Designation: D117 – 22

Standard Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Liquids[1]

This standard is issued under the fixed designation D117; 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.

1. Scope

1.1 This guide describes methods of testing and specifications for electrical insulating liquids intended for use in electrical cables, transformers, liquid-filled circuit breakers, and other electrical apparatus where the liquids are used as insulating, or heat transfer media, or both.

1.2 The purpose of this guide is to outline the applicability of the available test methods. Where more than one is available for measuring a given property, their relative advantages are described, along with an indication of laboratory convenience, precision, (95 % confidence limits), and applicability to specific types of electrical insulating liquids.

1.3 This guide is classified into the following categories: Sampling Practices, Physical Tests, Electrical Tests, Chemical Tests, and Specifications. Within each test category, the test methods are listed alphabetically by property measured. A list of standards follows:

Category	Section	ASTM Standard
Sampling:	3	D923
Physical Tests:		
Aniline Point	4	D611
Coefficient of Thermal Expansion	5	D1903
Color	6	D1500
Examination: Visual Infrared	7	D1524, D2144, D2129
Flash and Fire Point	8	D92
Interfacial Tension	9	D971
Pour Point of Petroleum Products	10	D97, D5949, D5950
Particle Count in Mineral Insulating Oil	11	D6786
Refractive Index and Specific Optical Dispersion	12	D1218
Relative Density (Specific Gravity)	13	D287, D1217, D1298, D1481, D4052
Specific Heat	14	D2766
Thermal Conductivity	15	D2717
Viscosity	16	D445, D2161, D7042
Electrical Tests:		
Dielectric Breakdown Voltage	17	D877, D1816, D3300
Dissipation Factor and Relative Permittivity (Dielectric Constant)	18	D924
Gassing Characteristic Under Thermal Stress	19	D7150
Gassing Tendency	20	D2300
Resistivity	21	D1169
Chemical Tests:		
Acidity, Approximate	22	D1534
Carbon-Type Composition	23	D2140
Compatibility with Construction Material	24	D3455
Copper Content	25	D3635
Elements by Inductively Coupled Plasma (ICP-AES)	26	D7151
Furanic Compounds in Electrical Insulating Liquids	27	D5837
Dissolved Gas Analysis	28	D3612
Gas Content of Cable and Capacitor Liquids	29	D831, D1827, D2945
Neutralization (Acid and Base) Numbers	30	D664, D974
Oxidation Inhibitor Content	31	D2668, D4768
Oxidation Stability	32	D1934, D2112, D2440
Polychlorinated Biphenyl Content (PCB)	33	D4059
Sulfur, Corrosive	34	D1275
Water Content	35	D1533
Specification:		
Mineral Insulating Liquid for Electrical Apparatus	36	D3487
Less Flammable Electrical Insulating Liquids	37	D5222
Silicone Fluid used for Electrical Insulation	38	D4652
Natural (Vegetable Oil) Ester Fluids used in Electrical Apparatus	39	D6871

1.4 The values stated in SI units are to be regarded as standard. The values stated in parentheses are provided for information only.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

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[1] This guide is under the jurisdiction of ASTM Committee D27 on Electrical Insulating Liquids and Gases and is the direct responsibility of Subcommittee D27.01 on Mineral.

