Designation: D 1816 – 97

Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes[1]

This standard is issued under the fixed designation D 1816; 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 test method covers the determination of the dielectric breakdown voltage of insulating oils of petroleum origin. This test method is applicable to liquid petroleum oils commonly used in cables, transformers, oil circuit breakers, and similar apparatus as an insulating and cooling medium. The suitability of this test method for testing oils having viscosity of more than 19 cSt, (100SUS) at 40°C (104°F) has not been determined. Refer to Terminology D 2864 for definitions used in this test method.

1.2 This test method is more sensitive to the deleterious effects of moisture in solution than is Test Method D 877, especially when cellulosic fibers are present in the oil. It has been found to be especially useful in diagnostic and laboratory investigations of the dielectric breakdown strength of oil in insulating systems.[2]

1.3 This test method should be used for the testing of oil in power system equipment where the oil has been filtered and vacuum filled.

1.4 Both the metric and the alternative inch-pound units are acceptable.

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:*

D 235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)[3]

D 877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes[4]

D 923 Test Method for Sampling Electrical Insulating Liquids[4]

D 2864 Terminology Relating to Electrical Insulating Liquids and Gases[4]

2.2 *IEEE Standard:*

No. 4 Techniques for High Voltage Testing[5]

3. Significance and Use

3.1 The dielectric breakdown voltage of an insulating liquid is of importance as a measure of the liquid's ability to withstand electric stress without failure. It serves to indicate the presence of contaminating agents such as water, dirt, cellulosic fibers, or conducting particles in the liquid, one or more of which may be present in significant concentrations when low breakdown voltages are obtained. However, a high dielectric breakdown voltage does not necessarily indicate the absence of all contaminants; it may merely indicate that the concentrations of contaminants that are present in the liquid between the electrodes are not large enough to deleteriously affect the average breakdown voltage of the liquid when tested by this test method (see Appendix X1.)

4. Apparatus

4.1 *Transformer*— The desired test voltage may be most readily obtained by a step-up transformer energized from a variable low-voltage commercial power frequency source. To reduce the likelihood of external flashover and to minimize field distortion between the electrodes, a two-bushing, center-tap-grounded transformer is recommended. Design the transformer and controlling element of such size that, with the test specimen in the circuit, the voltage waveshape is approximately a sinusoid with both half cycles alike, and it should have a ratio of peak-to-rms value equal to the square root of two within ± 5 %. The peak to rms value may be checked by means of an oscilloscope, a spheregap, or a peak-reading voltmeter in conjunction with an rms voltmeter. Where the wave form cannot be determined conveniently, a transformer having a rating of not less than ½ kVA at the usual breakdown voltage shall be used. Transformers of larger kVA capacity may be used, but in no case should the short-circuit current in the specimen circuit be outside the range from 1 to 10 mA/kV of applied voltage. This limitation of current may be accomplished by using a suitable external series resistor or by

[1] This test method is under the jurisdiction of ASTM Committee D-27 on Electrical Insulating Liquids and Gases and is the direct responsibility of Subcommittee D27.05on Electrical Tests.

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[2] Supporting data is available from ASTM Headquarters. Request RR:D27-1006.

[3] *Annual Book of ASTM Standards,* Vol 06.04.

[4] *Annual Book of ASTM Standards,* Vol 10.03.

[5] Available from the Institute of Electrical and Electronic Engineers, Inc., PO Box 1331, Piscataway, NJ 08855.

employing a transformer with sufficient inherent reactance.

4.2 *Circuit-Interrupting Equipment*—Protect the primary of the test transformer with an automatic circuit-breaking device capable of opening in three cycles or less on the current produced by breakdown of the test specimen, or up to five cycles if the short-circuit current as described in 4.1 does not exceed 200 mA. The current-sensing element that trips the circuit-breaker should operate when the specimen-circuit current is in the range from 2 to 20 mA. A prolonged flow of current at the time of breakdown causes carbonization of the liquid and pitting and heating of the electrodes, and thereby increases the electrode and test cell maintenance, and time of testing.

4.3 *Voltage-Control Equipment*—Raise the voltage ½ kV/s ± 20 %. The rate-of-rise may be calculated from measurements of the time required to raise the voltage between two prescribed values. Voltage control may be secured by a motor-driven variable-ratio-autotransformer. Preference should be given to equipment having an approximate straight-line voltage-time curve over the desired operating range. Motor drive is preferred to manual drive because of the ease of maintaining a reasonably uniform rate-of-voltage rise with this test method. When motor driven equipment is used, the speed control rheostat should be calibrated in terms of rate-of-voltage rise for the test transformer used.

