



Designation: ~~D117–18~~ D117 – 22

Standard Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Liquids¹

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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

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~~ 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 ~~oil~~ 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
<i>Sampling:</i>	<u>3</u>	D923
<i>Physical Tests:</i>		
Aniline Point	<u>4</u>	D611
Coefficient of Thermal Expansion	<u>5</u>	D1903
Color	<u>6</u>	D1500
Examination: Visual Infrared	<u>7</u>	D1524, D2144, D2129
Flash and Fire Point	<u>8</u>	D92
Interfacial Tension	<u>9</u>	<u>D971, D2285</u>
<u>Interfacial Tension</u>	<u>9</u>	<u>D971</u>
Pour Point of Petroleum Products	<u>10</u>	D97, D5949, D5950
Particle Count in Mineral Insulating Oil	<u>11</u>	<u>D6786</u>
<u>Particle Count in Mineral Insulating Oil</u>	<u>11</u>	<u>D6786</u>
Refractive Index and Specific Optical Dispersion	<u>12</u>	<u>D1218, D1807</u>
<u>Refractive Index and Specific Optical Dispersion</u>	<u>12</u>	<u>D1218</u>
Relative Density (Specific Gravity)	<u>13</u>	D287, D1217, D1298, D1481, D4052
Specific Heat	<u>14</u>	D2766
Thermal Conductivity	<u>15</u>	D2717

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.

Current edition approved Nov. 1, 2018; May 1, 2022. Published December 2018; June 2022. Originally published as D117 – 21 T. Last previous edition approved in 2010 as ~~D117 – 10; D117 – 18~~, DOI: ~~10.1520/D0117-18~~; 10.1520/D0117-22.

Category	Section	ASTM Standard
Turbidity	<u>16</u>	<u>D6181</u>
Viscosity	<u>17</u>	<u>D445, D2161</u>
Viscosity	<u>16</u>	<u>D445, D2161, D7042</u>
<i>Electrical Tests:</i>		
Dielectric Breakdown Voltage	<u>18</u>	<u>D877, D1816, D3300</u>
Dielectric Breakdown Voltage	<u>17</u>	<u>D877, D1816, D3300</u>
Dissipation Factor and Relative Permittivity (Dielectric Constant)	<u>19</u>	<u>D924</u>
Dissipation Factor and Relative Permittivity (Dielectric Constant)	<u>18</u>	<u>D924</u>
Gassing Characteristic Under Thermal Stress	<u>20</u>	<u>D7150</u>
Gassing Characteristic Under Thermal Stress	<u>19</u>	<u>D7150</u>
Gassing Tendency	<u>24</u>	<u>D2300</u>
Gassing Tendency	<u>20</u>	<u>D2300</u>
Resistivity	<u>22</u>	<u>D1169</u>
Resistivity	<u>21</u>	<u>D1169</u>
Stability Under Electrical Discharge	<u>23</u>	<u>D6180</u>
<i>Chemical Tests:</i>		
Acidity, Approximate	<u>24</u>	<u>D1534</u>
Acidity, Approximate	<u>22</u>	<u>D1534</u>
Carbon-Type Composition	<u>25</u>	<u>D2140</u>
Carbon-Type Composition	<u>23</u>	<u>D2140</u>
Compatibility with Construction Material	<u>26</u>	<u>D3455</u>
Compatibility with Construction Material	<u>24</u>	<u>D3455</u>
Copper Content	<u>27</u>	<u>D3635</u>
Copper Content	<u>25</u>	<u>D3635</u>
Elements by Inductively Coupled Plasma (ICP-AES)	<u>28</u>	<u>D7151</u>
Elements by Inductively Coupled Plasma (ICP-AES)	<u>26</u>	<u>D7151</u>
Furanic Compounds in Electrical Insulating Liquids	<u>29</u>	<u>D5837</u>
Furanic Compounds in Electrical Insulating Liquids	<u>27</u>	<u>D5837</u>
Dissolved Gas Analysis	<u>30</u>	<u>D3612</u>
Dissolved Gas Analysis	<u>28</u>	<u>D3612</u>
Gas Content of Cable and Capacitor Oils	<u>31</u>	<u>D831, D1827, D2945</u>
Gas Content of Cable and Capacitor Liquids	<u>29</u>	<u>D831, D1827, D2945</u>
Inorganic Chlorides and Sulfates	<u>32</u>	<u>D878</u>
Neutralization (Acid and Base) Numbers	<u>33</u>	<u>D664, D974</u>
Neutralization (Acid and Base) Numbers	<u>30</u>	<u>D664, D974</u>
Oxidation Inhibitor Content	<u>34</u>	<u>D2668, D4768</u>
Oxidation Inhibitor Content	<u>31</u>	<u>D2668, D4768</u>
Oxidation Stability	<u>35</u>	<u>D1934, D2112, D2440</u>
Oxidation Stability	<u>32</u>	<u>D1934, D2112, D2440</u>
Polychlorinated Biphenyl Content (PCB)	<u>36</u>	<u>D4059</u>
Polychlorinated Biphenyl Content (PCB)	<u>33</u>	<u>D4059</u>
Relative Content of Dissolved Decay	<u>37</u>	<u>D6802</u>
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Sulfur, Corrosive	<u>39</u>	<u>D1275</u>
Sulfur, Corrosive	<u>34</u>	<u>D1275</u>
Water Content	<u>40</u>	<u>D1533</u>
Water Content	<u>35</u>	<u>D1533</u>
<i>Specification:</i>		
Mineral Insulating Oil for Electrical Apparatus	<u>41</u>	<u>D3487</u>
Mineral Insulating Liquid for Electrical Apparatus	<u>36</u>	<u>D3487</u>
High Firepoint Electrical Insulating Oils	<u>42</u>	<u>D5222</u>
Less Flammable Electrical Insulating Liquids	<u>37</u>	<u>D5222</u>