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Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D831 Test Method for Gas Content of Cable and Capacitor Oils
D877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes
D923 Practices for Sampling Electrical Insulating Liquids
D924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
D971 Test Method for Interfacial Tension of Insulating Liquids Against Water by the Ring Method
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1169 Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids
D1217 Test Method for Density and Relative Density (Specific Gravity) of Liquids by Bingham Pycnometer
D1218 Test Method for Refractive Index and Refractive Dispersion of Hydrocarbon Liquids
D1250 Guide for the Use of the Joint API and ASTM Adjunct for Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils: API MPMS Chapter 11.1
D1275 Test Method for Corrosive Sulfur in Electrical Insulating Liquids
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1481 Test Method for Density and Relative Density (Specific Gravity) of Viscous Materials by Lipkin Bicapillary Pycnometer
D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)
D1524 Test Method for Visual Examination of Used Electrical Insulating Liquids in the Field
D1533 Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration
D1534 Test Method for Approximate Acidity in Electrical Insulating Liquids by Color-Indicator Titration
D1816 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes
D1827 Test Method for Gas Content (Nonacidic) of Insulating Liquids by Displacement with Carbon Dioxide (Withdrawn 2009)[3]
D1903 Practice for Determining the Coefficient of Thermal Expansion of Electrical Insulating Liquids of Petroleum Origin, and Askarels
D1934 Test Method for Oxidative Aging of Electrical Insulating Liquids by Open-Beaker Method
D2112 Test Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Pressure Vessel
D2129 Test Method for Color of Clear Electrical Insulating Liquids (Platinum-Cobalt Scale)
D2140 Practice for Calculating Carbon-Type Composition of Insulating Oils of Petroleum Origin
D2144 Practices for Examination of Electrical Insulating Oils by Infrared Absorption
D2161 Practice for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
D2300 Test Method for Gassing of Electrical Insulating Liquids Under Electrical Stress and Ionization (Modified Pirelli Method)
D2440 Test Method for Oxidation Stability of Mineral Insulating Oil
D2668 Test Method for 2,6-*di-tert*-Butyl- *p*-Cresol and 2,6-*di-tert*-Butyl Phenol in Electrical Insulating Oil by Infrared Absorp
D2717 Test Method for Thermal Conductivity of Liquids (Withdrawn 2018)[3]
D2766 Test Method for Specific Heat of Liquids and Solids (Withdrawn 2018)[3]
D2864 Terminology Relating to Electrical Insulating Liquids and Gases
D2945 Test Method for Gas Content of Insulating Oils (Withdrawn 2012)[3]
D3300 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Under Impulse Conditions
D3455 Test Methods for Compatibility of Construction Material with Electrical Insulating Oil of Petroleum Origin
D3487 Specification for Mineral Insulating Oil Used in Electrical Apparatus
D3612 Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography
D3635 Test Method for Dissolved Copper In Electrical Insulating Oil By Atomic Absorption Spectrophotometry
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4059 Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography
D4652 Specification for Silicone Liquid Used for Electrical Insulation
D4768 Test Method for Analysis of 2,6-Ditertiary-Butyl

[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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Insulating Liquids by Gas Chromatography

D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

D5222 Specification for High Fire-Point Mineral Electrical Insulating Oils

D5837 Test Method for Furanic Compounds in Electrical Insulating Liquids by High-Performance Liquid Chromatography (HPLC)

D5949 Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method)

D5950 Test Method for Pour Point of Petroleum Products (Automatic Tilt Method)

D6786 Test Method for Particle Count in Mineral Insulating Oil Using Automatic Optical Particle Counters

D6871 Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus

D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)

D7150 Test Method for the Determination of Gassing Characteristics of Insulating Liquids Under Thermal Stress

D7151 Test Method for Determination of Elements in Insulating Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

2.2 *ASTM Adjunct:*[4]

Adjunct to D1250 Guide for Petroleum Measurement Tables (API *MPMS* Chapter 11.1)

SAMPLING

3. Sampling

3.1 Accurate sampling, whether of the complete contents or only parts thereof, is extremely important from the standpoint of evaluation of the quality of the product sampled. Obviously, careless sampling procedure or contamination in the sampling equipment will result in a sample that is not truly representative. This generally leads to erroneous conclusions concerning quality and incurs loss of the time, effort, and expense involved in securing, transporting, and testing the sample.

3.2 Sample the insulating liquid in accordance with Practices D923 as appropriate.

PHYSICAL PROPERTIES

4. Aniline Point

4.1 *Scope*—Test Method D611 covers the determination of the aniline point of petroleum products, provided that the aniline point is below the bubble point and above the solidification point of the aniline-sample mixture.

