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

This standard is issued under the fixed designation D445; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method specifies a procedure for the determination of the kinematic viscosity, ν , of liquid petroleum products, 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 kinematic viscosity, ν , by the density, ρ , of the liquid.

NOTE 1—For the measurement of the kinematic viscosity and viscosity of bitumens, see also Test Methods **D2170** and **D2171**.

NOTE 2—ISO 3104 corresponds to Test Method **D445D445 – 03**.

1.2 The result obtained from this test method is dependent upon the behavior of the sample and is intended for application to liquids for which primarily the shear stress and shear rates are proportional (Newtonian flow behavior). If, however, the viscosity varies significantly with the rate of shear, different results may be obtained from viscometers of different capillary diameters. The procedure and precision values for residual fuel oils, which under some conditions exhibit non-Newtonian behavior, have been included.

1.3 The range of kinematic viscosities covered by this test method is from ~~0.20~~ **0.2** mm²/s to ~~300 000~~ **300 000** mm²/s (see **Table A1.1**) at all temperatures (see **6.3** and **6.4**). The precision has only been determined for those materials, kinematic viscosity ranges and temperatures as shown in the footnotes to the precision section.

1.4 The values stated in SI units are to be regarded as standard. The SI unit used in this test method for kinematic viscosity is mm²/s, and the SI unit used in this test method for dynamic viscosity is mPa·s. For user reference, 1 mm²/s = 10⁻⁶ m²/s = 1 cSt and 1 mPa·s = 1 cP = 0.001 Pa·s.

1.5 **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 and/or mercury containing products into your state or country may be prohibited by law.

1.6 *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:²

D446 Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers

D1193 Specification for Reagent Water

D1217 Test Method for Density and Relative Density (Specific Gravity) of Liquids by Bingham Pycnometer

¹ This test method is under the jurisdiction of ASTM Committee **D02** on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee **D02.07** on Flow Properties.

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

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

- D1480 Test Method for Density and Relative Density (Specific Gravity) of Viscous Materials by Bingham Pycnometer
 D1481 Test Method for Density and Relative Density (Specific Gravity) of Viscous Materials by Lipkin Bicapillary Pycnometer
 D2162 Practice for Basic Calibration of Master Viscometers and Viscosity Oil Standards
 D2170 Test Method for Kinematic Viscosity of Asphalts (Bitumens)
 D2171 Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer
 D6071 Test Method for Low Level Sodium in High Purity Water by Graphite Furnace Atomic Absorption Spectroscopy
 D6074 Guide for Characterizing Hydrocarbon Lubricant Base Oils
 D6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance
 D6300 Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products and Lubricants
 D6617 Practice for Laboratory Bias Detection Using Single Test Result from Standard Material
 E1 Specification for ASTM Liquid-in-Glass Thermometers
 E77 Test Method for Inspection and Verification of Thermometers
 E1137/E1137M Specification for Industrial Platinum Resistance Thermometers
 2.2 *ISO Standards:*³
 ISO 3104 Petroleum Products—Transparent and Opaque Liquids—Determination of Kinematic Viscosity and Calculation of Dynamic Viscosity
 ISO 3105 Glass Capillary Kinematic Viscometers—Specification and Operating Instructions
 ISO 3696 Water for Analytical Laboratory Use—Specification and Test Methods
 ISO 5725 Accuracy (trueness and precision) of measurement methods and results.
 ISO 9000 Quality Management and Quality Assurance Standards—Guidelines for Selection and Use
 ISO 17025 General Requirements for the Competence of Testing and Calibration Laboratories
 2.3 *NIST Standards:*⁴
 NIST Technical Note 1297 Guideline for Evaluating and Expressing the Uncertainty of NIST Measurement Results⁵
 NIST GMP 11 Good Measurement Practice for Assignment and Adjustment of Calibration Intervals for Laboratory Standards⁶
 NIST Special Publication 819 Guide for the Use of the International System of Units (SI)⁷

3. Terminology

3.1 See also *International Vocabulary of Metrology*.⁸

3.2 *Definitions:*

3.2.1 *digital contact thermometer (DCT), n*—an electronic device consisting of a digital display and associated temperature sensing probe.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *automated viscometer, n*—apparatus which, in part or in whole, has mechanized one or more of the procedural steps indicated in Section 11 or 12 without changing the principle or technique of the basic manual apparatus. The essential elements of the apparatus in respect to dimensions, design, and operational characteristics are the same as those of the manual method.

³ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

⁴ Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 3460, Gaithersburg, MD 20899-3460.

⁵ <http://physics.nist.gov/cuu/Uncertainty/bibliography.html>

⁶ http://ts.nist.gov/WeightsAndMeasures/upload/GMP_11_Mar_2003.pdf

⁷ <http://www.nist.gov/pml/pubs/sp811/index.cfm>

⁸ *International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (VIM)*, 3rd ed., 2008, <http://www.bipm.org/en/publications/guides/vim.html>.

3.3.1.1 *Discussion—*

Automated viscometers have the capability to mimic some operation of the test method while reducing or removing the need for manual intervention or interpretation. Apparatus which determine kinematic viscosity by physical techniques that are different than those used in this test method are not considered to be Automated Viscometers.

3.3.2 *density, n*—the mass per unit volume of a substance at a given temperature.

3.3.3 *dynamic viscosity, η , n*—the ratio between the applied shear stress and rate of shear of a material.

3.3.3.1 *Discussion—*

It is sometimes called the coefficient of dynamic viscosity or absolute viscosity. Dynamic viscosity is a measure of resistance to flow or deformation which constitutes a material's ability to transfer momentum in response to steady or time-dependent external

shear forces. Dynamic viscosity has the dimension of mass divided by length and time and its SI unit is pascal times second (Pa·s). Among the transport properties for heat, mass, and momentum transfer, dynamic viscosity is the momentum conductivity.

3.3.4 *kinematic viscosity*, ν , n —the ratio of the dynamic viscosity (η) to the density (ρ) of a material at the same temperature and pressure.

3.3.4.1 *Discussion*—

Kinematic viscosity is the ratio between momentum transport and momentum storage. Such ratios are called diffusivities with dimensions of length squared divided by time and the SI unit is metre squared divided by second (m^2/s). Among the transport properties for heat, mass, and momentum transfer, kinematic viscosity is the momentum diffusivity.

3.3.4.2 *Discussion*—

Formerly, kinematic viscosity was defined specifically for viscometers covered by this test method as the resistance to flow under gravity. More generally, it is the ratio between momentum transport and momentum storage.

3.3.4.3 *Discussion*—

For gravity-driven flow under a given hydrostatic head, the pressure head of a liquid is proportional to its density, ρ , if the density of air is negligible compared to that of the liquid. For any particular viscometer covered by this test method, the time of flow of a fixed volume of liquid is directly proportional to its kinematic viscosity, ν , where $\nu = \eta/\rho$, and η is the dynamic viscosity.

4. Summary of Test Method

4.1 The time is measured 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 and known temperature. The kinematic viscosity (determined value) is the product of the measured flow time and the calibration constant of the viscometer. Two such determinations are needed from which to calculate a kinematic viscosity result that is the average of two acceptable determined values.

5. Significance and Use

5.1 Many petroleum products, and some non-petroleum materials, are used as lubricants, and the correct operation of the equipment depends upon the appropriate viscosity of the liquid being used. In addition, the viscosity of many petroleum fuels is important for the estimation of optimum storage, handling, and operational conditions. Thus, the accurate determination of viscosity is essential to many product specifications.

6. Apparatus

6.1 *Viscometers*—Use only calibrated viscometers of the glass capillary type, capable of being used to determine kinematic viscosity within the limits of the precision given in the precision section.

6.1.1 Viscometers listed in **Table A1.1**, whose specifications meet those given in Specifications **D446** and in ISO 3105 meet these requirements. It is not intended to restrict this test method to the use of only those viscometers listed in **Table A1.1**. **Annex A1** gives further guidance.

