Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes[1]

This standard is issued under the fixed designation D877/D877M; 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 U.S. Department of Defense.

1. Scope

1.1 This test method describes two procedures, A and B, for determining the electrical breakdown voltage of insulating liquid specimens. The breakdown test uses ac voltage in the power-frequency range from 45 to 65 Hz.

1.2 This test method is used to judge if the disk electrode breakdown voltage requirements are met for insulating liquids, as delivered from the manufacturer, that have never been filtered or dried. See Specification D3487, Specification D4652, Specification D6871 and Guide D5222 for the minimum specified electrical breakdown. This test method should be used as recommended by professional organization standards such as IEEE C57.106.

1.3 *Limitations of the Procedures:*

1.3.1 The sensitivity of this test method to the general population of contaminants present in a liquid sample decreases as applied test voltages used in this test method become greater than approximately 25 kV rms.

1.3.2 If the concentration of water in the sample at room temperature is less than 60 % of saturation, the sensitivity of this test method to the presence of water is decreased. For further information refer to RR:D27-1006.[2]

1.3.3 The suitability for this test method has not been determined for a liquid's viscosity higher than 900 cSt at 40°C.

1.4 *Procedure Applications*

1.4.1 *Procedure A:*

1.4.1.1 Procedure A is used to determine the breakdown voltage of liquids in which any insoluble breakdown products easily settle during the interval between the required repeated breakdown tests. These liquids include petroleum oils, hydrocarbons, natural and synthetic esters, and askarels (PCB) used as insulating and cooling liquids in transformers, cables, and similar apparatus.

1.4.1.2 Procedure A may be used to obtain the dielectric breakdown of silicone fluid as specified in Test Methods D2225, provided the discharge energy into the sample is less than 20 mJ (milli joule) per breakdown for five consecutive breakdowns.

1.4.2 *Procedure B:*

1.4.2.1 This procedure is used to determine the breakdown voltage of liquids in which any insoluble breakdown products do not completely settle from the space between the disks during the 1–min interval required in Procedure A. Procedure B, modified in accordance with Section 17 of Test Methods D2225, is acceptable for testing silicone dielectric liquids if the requirements of 1.4.1.2 can not be achieved.

1.4.2.2 Procedure B should also be applied for the determination of the breakdown voltage of liquid samples containing insoluble materials that settle from the specimen during testing. These may include samples taken from circuit breakers, load tap changers, and other liquids heavily contaminated with insoluble particulate material. These examples represent samples that may have large differences between replicate tests. The use of Procedure B will result in a more accurate value of breakdown voltage when testing such liquids.

1.4.2.3 Use Procedure B to establish the breakdown voltage of an insulating liquid where an ASTM specification does not exist or when developing a value for an ASTM guide or standard. Procedure A may be used once the single operator precision of 13.1 has been demonstrated.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

---

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

Current edition approved Dec. 1, 2013. Published January 2014. Originally approved in 1946. Last previous edition approved in 2007 as D877–02(2007). DOI: 10.1520/D0877_D0877M-13.

[2] RR:D27-1006, Round-Robin Data Using Modified VDE Electrode Cell for Dielectric Strength Tests on Oil, is available from ASTM Headquarters.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D923 Practices for Sampling Electrical Insulating Liquids

D1816 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes

D2225 Test Methods for Silicone Fluids Used for Electrical Insulation

D2864 Terminology Relating to Electrical Insulating Liquids and Gases

D3487 Specification for Mineral Insulating Oil Used in Electrical Apparatus

D4652 Specification for Silicone Fluid Used for Electrical Insulation

D5222 Specification for High Fire-Point Mineral Electrical Insulating Oils

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

2.2 *IEEE Standards:*[4]

Standard 4, IEEE Standard Techniques for High-Voltage Testing

C57.106 Guide for Acceptance and Maintenance of Insulating Oil in Equipment

3. Significance and Use

3.1 The dielectric breakdown voltage is a measure of the ability of an insulating liquid to withstand electrical stress. The power-frequency breakdown voltage of a liquid is reduced by the presence of contaminants such as cellulosic fibers, conducting particles, dirt, and water. A low result in this test method indicates the presence of significant concentrations of one or more of these contaminants in the liquid tested. See Appendix X1.