4.2 *Summary of Test Method:*

4.2.1 *Test Method D611*—Equal volumes of aniline and test specimen or aniline and test specimen plus *n*-heptane are placed in a tube and mixed mechanically. The mixture is heated at a controlled rate until the two phases become miscible. The mixture is then cooled at a controlled rate, and the temperature at which the two phases separate is recorded as the aniline point.

4.3 *Significance and Use*—The aniline point of an insulating liquid indicates the solvency of the liquid for some materials that are in contact with the liquid. A higher aniline point implies a lower aromaticity and a lower degree of solvency for some materials.

5. Coefficient of Thermal Expansion

5.1 *Scope*—Practice D1903 covers the determination of the coefficient of thermal expansion of electrical insulating liquids of petroleum origin.

5.2 *Definition:*

5.2.1 *coefficient of thermal expansion*—the change in volume per unit volume per degree change in temperature. It is commonly stated as the average coefficient over a given temperature range.

5.3 *Summary of Practice*—The specific gravity of insulating liquids is determined at two temperatures below 90 °C and separated by not less than 5 °C nor more than 14 °C. Test methods used may be D287, D1217, D1298, or D1481. The calculation of average coefficient of thermal expansion over this temperature range is given in Practice D1903.

5.4 *Significance and Use*—A knowledge of the coefficient of expansion of a liquid is essential to compute the required size of a container to accommodate a volume of liquid over the full temperature range to which it will be subjected. It is also used to compute the volume of void space that would exist in an inelastic device filled with the liquid after the liquid has cooled to a lower temperature.

6. Color

6.1 *Scope*—Test Method D1500 covers the visual determination of color of a wide variety of liquid petroleum products, including mineral insulating liquids.

6.2 *Summary of Test Method:*

6.2.1 *Test Method D1500*—The test specimen is placed in a glass sample jar (an ordinary 125-mL test specimen bottle is satisfactory for routine tests). The color of the sample by transmitted light is compared with a series of tinted glass standards. The glass standard matching the sample is selected, or if an exact match is not possible, the next darker glass is selected. The results are reported numerically on a scale of 0.5 to 8.0.

6.3 *Significance*—A low color number is an essential requirement for inspection of assembled apparatus in a tank. An increase in the color number during service is an indicator of deterioration or contamination of the insulating liquid.

7. Examination: Visual/Infrared

7.1 *Scope:*

7.1.1 Both visual examination and qualitative infrared absorption are described in this section. The test methods are:

[4] Available from ASTM International Headquarters. Order Adjunct No. ADJADJD1250. Original adjunct produced in 1983.

7.1.2 *Test Method D1524*—This is a visual examination of mineral insulating liquids that have been used in transformers, liquid-filled circuit breakers, or other electrical apparatus as insulating or cooling media, or both.

7.1.3 *Practices D2144*—The infrared absorption from 2.5 to 25 µm (4000 to 400 cm^{-1}) is recorded as a means of (*a*) establishing continuity by comparison with the spectra of previous shipments by the same supplier, (*b*) for the detection of some types of contaminants, (*c*) for the identification of liquids in storage or service. This practice is not intended for the determination of the various constituents of a liquid.

7.2 *Summary of Test Methods:*

7.2.1 *Test Method D1524*—The condition of the test specimen is estimated by observation of cloudiness, foreign particles, or suspended matter in the sample by reflected light. By use of this test method and Test Methods D1500 or D2129, the color and condition of a test specimen of electrical insulating liquid may be estimated during a field inspection, thus assisting in the decision as to whether or not the sample should be sent to a central laboratory for full evaluation.

7.2.2 *Practices D2144*—The infrared spectrum is recorded from 2.5 to 25 µm (4000 to 400 cm^{-1}) either as the absorption spectrum itself, or as the differential between the test specimen and reference liquid. The spectra are compared with reference spectra to establish the identity of the liquid.