6.1.2 *Automated Viscometers*—Automated apparatus may be used as long as they mimic the physical conditions, operations or processes of the manual apparatus. Any viscometer, temperature measuring device, temperature control, temperature controlled bath or timing device incorporated in the automated apparatus shall conform to the specification for these components as stated in Section 6 of this test method. Flow times of less than 200 s are permitted, however, a kinetic energy correction shall be applied in accordance with Section 7 on Kinematic Viscosity Calculation of Specifications **D446**. The kinetic energy correction shall not exceed 3.0 % of the measured viscosity. The automated apparatus shall be capable of determining kinematic viscosity of a certified viscosity reference standard within the limits stated in **9.2.1** and Section 17. The precision shall be of statistical equivalence to, or better (has less variability) than the manual apparatus.

NOTE 3—Precision and bias of kinematic viscosity measurements for flow times of less than 200 s has not been determined. The precision stated in Section 17 is not known to be valid for kinematic viscosity measurements with flow times less than 200 s.

6.2 *Viscometer Holders*—Use viscometer holders to enable all viscometers which have the upper meniscus directly above the lower meniscus to be suspended vertically within 1° in all directions. Those viscometers whose upper meniscus is offset from directly above the lower meniscus shall be suspended vertically within 0.3° in all directions (see Specifications **D446** and ISO 3105).

6.2.1 Viscometers shall be mounted in the constant temperature bath in the same manner as when calibrated and stated on the certificate of calibration. See Specifications **D446**, see Operating Instructions in Annexes A1–A3. For those viscometers which have Tube L (see Specifications **D446**) held vertical, vertical alignment shall be confirmed by using (*I*) a holder ensured to hold

Tube L vertical, or (2) a bubble level mounted on a rod designed to fit into Tube L, or (3) a plumb line suspended from the center of Tube L, or (4) other internal means of support provided in the constant temperature bath.

6.3 Temperature-Controlled Bath—Use a transparent liquid bath of sufficient depth such, that at no time during the measurement of flow time, any portion of the sample in the viscometer is 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 Temperature Control—For each series of flow time measurements, the temperature control of the bath liquid shall be such that within the range from $\pm 15\text{ }^{\circ}\text{C}$ to $\pm 100\text{ }^{\circ}\text{C}$; $100\text{ }^{\circ}\text{C}$, the temperature of the bath medium does not vary by more than $\pm 0.02\text{ }^{\circ}\text{C}$; $\pm 0.02\text{ }^{\circ}\text{C}$ of the selected temperature over the length of the viscometer, or between the position of each viscometer, or at the location of the thermometer. For temperatures outside this range, the deviation from the desired temperature must not exceed $\pm 0.05\text{ }^{\circ}\text{C}$; $\pm 0.05\text{ }^{\circ}\text{C}$.

6.4 Temperature Measuring Device in the Range from 0 to $\pm 100\text{ }^{\circ}\text{C}$ — $100\text{ }^{\circ}\text{C}$ —Use either calibrated liquid-in-glass thermometers (**Annex A2**) with an accuracy after correction of $\pm 0.02\text{ }^{\circ}\text{C}$; $\pm 0.02\text{ }^{\circ}\text{C}$ or better, or a digital contact thermometer as described in **6.4.2** with equal or better accuracy.

6.4.1 If calibrated liquid-in-glass thermometers are used, the use of two thermometers is recommended. The two thermometers shall agree within $0.04\text{ }^{\circ}\text{C}$; $0.04\text{ }^{\circ}\text{C}$.

6.4.2 When using a digital contact thermometer (DCT) the following shall apply:

(1) The only acceptable sensors are a resistance temperature device (RTD), such as a platinum resistance thermometer (PRT), or a thermistor.

(2) A minimum display resolution of $0.01\text{ }^{\circ}\text{C}$; $0.01\text{ }^{\circ}\text{C}$.

(3) A combined (display and probe) minimum accuracy of $\pm 0.02\text{ }^{\circ}\text{C}$; $\pm 0.02\text{ }^{\circ}\text{C}$.

(4) A response time of less than 6 s as defined in Specification **E1137/E1137M**.