4.4 *Voltmeter*—Measure the voltage using a method that fulfills the requirements of IEEE Standard No. 4, giving rms values, preferably by means of:

4.4.1 A voltmeter connected to the secondary of a separate potential transformer, or

4.4.2 A voltmeter connected to a well-designed tertiary coil in the test transformer, or

4.4.3 A voltmeter connected to the low-voltage side of the testing transformer if the measurement error can be maintained within the limit specified in 4.5.

4.5 *Accuracy*—The combined accuracy of the voltmeter and voltage divider circuit shall be such that measurement error does not exceed 5 % at the rate-of-voltage rise specified in 4.3.

5. Electrodes

5.1 The electrodes shall be polished brass spherically-capped electrodes of the VDE (Verband Deutscher Elektrotechniker, Specification 0370) type having the dimensions shown in Fig. 1 ± 1 %, mounted with axes horizontal and coincident.

5.2 The test cell shall be designed to permit easy removal of the electrodes for cleaning and polishing.

6. Test Cell

6.1 Construct the test cell as a cube. A cell having a capacity of approximately 0.95 L, has been found to be satisfactory for an electrode spacing of 2 mm or 0.080 in. A cell having a capacity of approximately 0.5 L has been found to be satisfactory for an electrode spacing of 1 mm or 0.040 in. Mount the electrodes rigidly from opposite sides with the gap approximately centered. Clearance from all other sides and any part of the stirring device is at least 12.7 mm (½ in.). Provide the test cell with a motor-driven two-bladed impeller measuring approximately 35 mm (1⅜ in.) between the blade extremities, having a pitch of approximately 40 mm or 1.57 in. (blade angle of 20° ± 5 %), operating at a speed between 200 and 300 rpm. The impeller, located below the lower edge of the electrodes, rotating in such a direction that the resulting liquid flow is directed downward against the bottom of the test cell. Construct the test cell of a material of high dielectric strength, that is not soluble in or attacked by any of the cleaning or test liquids used, and is nonabsorbent to moisture and the cleaning and test liquids. So that the breakdown may be observed, transparent materials are desirable, but not essential. In order to preclude stirring air with the sample, provide the cell with a cover or baffle that will effectively prevent air from contacting the circulating liquid.

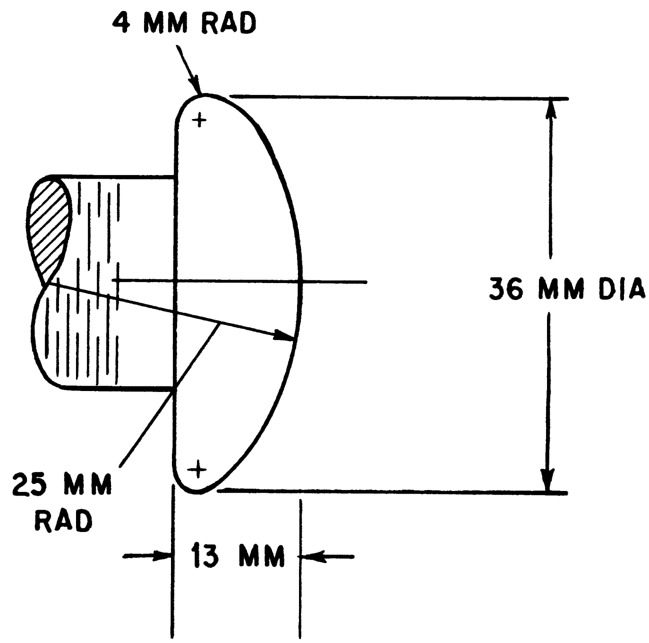

FIG. 1 VDE Electrode

7. Adjustment and Care of Electrodes and Test Cell

7.1 *Spacing*—With the electrodes firmly locked in position, check the electrodes with a standard round gage for 2-mm or 0.080-in. spacing, when a voltage source of a suitable range is available, or for 1-mm or 0.040-in. spacing when the test transformer voltage limit is restricted to approximately 50 kV. Flat "go" and "no-go" gages may be substituted having thicknesses of the specified value ±0.03 mm for electrode spacings of 1 or 2 mm, or thicknesses of the specified value ±0.001 in. for spacings of 0.040 or 0.080 in. If it is necessary to readjust the electrodes, lock the electrodes and check the spacing. For referee tests or tests that will be used for close comparisons, the laboratories shall agree in advance on the gap spacing for the tests. Four gaps are possible 0.040 or 0.080 in. or 1 or 2 mm. The gap agreed upon shall be measured with the gage that corresponds exactly to one of the selected gap within tolerance stated above for the gage.