7.3 *Significance and Use:*

7.3.1 *Practices D2144*—The infrared spectrum of an electrical insulating liquid indicates the general chemical composition of the sample. Because of the complex mixture of compounds present in insulating liquids, the spectrum is not sharply defined and may not be suitable for quantitative estimation of components. The identity of the liquid can be quickly established as being the same or different from previous samples by comparison with the reference spectra.

8. Flash and Fire Point

8.1 *Scope:*

8.1.1 Test Method D92 covers the determination of flash and fire points of all petroleum products except fuel oil and those having an open cup flash below 79 °C (175 °F).

8.1.2 This test method should be used solely to measure and describe the properties of materials in response to heat and flame under controlled laboratory conditions and should not be used for the description, appraisal, or regulation of the fire hazard of materials under actual fire conditions.

8.2 *Definitions:*

8.2.1 *flash point*—the temperature at which vapors above the liquid surface first ignite when a small test flame is passed across the surface under specified conditions.

8.2.2 *fire point*—the temperature at which liquid first ignites and burns for at least 5 s when a small test flame is passed across the surface under specified conditions.

8.3 *Summary of Test Method*—Fill the test cup to the specified level with the test specimen. Heat the sample initially at 14 °C/min to 17 °C/min (25 °F/min to 30 °F/min) until the temperature is 56 °C (100 °F) below the expected flash point. Reduce the rate of temperature change to 5 °C/min to 6 °C/min (9 °F/min to 11 °F/min) and apply the test flame every 2 °C (or 5 °F) until a flash occurs. Continue heating and testing every 2 °C (or 5 °F) until the liquid continues to burn for at least 5 s. The procedure is described in Test Method D92.

8.4 *Significance and Use*—The flash point and fire point tests give an indication of the flammability of a liquid. They may also be used to provide a qualitative indication of contamination with more flammable materials. In the latter context, the flash point test is more sensitive.

9. Interfacial Tension

9.1 *Scope*—These test methods cover the measurement, under nonequilibrium conditions, of the interfacial tension of insulating liquids against water. These test methods have been shown by experience to give a reliable indication of the presence of hydrophilic compounds.

9.2 *Definition:*

9.2.1 *interfacial tension*—the molecular attractive force between unlike molecules at an interface. It is usually expressed in millinewtons per meter.

9.3 *Summary of Test Methods:*

9.3.1 *Test Method D971*—Interfacial tension is determined by measuring the force necessary to detach a platinum wire upward from the oil water interface. To calculate the interfacial tension, the force so measured is corrected by an empirically determined factor which depends upon the force applied, the densities of both oil and water, and the dimensions of the ring. The measurement is completed within 1 min of the formation of the interface.

9.4 *Significance and Use*—Interfacial tension measurements on electrical insulating liquids provide a sensitive means of detecting small amounts of soluble polar contaminants and products of oxidation. A high value for new mineral insulating liquid indicates the absence of most undesirable polar contaminants. The test is frequently applied to service-aged liquids as an indication of the degree of deterioration.

10. Pour Point of Petroleum Products

10.1 *Scope*—The pour point is applicable to any petroleum liquid.

10.2 *Definition:*

10.2.1 *pour point*—the lowest temperature, expressed as a multiple of 3 °C at which the liquid is observed to flow when cooled and examined under prescribed conditions.

10.3 *Summary of Test Methods:*

10.3.1 After preliminary heating, the test specimen is cooled at a specified rate and examined at intervals of 3 °C for flow characteristics. The lowest temperature at which movement of the liquid is observed within 5 s is reported as the pour point. The procedure is described in Test Method D97.

10.3.2 Test Method D5949 covers the determination of pour point of petroleum products by an automatic instrument that applies a controlled burst of nitrogen gas onto the specimen surface while the specimen is being cooled and detects movement of the surface of the test specimen with an optical eye.