(5) A drift of less than 10 mK ($0.01\text{ }^{\circ}\text{C}$); ($0.01\text{ }^{\circ}\text{C}$) per year.

(6) Linearity of 10 mK over the range of intended use.

(7) The DCT shall have a report of temperature calibration traceable to a national calibration or metrology standards body issued by a competent calibration laboratory with demonstrated competency in temperature calibration.

(8) The calibration report shall include data for the series of test points which are appropriate for its intended use.

6.4.2.1 For a constant temperature bath employed in manual viscosity measurements, the probe shall be immersed at least 100 mm below the liquid level of the bath but no less than 3 times the sensor element length. See **Fig. 1**. The end of the probe sheath shall not extend past the bottom of the viscometer. It is preferable for the center of the sensing element to be located at the same level as the lower half of the working capillary as long as the minimum immersion requirements are met.

6.4.2.2 In the case of constant temperature baths used in instruments for automatic viscosity determinations, the user is to contact the instrument manufacturer for the correct DCT that has performance equivalence to that described here.

6.4.3 Outside the range from $0\text{ }^{\circ}\text{C}$ to $\pm 100\text{ }^{\circ}\text{C}$; $100\text{ }^{\circ}\text{C}$, use either calibrated liquid-in-glass thermometers of an accuracy after correction of $\pm 0.05\text{ }^{\circ}\text{C}$; $\pm 0.05\text{ }^{\circ}\text{C}$ or better, or any other thermometric device of equal or better accuracy. When two temperature measuring devices are used in the same bath, they shall agree within $\pm 0.1\text{ }^{\circ}\text{C}$; $\pm 0.1\text{ }^{\circ}\text{C}$.

6.4.4 When using liquid-in-glass thermometers, such as those in **Table A2.1**, use a magnifying device to read the thermometer to the nearest $\frac{1}{2}$ division (for example, $0.01\text{ }^{\circ}\text{C}$; $0.01\text{ }^{\circ}\text{C}$ or $0.02\text{ }^{\circ}\text{F}$); ($0.02\text{ }^{\circ}\text{F}$) to ensure that the required test temperature and temperature control capabilities are met (see **10.1**). It is recommended that thermometer readings (and any corrections supplied on the certificates of calibrations for the thermometers) be recorded on a periodic basis to demonstrate compliance with the test method requirements. This information can be quite useful, especially when investigating issues or causes relating to testing accuracy and precision.

6.5 Timing Device—Use any timing device that is capable of taking readings with a discrimination of 0.1 s or better and has an accuracy within $\pm 0.07\%$ (see **Annex A3**) of the reading when tested over the minimum and maximum intervals of expected flow times.

6.5.1 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 kinematic viscosity flow time measurements.

6.6 Ultrasonic Bath, Unheated—(optional), with an operating frequency between 25 kHz to 60 kHz and a typical power output of $\leq 100\text{ W}$, of suitable dimensions to hold container(s) placed inside of bath, for use in effectively dissipating and removing air or gas bubbles that can be entrained in viscous sample types prior to analysis. It is permissible to use ultrasonic baths with operating frequencies and power outputs outside this range, however it is the responsibility of the laboratory to conduct a data comparison study to confirm that results determined with and without the use of such ultrasonic baths does not materially impact results.

7. Reagents and Materials

7.1 Chromic Acid Cleaning Solution, or a nonchromium-containing, strongly oxidizing acid cleaning solution. (**Warning**—Chromic acid is a health hazard. It is toxic, a recognized carcinogen, highly corrosive, and potentially hazardous in contact with organic materials. If used, wear a full face-shield and full-length protective clothing including suitable gloves. Avoid breathing

