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Standard Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Oils of Petroleum Origin[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.

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

1. Scope

1.1 This guide describes methods of testing and specifications for electrical insulating oils of petroleum origin intended for use in electrical cables, transformers, oil circuit breakers, and other electrical apparatus where the oils 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 oils.

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:

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Sampling:	3	D923, D2759, D3305 , D3613
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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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1.4

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D88 Test Method for Saybolt Viscosity
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
D878 Test Method for Inorganic Chlorides and Sulfates in Insulating Oils
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 Oil 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 Use of the Petroleum Measurement Tables
D1275 Test Method for Corrosive Sulfur in Electrical Insulating Oils
D1298 Test Method for Density, Relative Density (Specific Gravity), 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 Oils of Petroleum Origin 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
D1698 Test Method for Sediments and Soluble Sludge in Service-Aged Insulating Oils
D1807 Test Methods for Refractive Index and Specific Optical Dispersion of Electrical Insulating Liquids
D1816 Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes
D1827 Test Method for Gas Content (Nonacidic) of Insulating Liquids by Displacement with Carbon Dioxide
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 Petroleum Oils by Open-Beaker Method
D2112 Test Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Pressure Vessel
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
D2285 Test Method for Interfacial Tension of Electrical Insulating Oils of Petroleum Origin Against Water by the Drop-Weight Method
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 Absorption
D2717 Test Method for Thermal Conductivity of Liquids
D2759 Practice for Sampling Gas from a Transformer Under Positive Pressure
D2766 Test Method for Specific Heat of Liquids and Solids
D2945 Test Method for Gas Content of Insulating Oils

[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.

D3300 Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Under Impulse Conditions
D3305 Practice for Sampling Small Gas Volume in a Transformer
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
~~D3613Practice for Sampling Insulating Liquids for Gas Analysis and Determination of Water Content~~
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
D4768 Test Method for Analysis of 2,6-Ditertiary-Butyl Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Insulating Liquids by Gas Chromatography
D5185 Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in 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)
D6180 Test Method for Stability of Insulating Oils of Petroleum Origin Under Electrical Discharge
D6181 ~~Test Method for Measurement of Turbidity in Mineral Insulating Oil of Petroleum Origin~~ Test Method for Measurement of Turbidity in Mineral Insulating Oil of Petroleum Origin
D6786 Test Method for Particle Count in Mineral Insulating Oil Using Automatic Optical Particle Counters
D6802 Test Method for Determination of the Relative Content Of Dissolved Decay Products in Mineral Insulating Oils by Spectrophotometry
D7150 Test Method for the Determination of Gassing Characteristics of Insulating Liquids Under Thermal Stress at Low Temperature
D7151 Test Method for Determination of Elements in Insulating Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

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 oil in accordance with Practices D923, D2759 ~~, and~~ and D3305 ~~, and D3613, as appropriate.~~ as appropriate.

PHYSICAL PROPERTIES

4. Aniline Point

4.1 *Scope*—This test method 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 oil indicates the solvency of the oil for some materials that are in contact with the oil. 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*—This test method 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 Test Method*—The specific gravity of insulating oils 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,~~D287, D1217, ~~D1298,~~D1298, or ~~D1481.~~D1481. The calculation of average coefficient of thermal expansion over this temperature range is given in Test Method 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*—This test method covers the visual determination of color of a wide variety of liquid petroleum products, including mineral insulating oils.

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 oil.

7. Examination

7.1 *Scope*:

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

7.1.2 *Test Method* D1524—This is a visual examination of mineral insulating oils that have been used in transformers, oil circuit breakers, or other electrical apparatus as insulating or cooling media, or both. This test is intended for use in the field.

7.1.3 *Test Method* D2144—The infrared absorption from 2.5 to 25 µm (4000 to 667 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 oils in storage or service. This test method is not intended for the determination of the various constituents of an oil.

7.2 *Summary of Test Methods*:

7.2.1 *Test Method* D1524—Estimate the color of the oil by use of an oil comparator, matching the oil test specimen with tinted glass color standards. Note the presence of cloudiness, particles of insulation, metal corrosion products, or other undesirable suspended materials in the oil.

7.2.2 *Test Methods* D2144—The infrared spectrum is recorded from 2.5 to 25 µm (4000 to 667 cm^{-1}) either as the absorption spectrum itself, or as the differential between the test specimen and reference oil. The spectra are compared with reference spectra to establish the identity of the oil.

7.3 *Significance and Use*:

7.3.1 *Test Method* D1524—The observation of the color and condition of the oil in a field inspection permits a determination of whether the sample should be sent to a central laboratory for full evaluation.