10.3.3 Test method D5950 covers the determination of pour point of petroleum products by an automatic instrument that tilts the test jar during cooling and detects movement of the surface of the test specimen with an optical eye.

10.4 *Significance and Use:*

10.4.1 The pour point of an insulating liquid gives an indication of the temperature below which it may not be possible to pour or remove the liquid from its container.

10.4.2 In connection with liquid for use in cable systems, the pour point may be useful to indicate the point at which no free movement will take place in the cable or to indicate the temperature at which partial separation of wax may occur.

10.4.3 The pour point of an electrical insulating liquid is important as an index of the lowest temperature to which the material may be cooled without seriously limiting the degree of circulation of the liquid. Some materials are sensitive to temperature cycling or prolonged storage at low temperatures, and their pour points may not adequately predict their low temperature flow properties.

11. Particle Count in Mineral Insulating Oil Using Automatic Optical Particle Counters

11.1 *Scope*—Test Method D6786 covers the determination of particle concentration and particle size distribution in mineral insulating liquid. It is suitable for testing liquids having a viscosity of 6 to 20 mm^2/s at 40 °C. The test method is specific to liquid automatic particle analyzers that use the light extinction principle.

11.2 *Summary of Test Method:*

11.2.1 Samples are taken in particle-clean bottles that are suitable for particle analysis. The sample bottle is agitated to redistribute particles in the liquid, then the liquid is placed in an automatic particle counter, where the number of particles and their size distribution are determined by the light extinction principle.

11.2.2 As particles pass through the sensing zone of the instrument, the quantity of light reaching the detector is obscured. This signal is translated to an equivalent projected area diameter based on calibration with a NIST-traceable liquid (ISO Medium Test Dust suspension).

11.3 *Significance and Use:*

11.3.1 Particles in insulating liquid can have a detrimental effect on the dielectric properties of the liquid, depending on the size, concentration, and nature of the particles. The source of these particles can be external contaminants, liquid degradation byproducts, or internal materials such as metals, carbon, or cellulose fibers.

11.3.2 Particle counts provide a general degree of contamination level and may be useful in assessing the condition of specific types of electrical equipment. Particle counts can also be used to determine filtering effectiveness when processing liquid.

11.3.3 If more specific knowledge of the nature of the particles is needed, other tests such as metals analysis or fiber identification and counting must be performed.

12. Refractive Index and Specific Optical Dispersion

12.1 *Scope:*

12.1.1 *Test Method D1218*—Describes a precise method for determining refractive index accurate to 0.00006 and refractive dispersion accurate to 0.00012. The liquid must be transparent, no darker than ASTM 4.0 color (see Test Method D1500) and have a refractive index between 1.33 and 1.50. The specific optical dispersion is calculated by dividing the refractive dispersion value by the specific gravity of the liquid.

12.2 *Definitions:*

12.2.1 *refractive index*—the ratio of the velocity of light in air to its velocity in the substance under test.

12.2.2 *specific optical dispersion* —the difference between the refractive indexes of light of two different wave lengths, both indexes measured at the same temperature, the difference being divided by the specific gravity also measured at the test temperature. For convenience, the specific dispersion value is multiplied by 10^4.

12.3 *Summary of Test Method:*

12.3.1 The two methods differ in the accuracy of the refractometer used. After adjusting the instrument temperature to 25°C, apply the test specimen to the refracting prism, read the refractive index, and read the compensator dial reading. From the correlation tables supplied with the instrument obtain the refractive dispersion. Calculate the specific optical dispersion by dividing refractive dispersion by the specific gravity of the liquid.

12.4 *Significance and Use:*

12.4.1 *Refractive Index* of an insulating liquid varies with its composition and with the nature and amount of contaminants held in solution. Where the refractive index of an insulating liquid when new is known, determinations made on the same liquid after periods of service may form a basis for estimating any change in composition or the degree of contamination acquired through service.