Category	Section	ASTM Standard
Silicone Fluid used for Electrical Insulation	43	D4652
Silicone Fluid used for Electrical Insulation	38	D4652
Natural (Vegetable Oil) Ester Fluids used in Electrical Apparatus	44	D6871
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 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](#)
- ~~[D878 Test Methods for Inorganic Chlorides and Sulfates in Insulating Oils \(Withdrawn 2015\)³](#)~~
- [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](#)
- ~~[D1698 Test Method for Sediments and Soluble Sludge in Service-Aged Insulating Oils \(Withdrawn 2014\)³](#)~~
- ~~[D1807 Test Methods for Refractive Index and Specific Optical Dispersion of Electrical Insulating Liquids \(Withdrawn 2014\)³](#)~~
- [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](#)

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.

- 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
- ~~D2285 Test Method for Interfacial Tension of Electrical Insulating Oils of Petroleum Origin Against Water by the Drop-Weight Method (Withdrawn 2008)³~~
- 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 (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 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)
- ~~D6180 Test Method for Stability of Insulating Oils of Petroleum Origin Under Electrical Discharge (Withdrawn 2014)³~~
- ~~D6181 Test Method for Measurement of Turbidity in Mineral Insulating Oil of Petroleum Origin (Withdrawn 2012)³~~
- 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 (Withdrawn 2019)³~~
- 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.

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

3.2 Sample the insulating oil 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 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*—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 Test Method—Practice*—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**, **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 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: Visual/Infrared

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/liquids that have been used in transformers, oil/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 oils/liquids in storage or service. This ~~test method~~ practice is not intended for the determination of the various constituents of an oil/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 oil/liquid. The spectra are compared with reference spectra to establish the identity of the oil/liquid.

7.3 Significance and Use:

7.3.1 *Practices D2144*—The infrared spectrum of an electrical insulating oil/liquid indicates the general chemical composition of the sample. Because of the complex mixture of compounds present in insulating oils/liquids, the spectrum is not sharply defined and may not be suitable for quantitative estimation of components. The identity of the oil/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/soil and those having an open cup flash below 79°C (175°F); 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/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 oil/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) 30 °F/min until the temperature is 56°C (100°F); 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) 11 °F/min and apply the test flame every 2°C (or 5°F); 5 °F until a flash occurs. Continue heating and testing every 2°C (or 5°F); 5 °F until the oil/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 an oil 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 oil 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-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 millinewtons per meter 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 oil liquids provide a sensitive means of detecting small amounts of soluble polar contaminants and products of oxidation. A high value for new mineral insulating oil liquid indicates the absence of most undesirable polar contaminants. The test is frequently applied to service-aged oil 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 oil liquid.

10.2 Definition:

10.2.1 *pour point*—the lowest temperature, expressed as a multiple of $3^{\circ}\text{C}-3^{\circ}\text{C}$ at which the oil 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 $3^{\circ}\text{C}-3^{\circ}\text{C}$ for flow characteristics. The lowest temperature at which movement of the oil 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 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~~ 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 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. 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 oil. It is suitable for testing oils having a viscosity of 6 to 20 mm²/s at ~~40°C~~ 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 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 liquid (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 oil, 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 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.

~~12.1.2 *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.~~

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 ~~oil~~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 ~~solution~~service.

12.4.2 *Specific Optical Dispersion* serves as a quick index to the amount of unsaturated compounds present in ~~an oil~~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 ~~oil~~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. <https://standards.iteh.ai/catalog/standards/sist/d251945f-be9d-4ed2-891b-9a904896b1aa/astm-d117-22>

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

13.1.1.4 *Test Method D1481*—Covers the determination of the densities of ~~oils~~liquids more viscous than 15 mm²/s at ~~20°C~~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 ~~15.6°C (60°F)~~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 ~~15.6/15.6°C~~15/15 °C.

13.3 *Summary of Test Method:*

13.3.1 API gravity may be measured at the oilliquid temperature using a hydrometer (Test Methods **D287** or **D1298**) or Digital Density Meter (Test Method **D4052**) and converting to 15.6°C–15 °C or 60 °F using adjunct to Guide **D1250**.⁴

13.3.2 Relative density (specific gravity) may be measured at the oilliquid temperature using a hydrometer (Test Method **D1298**) or by Digital Density Meter (Test Method **D4052**) and converted to 15.6°C–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 oilliquids are usually sold on the basis of volume delivered at 15.6°C (60°F), 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 15.6°C–15 °C. The values of relative density (specific gravity) at 15.6°C–15 °C must be known to calculate the volume at 15.6°C–15 °C of the oilliquid delivered.

13.4.2 The relative density (specific gravity) of a mineral insulating oilliquid 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 electrical equipment exposed to temperatures below 0°C, 0 °C, and the maximum specific gravity of the oilliquid used in such equipment should be at a value that will ensure that ice will not float in the oilliquid at any temperature the oilliquid 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:

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. Turbidity

16.1 *Scope*—Test Method **D6181** determines the amount of suspended particulate matter in electrical insulating oil of petroleum origin.

16.2 *Definition:*

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.

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

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 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), 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 to 50.0°C and 98.9°C (210°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:*