

9.4.1. After 10 minutes, adjust the volume of the sample to coincide with the filling marks as in the viscometer specification. For example, for the BS U-Tube viscometers for opaque liquids, this is described in Appendix C to this Method. Allow the viscometers to reach the test temperature. Because this time will vary for the different instruments and for different test temperatures, establish a safe equilibrium time by trial (30 minutes is normally sufficient). 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.

9.5. With the sample flowing freely, measure in seconds to within 0.2 sec (see 5.5), the time required for the advancing ring of contact to pass from the first timing mark to the second.

NOTE to 9.3. A conical flask complying with BS 2734 is suitable.

NOTE to 9.4. If the viscometer is pre-heated in an oven, the oven temperature should be similar to that of the viscometer bath.