12.4.2 *Specific Optical Dispersion* serves as a quick index to the amount of unsaturated compounds present in a liquid. As the dispersion values for paraffinic and naphthenic compounds are nearly the same and are essentially independent of molecular weight and structural differences, values above a minimum of about 97 bear a direct relationship to the amount of aromatic compounds present in insulating liquid.

13. Relative Density (Specific Gravity)

13.1 *Scope:*

13.1.1 The methods used to measure relative density (specific gravity) may use a hydrometer, pycnometer, or an oscillating tube.

13.1.1.1 *Test Method D287*—Uses an API hydrometer and is limited to liquids having a Reid vapor pressure of 180 kPa (26 psi) or less.

13.1.1.2 *Test Method D1217*—Covers the use of a pycnometer to measure the relative density (specific gravity) of petroleum fractions.

13.1.1.3 *Test Method D1298*—Covers the use of a hydrometer to measure relative density (specific gravity) directly or the measurement of API gravity followed by conversion to relative density (specific gravity). This test method is limited to liquids having a Reid vapor pressure of 179 kPa (26 psi) or less. This test method is most suitable for use with mobile transparent liquids, although it can also be used with viscous liquids if sufficient care is taken in the measurement.

13.1.1.4 *Test Method D1481*—Covers the determination of the densities of liquids more viscous than 15 mm^2/s at 20 °C. The liquid should not have a vapor pressure greater than 13 kPa (100 mm Hg) at the test temperature. To measure the density of less viscous liquids more accurately than permitted by the hydrometer method, Test Method D1217 is available.

13.1.1.5 *Test Method D4052*—Covers the measurement of relative density (specific gravity) by the measurement of change in oscillation frequency of a vibrating glass tube filled with test liquid.

13.2 *Definition:*

13.2.1 *relative density (specific gravity)*—the ratio of the mass (weighed in vacuum) of a given volume of liquid at 15 °C (60 °F) to the mass of an equal volume of pure water at the same temperature. When reporting results, explicitly state the reference temperature, for example, specific gravity 15/15 °C.

13.3 *Summary of Test Method:*

13.3.1 API gravity may be measured at the liquid temperature using a hydrometer (Test Methods D287 or D1298) or Digital Density Meter (Test Method D4052) and converting to 15 °C or 60 °F using adjunct to Guide D1250.[4]

13.3.2 Relative density (specific gravity) may be measured at the liquid temperature using a hydrometer (Test Method D1298) or by Digital Density Meter (Test Method D4052) and converted to 15 °C or 60 °F using adjunct to Guide D1250.[4]

13.3.3 *Test Method D1481*—The liquid is drawn into the bicapillary pycnometer through the removable siphon arm and adjusted to volume at the temperature of test. After equilibration at the test temperature, liquid levels are read; and the pycnometer is removed from the thermostated bath, cooled to room temperature, and weighed. Density or relative density (specific gravity), as desired, is then calculated from the volume at the test temperature, and the weight of the sample. The effect of air buoyancy is included in the calculation.

13.4 *Significance and Use:*

13.4.1 Electrical insulating liquids are usually sold on the basis of volume delivered at 15 °C (60 °F). Delivery is often made on the basis of net weight of product in drums, and the specific gravities often are measured at temperatures other than 15 °C. The values of relative density (specific gravity) at 15 °C must be known to calculate the volume at 15 °C of the liquid delivered.

13.4.2 The relative density (specific gravity) of a mineral insulating liquid influences the heat transfer rates and may be pertinent in determining suitability for use in specific applications. In certain cold climates, ice may form in de-energized electrical equipment exposed to temperatures below 0 °C, and the maximum specific gravity of the liquid used in such equipment should be at a value that will ensure that ice will not float in the liquid at any temperature the liquid might attain.