7.3.2 *Test Methods* D2144—The infrared spectrum of an electrical insulating oil indicates the general chemical composition of the sample. Because of the complex mixture of compounds present in insulating oils, the spectrum is not sharply defined and may not be suitable for quantitative estimation of components. The identity of the oil 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 This test method covers the determination of flash and fire points of all petroleum products except fuel oils 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 oil 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 oil 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 to 17°C/min (25 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 to 6°C/min (9 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 oil 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 an oil. 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 oils 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 dynes per centimetre or millinewtons per metre.

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.

9.3.2 *Test Method* D2285—Interfacial tension is determined by measuring the volume of a drop of water that the oil will support. The larger the drop of water, the higher the interfacial tension of the oil. The instrument used to measure the volume of the drops of water is calibrated to read approximately in dynes per centimet~~re~~er interfacial tension. For better accuracy, the reading can be corrected by a factor that depends on the density of the oil. The drop is allowed to age for 30 s and to fall between 45 and 60 s after formation.

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

10. Pour Point

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

10.2 *Definition*:

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

10.3 *Summary of Test Method*—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 oil is observed within 5 s is reported as the pour point. The procedure is described in Test Method D97.

10.4 *Significance and Use*:

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

10.4.2 In connection with oil 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 a transformer oil 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 oil. 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.Refractive Index and Specific Optical Dispersion~~

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

11.1 *Scope*—This test method covers the determination of particle concentration and particle size distribution in mineral insulating oil. It is suitable for testing oils having a viscosity of 6 to 20 cSt 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*:

~~11.1.1~~

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 oil, then the oil 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 fluid (ISO Medium Test Dust suspension).

11.3 *Significance and Use*:

11.3.1 Particles in insulating oil can have a detrimental effect on the dielectric properties of the fluid, depending on the size, concentration, and nature of the particles. The source of these particles can be external contaminants, oil 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 oil.

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 precision 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.

~~11.1.2~~

12.1.2 *Test Method* D1807—Describes a routine method for measuring refractive index accurate to three units in the fourth decimal place, measuring refractive dispersion, and calculating specific optical dispersion accurate to three units in the fourth decimal place. The oils must be transparent and light colored.

~~11.2~~

12.2 *Definitions*:

~~11.2.1~~

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

~~11.2.2~~

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.

~~11.3~~

12.3 *Summary of Test Method*:

1~~1~~2.3.1 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 oil.

~~11.4~~12.4 *Significance and Use*:

~~11.4.1~~

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 solution.

~~11.4.2~~

12.4.2 *Specific Optical Dispersion* serves as a quick index to the amount of unsaturated compounds present in an oil. 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 oil.

~~**12.**~~

13. Relative Density (Specific Gravity)

~~12.1~~

13.1 *Scope*:

1~~2~~3.1.1 The methods used to measure relative density (specific gravity) may use a hydrometer, pycnometer, or an oscillating tube.

~~12.1.1.1~~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.

~~12.1.1.2~~

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

~~12.1.1.3~~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 oils if sufficient care is taken in the measurement.

~~12.1.1.4~~13.1.1.4 *Test Method* D1481—Covers the determination of the densities of oils more viscous than 15 cSt 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.

~~12.1.1.5~~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.

~~12.2~~13.2 *Definition*:
~~12.2.1~~
13.2.1 *relative density (specific gravity)*—the ratio of the mass (weighed in vacuum) of a given volume of liquid at 15.6°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 15.6/15.6°C.

~~12.3~~
13.3 *Summary of Test Method*:

1~~2~~3.3.1 API gravity may be measured at the oil temperature using a hydrometer (Test Methods D287 or D1298) and converting to 15.6°C using Guide D1250.

1~~2~~3.3.2 Relative density (specific gravity) may be measured at the oil temperature using a hydrometer (Test Method D1298) and converted to 15.6°C using Guide D1250.

~~12.3.3~~
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.

~~12.4~~
13.4 *Significance and Use*:

1~~2~~3.4.1 Electrical insulating oils are usually sold on the basis of volume delivered at 15.6°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 15.6°C. The values of relative density (specific gravity) at 15.6°C must be known to calculate the volume at 15.6°C of the oil delivered.

1~~2~~3.4.2 The relative density (specific gravity) of a mineral insulating oil 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 transformers exposed to temperatures below 0°C, and the maximum specific gravity of the oil used in such equipment should be at a value that will ensure that ice will not float in the oil at any temperature the oil might attain.

1~~2~~3.4.3 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.

~~13.~~14. Specific Heat

~~13.1~~
14.1 *Scope*—This test method covers determination of the specific heat of electrical insulating liquids of petroleum origin.
~~13.2~~
14.2 *Definition*:
~~13.2.1~~
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 Joules/Kg°C at some defined temperature; specific heat is dimensionless as it is the ratio of the substance's heat capacity relative to that of water.