7.2 *Cleaning*—Wipe the electrodes and cell clean with dry, lint-free tissue paper, or a clean dry chamois. It is important to avoid touching the electrodes or the cleaned gage with the fingers or with portions of the tissue paper or chamois that have been in contact with the hands. After adjustment of the gap spacing, rinse the cell with a dry hydrocarbon solvent, such as kerosine or solvents of Specification D 235. Do not use a low boiling point solvent, as its rapid evaporation may cool the cell, causing moisture condensation. If this occurs, before using, warm the cell to evaporate the moisture. Avoid touching the electrodes or the inside of the cell after cleaning. After thorough cleaning, flush the cell with new, dry, filtered oil of the type to be tested (preferably degassed oil). Conduct a voltage breakdown test on a specimen of this oil in the manner specified in this test method. If the breakdown voltage is in the expected range for this conditioned oil, the cell is considered properly prepared for testing other samples. A lower than anticipated value is considered as evidence of cell contamination, then repeat the cleaning and the breakdown test with clean dry oil.

7.3 *Daily Use*—At the beginning of each day's testing, the electrodes shall be examined for pitting and carbon accumulation, and the spacing checked. If the test of any sample is below the breakdown value being used by the operator as a minimum satisfactory value, drain the cell and flush with a good quality oil of the type being tested before testing the next specimen. When not in use, keep the cell filled with good quality oil of the type normally tested. Alternatively, the cell may be stored empty in a dust-free cabinet. At the beginning of each days testing, clean according to 7.2.

7.4 *Polishing of Electrodes*—When electrodes show slight etching, scratching, pitting, or carbon accumulation, they should be removed from the test cup and polished by buffing with jeweler's rouge using a soft cloth or soft buffing wheel. The residue from the buffing should be removed by repeated wiping with lint-free tissue paper saturated with a suitable solvent, followed by solvent rinsing or ultrasonic cleaning. After careful inspection, any electrodes from which pitting cannot be removed by light buffing should be discarded, as more refinishing would destroy the electrode contour and dimensions shown in Fig. 1. Reinstall the electrodes in the test cup and adjust spacing and clean in accordance with 7.1 and 7.2.

8. Sampling and Filling Cup

8.1 Obtain a sample of the oil to be tested using appropriate ASTM sampling apparatus. Oil sampling procedures are detailed in Test Method D 923. Particular reference should be made to the general precaution statement of this test method. The sample shall be taken in a dry, clean, non-permeable bottle. Tightly seal and shield from light until ready to be tested. Plastic bottles are permeable and moisture content of the sample may change as time elapses after sample collection. As the moisture content changes in a sample the dielectric test results may have an observable difference when compared to samples collected in non-permeable containers.

8.2 The dielectric breakdown voltage of liquids may be seriously impaired by the migration of impurities through the liquid. Gently invert and swirl the oil in the sample container several times before filling the test cell. Rapid agitation is undesirable, since an excessive amount of air may be introduced into the liquid. Immediately after agitation, use a small portion of the sample to rinse the test cell. Fill the cell slowly with the remaining portion of the sample. The cell is full when closing the cover or baffle allows no air to be in contact with the oil. Wait at least 3 min but no more than 5 min between filling and application of voltage for the first breakdown, and at least 1-min intervals before applications of voltage for successive breakdowns. During these intervals and at the time voltage is being applied, the propeller shall be circulating the oil.

9. Test Temperature

9.1 The temperature of the sample shall be the same as the test cup and the ambient, at the time of testing. Record the temperature of the sample and the ambient. Tests conducted in a laboratory or referee tests shall be done at room temperature (20 to 30°C).

10. Procedure

10.1 *Rate-of-Rise of Voltage*—Apply the voltage and increase from zero at the rate of ½ kV/s ± 20 % until breakdown occurs, as indicated by operation of the circuit-interrupting equipment; record the rms value. Occasional momentary discharges may occur which do not result in operation of the interrupting equipment; these shall be disregarded.