13.4.3 When making additions of insulating liquid to apparatus in service, a difference in relative density (specific gravity) may indicate a tendency of the two bodies of liquid to remain in separate layers rather than mixing into a homogeneous single body of liquid. Such conditions have caused serious overheating of self-cooled apparatus. Suitable precautions should be taken to ensure mixing.

14. Specific Heat

14.1 *Scope*—Test Method D2766 covers determination of the specific heat of electrical insulating liquids of petroleum origin.

14.2 *Definition:*

14.2.1 *specific heat (or heat capacity) of a substance*—a thermodynamic property that is a measure of the amount of energy required to produce a given temperature change within a unit quantity of that substance. The standard unit of heat capacity is J/(kg·°C) at some defined temperature.

14.3 *Summary of Test Method*—The specific heat is determined by Test Method D2766. The measurement is made by heating a test specimen at a known and fixed rate. Once dynamic heating equilibrium is obtained, the heat flow is recorded as a function of temperature. The heat flow normalized to specimen mass and heating rate is directly proportional to the specimen's specific heat capacity.

14.4 *Significance and Use*—A knowledge of the specific heat is helpful in designing adequate heat transfer properties for electrical apparatus. A higher specific heat value indicates a more efficient heat transfer medium.

15. Thermal Conductivity

15.1 *Scope*—Test Method D2717 covers the determination of the thermal conductivity of electrical insulating liquids of petroleum origin.

15.2 *Definition:*

15.2.1 *thermal conductivity*—the ability of a substance to transfer energy as heat in the absence of mass transport phenomena. The standard unit of thermal conductivity is as follows:

$$W/(m \cdot °C)$$

15.3 *Summary of Test Method*—The thermal conductivity is determined by Test Method D2717. This test method measures the temperature gradient produced across the liquid by a known amount of energy introduced into the test cell by an electrically heated platinum element.

15.4 *Significance and Use*—A knowledge of thermal conductivity is helpful in designing adequate heat transfer properties for electrical apparatus. A high value indicates a good heat transfer efficiency property for the liquid.

16. Viscosity

16.1 *Scope:*

16.1.1 *Test Method D445*—This test method specifies a procedure for the determination of the kinematic viscosity 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 can be obtained by multiplying the kinematic viscosity by the density of the liquid.

16.1.2 *Practice D2161*—Provides tables or equations for the conversion of centistokes into Saybolt Universal Seconds or Saybolt Furol Seconds at the same temperatures.

16.2 *Summary of Test Methods:*

16.2.1 *Test Method D445*—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.

16.2.2 *Practice D2161*—The Saybolt Universal viscosity equivalent to a given kinematic viscosity varies with the temperature at which the determination is made. The basic conversion values are given in Table 1 of this practice for 37.8 °C (100 °F). Factors are given for converting units at other temperatures. The Saybolt Furol viscosity equivalents are given in Table 3 of this practice for 50.0 °C and 98.9 °C (122 °F and 210 °F) only.

16.2.3 *Test Method D7042*—This test method covers and specifies a procedure for the concurrent measurement of both the dynamic viscosity, η, and the density, ρ, of liquid petroleum products and crude oils, both transparent and opaque. The kinematic viscosity, ν, can be obtained by dividing the dynamic viscosity, η, by the density, ρ, obtained at the same test temperature.

16.3 *Significance and Use:*

16.3.1 The fundamental and preferred method for measuring kinematic viscosity is by use of Test Method D445.

16.3.2 Viscosity of electrical insulating liquids influences their heat transfer properties, and consequently the temperature rise of energized electrical apparatus containing the liquid. At low temperatures, the resulting higher viscosity influences the speed of moving parts, such as those in power circuit breakers, switchgear, load tapchanger mechanisms, pumps, and regulators. Viscosity controls insulating liquid processing conditions, such as dehydration, degassification and filtration, and liquid impregnation rates. High viscosity may adversely affect the starting up of apparatus in cold climates (for example, spare transformers and replacements). Viscosity affects pressure drop, liquid flow, and cooling rates in circulating liquid systems, such as in pipe-type cables and transformers.