~~13.3~~
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.

~~13.4~~
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.

~~14.~~

15. Thermal Conductivity

~~14.1~~
15.1 *Scope*—This test method covers the determination of the thermal conductivity of electrical insulating liquids of petroleum origin.

~~14.2~~
15.2 *Definition*:
~~14.2.1~~

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/(mK) (Cal/cm s °C)

~~14.3~~
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.

~~14.4~~
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.

~~15.~~

16. Turbidity

~~15.1~~
16.1 *Scope*—This test method determines the amount of suspended particulate matter in electrical insulating oil of petroleum origin.

~~15.2~~
16.2 *Definition*:

~~15.2.1~~
16.2.1 *turbidity, n*—the reduction of transparency due to presence of particulate matter. The standard unit of turbidity is the nephelometric turbidity unit (NTU), which is defined as the intensity of light scattered by a known aqueous suspension of formazine.

~~15.3~~
16.3 *Summary of Test Method*—The turbidity is determined by Test Method D6181. This test method measures the scattered light at 0.5 π rad (90°) or 0.5 and 1.5 π rad (90° and 270°) angles to the incident beam using a nephelometer that has been calibrated with a standard aqueous suspension of formazine.

~~15.4~~
16.4 *Significance and Use*—Turbidity measures particulate contamination in electrical insulating oil that may not be apparent to the unaided human eye and could affect the performance of the dielectric fluid.

~~16.~~

17. Viscosity

~~16.1~~
17.1 *Scope*:

~~16.1.1~~
17.1.1 *Test Method* D88—Covers the empirical measurement of Saybolt viscosity of petroleum products using the Saybolt viscometer at temperatures between ~~23.1~~ 25.1 and 98.9°C (70 and 210°F).

~~16.1.2~~
17.1.2 *Test Method* D445—Covers the determination of the kinematic viscosity of liquid petroleum products by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer.

~~16.1.3~~
17.1.3 *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~~
17.2 *Summary of Test Methods*:

~~16.2.1~~
17.2.1 *Test Method* D88—The efflux time in seconds for 60 mL of test specimen to flow through a calibrated orifice in the Saybolt viscometer is measured under carefully controlled conditions, particularly temperature and liquid head. The time is converted by an orifice factor and reported as the viscosity of the sample at that temperature.

~~16.2.2~~
17.2.2 *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.

~~16.2.3~~
17.2.3 *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 and 98.9°C (122 and 210°F) only.

~~16.3~~
17.3 *Significance and Use*:
1~~6~~7.3.1 The fundamental and preferred method for measuring kinematic viscosity is by use of Test Method D445. The Saybolt instrument in Test Method D88, being of all-metal construction, may be more rugged for field use, but values obtained are significantly less accurate than those obtained by the use of the capillary viscometers in Test Method D445.

1~~6~~7.3.2 Viscosity of electrical insulating oils 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 oil processing conditions, such as dehydration, degassification and filtration, and oil 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, oil flow, and cooling rates in circulating oil systems, such as in pipe-type cables and transformers.

ELECTRICAL PROPERTIES

~~**17.**~~

18. Dielectric Breakdown Voltage

~~17.1~~
18.1 *Scope*:
1~~7~~8.1.1 There are two standard test methods for determining the dielectric breakdown voltage of electrical insulating fluids at commercial power frequencies, D877 and D1816, and one standard test method for determining the dielectric breakdown voltage of insulating oils under impulse conditions, D3300.

~~17.1.2~~
18.1.2 *Test Method* D877—Applicable to liquid petroleum oils, hydrocarbons, and askarels commonly used as insulating and cooling media in cables, transformers, oil circuit breakers, and similar apparatus. The suitability of Test Method D877 for testing liquids having viscosities exceeding 900 cSt (5000 SUS) at 40°C (104°F) has not been determined.

~~17.1.3~~
18.1.3 *Test Method* D1816—Applicable to liquid petroleum oils commonly used as an insulating and cooling medium in cables, transformers, oil circuit breakers, and similar apparatus. The suitability of Test Method D1816 for testing oils having viscosities of more than 19 cSt (100 SUS) at 40°C (104°F) has not been determined.

~~17.1.4~~
18.1.4 *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~~
18.2 *Definition*:
~~17.2.1~~
18.2.1 *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~~
18.3 *Summary of Test Methods*:
~~17.3.1~~
18.3.1 *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~~
18.3.2 *Test Method* D1816—The oil 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 oil 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 ½ kV/s. The voltage at which the current produced by breakdown of the oil 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~~
18.3.3 *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