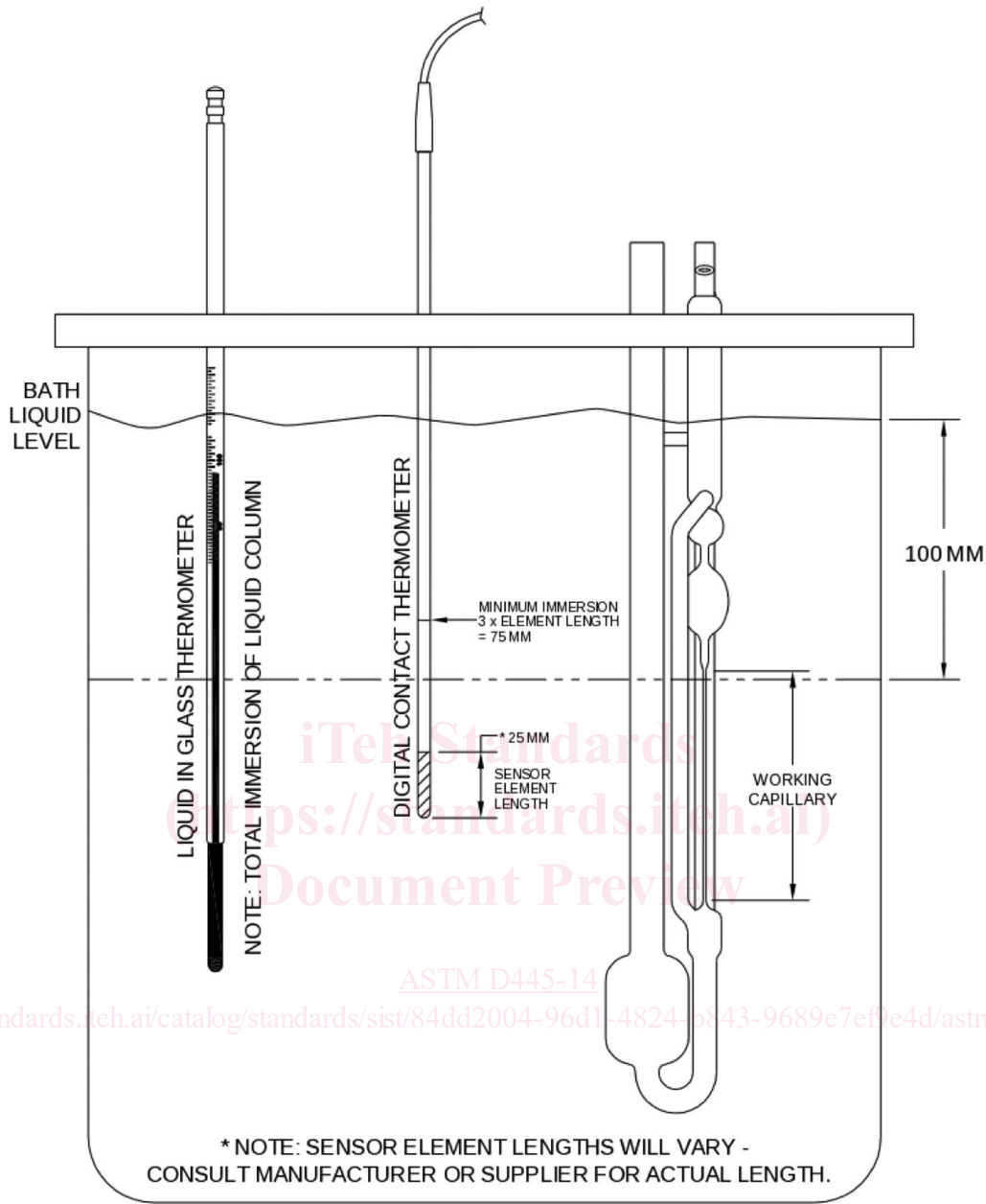


FIG. 1 Temperature Probe Immersion in Constant Temperature Bath

vapor. Dispose of used chromic acid carefully as it remains hazardous. Nonchromium-containing, strongly oxidizing acid cleaning solutions are also highly corrosive and potentially hazardous in contact with organic materials, but do not contain chromium which has special disposal problems.)

7.2 *Sample Solvent*, completely miscible with the sample. Filter before use.

7.2.1 For most samples a volatile petroleum spirit or naphtha is suitable. For residual fuels, a prewash with an aromatic solvent such as toluene or xylene may be necessary to remove asphaltenic material.