ELECTRICAL PROPERTIES

17. Dielectric Breakdown Voltage

17.1 *Scope:*

17.1.1 There are two standard test methods for determining the dielectric breakdown voltage of electrical insulating liquids at commercial power frequencies, D877 and D1816, and one standard test method for determining the dielectric breakdown voltage of insulating liquids under impulse conditions, D3300.

17.1.2 *Test Method D877*—Applicable to petroleum liquids, hydrocarbons, and askarels commonly used as insulating and cooling media in cables, transformers, liquid-filled circuit breakers, and similar apparatus. The suitability of Test Method D877 for testing liquids having viscosities exceeding 900 mm^2/s at 40 °C (104 °F) has not been determined.

17.1.3 *Test Method D1816*—This test method covers the determination of the dielectric breakdown voltage of insulating liquids (liquids of petroleum origin, silicone liquids, high fire-point mineral electrical insulating liquids, synthetic ester liquids and natural ester liquids). This test method is applicable to insulating liquids commonly used in cables, transformers, liquid-filled circuit breakers, and similar apparatus as an insulating and cooling medium. Refer to Terminology D2864 for definitions used in this test method.

17.1.4 *Test Method D3300*—Applicable to any liquid commonly used as an insulating and cooling medium in high-voltage apparatus subjected to impulse conditions, such as transient voltage stresses arising from such causes as nearby lightning strikes and high-voltage switching operations.

17.2 *Definition:*

17.2.1 *dielectric breakdown voltage*—the potential difference at which electrical failure occurs in an electrical insulating material or insulation structure, under prescribed test conditions.

17.3 *Summary of Test Methods:*

17.3.1 *Test Method D877*—The insulating liquid is tested in a test cup between two 25.4-mm (1-in.) diameter disk electrodes spaced 2.54 mm (0.100 in.) apart. A 60-Hz voltage is applied between the electrodes and raised from zero at a uniform rate of 3 kV/s. The dielectric breakdown voltage is recorded, prior to the occurrence of disruptive discharge, when the voltage across the specimen has dropped to less than 100 V. In the referee procedure, one breakdown test is made on each of five fillings of the test cup, and the average and individual values of breakdown voltage are reported.

17.3.2 *Test Method D1816*—The liquid is tested in a test cell between spherically capped (VDE) electrodes spaced either 1 mm (0.040 in.) or 2 mm (0.080 in.) apart. The liquid is stirred before and during application of voltage by means of a motor-driven stirrer. A 60-Hz voltage is applied between the electrodes and raised from zero at a uniform rate of 0.5 kV/s. The voltage at which the current produced by breakdown of the liquid reaches the range of 2 to 20 mA, tripping a circuit breaker, is considered to be the dielectric breakdown voltage. In the procedure, five breakdown tests are made on one filling of the test cell. If the five breakdowns fall within the statistical requirements, the average value is reported. If not, five additional breakdowns are required with the average of the ten values reported.

17.3.3 *Test Method D3300*—The electrode system consists of either: (*1*) two 12.7-mm (0.5-in.) diameter spheres spaced 3.8 mm (0.15 in.) apart or (*2*) a 12.7-mm (0.5-in.) diameter sphere and a steel phonograph needle of 0.06-mm radius of curvature of point, spaced 25.4 mm (1.0 in.) apart. The polarity of the needle with respect to the sphere can be either positive or negative. The electrodes are immersed in the liquid in a test cell. An impulse wave of 1.2 by 50 µs wave shape (times to reach crest value and to decay to half of crest value, respectively) is applied at progressively higher voltages until breakdown occurs.

17.4 *Significance and Use:*

17.4.1 *Power Frequencies (Test Methods D877 and D1816)*—The dielectric breakdown voltage of an insulating