10.2 When it is desired to determine the value of the dielectric breakdown voltage of an oil, make five breakdowns on one filling of the cup. Examine the five breakdowns for statistical consistency, and if they meet the criterion described in 10.3, report average as the dielectric breakdown voltage of the sample. If they do not meet this criterion, make five additional breakdowns on the sample, and report the average of all ten breakdowns as the dielectric breakdown voltage of the sample.

10.3 *Criterion for Statistical Consistency*:

10.3.1 Calculate the mean and standard deviation of the five breakdowns as follows:

$$\bar{X} = 1/5 \sum_{i=1}^{5} X_i \quad \text{and} \quad s = \sqrt{1/4[\sum_{i=1}^{5} X_i^2 - 5\bar{X}^2]}$$

where:

$\bar{X}_i$ = mean of the five individual values,
X_i = ith breakdown voltage, and
s = standard deviation.

If the ratio $s/\bar{X}$ exceeds 0.1, it is probable that the standard deviation of the five breakdowns is excessive and therefore that the probable error of their average is also excessive.

10.3.2 *Alternative Criterion*—Calculate the range of the five breakdowns (maximum breakdown voltage minus minimum breakdown voltage), and multiply this range by three. If the value so obtained is greater than the next to the lowest breakdown, it indicates that the standard deviation of the five breakdowns, and, therefore, the probable error of their average value, is excessive.

10.4 When it is desired merely to determine if the dielectric strength is above or below a specified level, only five breakdowns are required, provided the five values are all above or all below this level. Otherwise, follow the procedure described in 10.2.

11. Report

11.1 Include in the report the following:

11.1.1 The test method used,

11.1.2 If the number of tests are as specified in 10.2, the volts (rms value) at each breakdown, and the average of all breakdowns reported to the nearest 1 kV,

11.1.3 If the test is made in accordance with 10.4, the report shall be made in one of the following ways:

11.1.3.1 "Passed" if all of the five breakdowns were above a previously established value,

11.1.3.2 "Failed" if all of the five breakdowns were below a previously established value,

11.1.3.3 "Not less than the minimum of the five breakdowns" if all were above a previously established value, or

11.1.3.4 "Not greater than the maximum of the five breakdowns" if all were below a previously established value.

11.1.4 The approximate temperature of the oil at the time of the test, and

11.1.5 The electrode spacing.

12. Precision and Bias

12.1 *Precision*—No precision statement is possible because of the difficulty of making uniform specimens. For a reference see Footnote 6.[6]

12.2 *Bias*—No statement can be made about the bias of this test method because a standard reference material is not available.

13. Keywords

13.1 breakdown voltage; dielectric strength; insulating oils; test cell; VDE electrodes

[6] G. Shombert, H. Jr. "Some Problems in the Testing of Transformer Oil of Petroleum Origin for Dielectric Breakdown Strength", *Journal of Testing and Evaluation*, Vol. 1 No. 3, May 1973, pp. 227-230.

APPENDIX

(Nonmandatory Information)

X1. FACTORS THAT AFFECT THE DIELECTRIC BREAKDOWN VOLTAGE OF INSULATING LIQUIDS AT COMMERCIAL POWER FREQUENCIES

X1.1 The dielectric breakdown voltage of a liquid at commercial power frequencies is also affected by:

X1.1.1 The degree of uniformity of the electric field,

X1.1.2 The area of the electrodes,

X1.1.3 Volume of the liquid under maximum stress,

X1.1.4 Insulation on the electrodes,

X1.1.5 Water content of the oil,

X1.1.6 Size and number of particles in the oil,

X1.1.7 Length of time for which the liquid is under stress,

X1.1.8 The temperature of the liquid as it affects the relative saturation level of moisture in solution,

X1.1.9 Gassing tendencies of the liquid under the influence of electric stress,

X1.1.10 Concentration of dissolved gases if saturation levels are exceeded as a result of a sudden cooling or decrease in pressure, which may cause the formation of gas bubbles,

X1.1.11 Incompatibility with materials of construction, and

X1.1.12 Velocity of flow.

X1.1.13 A decrease in dielectric strength of the liquid can have an accentuated effect on the electric creepage strength of the solid insulating materials immersed in the liquid.

X1.2 Because of the separate, cumulative, and in some cases, interacting effects of the influences listed above, the average breakdown voltage of a liquid as determined by this test method cannot be used directly for design purposes. Procedures utilizing electrode shapes and configurations similar to those used in oil filled apparatus are used to determine design data and to study the influence of the variables. However, test results utilizing the rounded electrodes in this test method do give an indication of the relative dielectric strength of the oil in the insulation system.