7.3 *Drying Solvent*, a volatile solvent miscible with the sample solvent (see 7.2) and water (see 7.4). Filter before use.

7.3.1 Acetone is suitable. (**Warning**—Extremely flammable.)

7.4 *Water*, deionized or distilled and conforming to Specification D1193 or Grade 3 of ISO 3696. Filter before use.

8. Certified Viscosity Reference Standards

8.1 Certified viscosity reference standards shall be certified by a laboratory that has been shown to meet the requirements of ISO 17025 by independent assessment. Viscosity standards shall be traceable to master viscometer procedures described in Test Method D2162.

8.2 The uncertainty of the certified viscosity reference standard shall be stated for each certified value ($k = 2$, 95%–95 % confidence). See ISO 5725 or NIST 1297.

9. Calibration and Verification

9.1 *Viscometers*—Use only calibrated viscometers, thermometers, and timers as described in Section 6.

9.2 *Certified Viscosity Reference Standards* (Table A1.2)—These are for use as confirmatory checks on the procedure in the laboratory.

9.2.1 If the determined kinematic viscosity does not agree within the acceptable tolerance band, as calculated from Annex A4, of the certified value, recheck each step in the procedure, including thermometer and viscometer calibration, to locate the source of error. Annex A1 gives details of standards available.

NOTE 4—In previous issues of Test Method D445, limits of $\pm 0.35\% \pm 0.35\%$ of the certified value have been used. The data to support the limit of $\pm 0.35\% \pm 0.35\%$ cannot be verified. Annex A4 provides instructions on how to determine the tolerance band. The tolerance band combines both the uncertainty of the certified viscosity reference standard as well as the uncertainty of the laboratory using the certified viscosity reference standard.

9.2.1.1 As an alternative to the calculation in Annex A4, the approximate tolerance bands in Table 1 may be used.

9.2.2 The most common sources of error are caused by particles of dust lodged in the capillary bore and temperature measurement errors. It must be appreciated that a correct result obtained on a standard oil does not preclude the possibility of a counterbalancing combination of the possible sources of error.

9.3 The calibration constant, C , is dependent upon the gravitational acceleration at the place of calibration and this must, therefore, be supplied by the standardization laboratory together with the instrument constant. Where the acceleration of gravity, g , differs by more than 0.1 %, correct the calibration constant as follows:

$$C_2 = (g_2/g_1) \times C_1 \quad (1)$$

where the subscripts 1 and 2 indicate, respectively, the standardization laboratory and the testing laboratory.

10. General Procedure for Kinematic Viscosity

10.1 Adjust and maintain the viscometer bath at the required test temperature within the limits given in 6.3.1 taking account of the conditions given in Annex A2 and of the corrections supplied on the certificates of calibration for the thermometers.

10.1.1 Thermometers shall be held in an upright position under the same conditions of immersion as when calibrated.

10.1.2 In order to obtain the most reliable temperature measurement, it is recommended that two thermometers with valid calibration certificates be used (see 6.4).

10.1.3 They should be viewed with a lens assembly giving approximately five times magnification and be arranged to eliminate parallax errors.

TABLE 1 Approximate Tolerance Bands

NOTE 1—The tolerance bands were determined using Practice D6617. The calculation is documented in Research Report RR:D02-1498.^A

Viscosity of Reference Material, mm ² /s	Tolerance Band
< 10	±0.30%
10 to 100	±0.32%
100 to 1000	±0.36%
1000 to 10 000	±0.42%
10 000 to 100 000	±0.54%
> 100 000	±0.73%

TABLE 1 Approximate Tolerance Bands

NOTE 1—The tolerance bands were determined using Practice D6617. The calculation is documented in Research Report RR:D02-1498.^A

Viscosity of Reference Material, mm ² /s	Tolerance Band
< 10	±0.30 %
10 to 100	±0.32 %
100 to 1000	±0.36 %
1000 to 10 000	±0.42 %
10 000 to 100 000	±0.54 %
> 100 000	±0.73 %

^ASupporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1498.