3.2 A high breakdown voltage measured in this test method does not necessarily indicate that the amount of the contaminants present in a liquid from which the sample was taken is sufficiently low for the sampled liquid to be acceptable in all electrical equipment. Test Method D877 is not sensitive to low levels of these contaminants. Breakdown in this test method is dominated by events occurring at the electrode edges. The voltage stress distribution between the parallel disk electrodes used in this test method are quasi-uniform and there is substantial stress concentration at the sharp edges of the flat disk faces.

3.3 This test method may be used for evaluation of insulating liquids in equipment that is designed to be filled with unprocessed liquids as delivered by a vendor.

3.4 This test method is not recommended for evaluation of the breakdown voltage of liquids used in equipment that requires the application of vacuum and filtering of the oil before being placed into service. Test Method D1816 should be used to determine the breakdown voltage of filtered and degassed liquids.

3.5 This test method is used in laboratory or field tests. For field breakdown results to be comparable to laboratory results, all criteria including room temperature (20 to 30°C) must be met.

4. Electrical Apparatus

4.1 In addition to this section, use IEEE Standard 4 to determine other requirements necessary for conducting test methods and making measurements using alternating voltages. Procedures to ensure accuracy should follow the requirements of IEEE Standard 4. Calibration(s) shall be traceable to national standards and should be conducted annually or more often.

4.1.1 *Test Voltage*—The test voltage shall be an alternating voltage having a frequency in the range from 45 to 65 Hz, normally referred to as power-frequency voltage. The voltage waveshape should approximate a sinusoid with both half cycles closely alike, and it should have a ratio of peak-to-rms values equal to the square root of 2 within ±5 %.

4.1.2 *Generation of the Test Voltage*— The test voltage is generally supplied by a transformer or resonant circuit. The voltage in the test circuit should be stable enough to be practically unaffected by varying current flowing in the capacitive and resistive paths of the test circuit. Nondisruptive discharges in the test circuit should not reduce the test voltage to such an extent, and for such a time, that the disruptive discharge (breakdown) voltage of the test specimen is significantly affected. In the case of a transformer, the short-circuit current delivered by the transformer should be sufficient to maintain the test voltage within 3 % during transient current pulses or discharges, and a short circuit current of 0.1 A may suffice.

4.1.3 *Disruptive Voltage Measurement*— Design the measurement circuit so the voltage recorded at the breakdown is the maximum voltage across the test specimen immediately prior to the disruptive breakdown with an error no greater than 3 %.

4.2 *Circuit-Interrupting Equipment*— Design the circuit used to interrupt the disruptive discharge through the specimen to operate when the voltage across the specimen has collapsed to less than 100 V. It is recommended that the circuit design limit the disruptive current duration and magnitude to low values that will minimize damage to the disks and limit formation of non-soluble materials resulting from the breakdown, but consistent with the requirements of 4.1.1.

4.3 *Voltage Control Equipment*—Use a rate of voltage rise of 3 kV/s. The tolerance of the rate of rise should be 5 % for any new equipment. Automatic equipment should be used to control the voltage rate of rise because of the difficulty of maintaining a uniform voltage rise manually. The equipment should produce a straight-line voltage-time curve over the operating range of the equipment. Calibrate and label automatic controls in terms of rate-of-rise.

[3] 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.

[4] Available from The Institute of Electrical and Electronics Engineers, Inc., PO Box 1331, Piscataway, NJ 08855.

4.4 *Measuring Systems*—The voltage shall be measured by a method that fulfills the requirements of IEEE Standard No. 4, giving rms values.

4.5 Connect the electrodes such that the voltage measured from each electrode with respect to ground during the test is equal within 5 %.

5. Electrodes

5.1 The electrodes shall have parallel faces and axes in a coincident horizontal line when mounted in the cup. Construct the electrodes of polished brass as disks 25.4 mm [1.0 in.] in diameter ±2.0 %, and at least 3.18 mm [⅛ in.] thick, and with sharp edges. The sharp edge shall have a quarter circle radius no greater than 0.254 mm [0.010 in.]. Refer to Annex A1 for illustrations of measuring edge radius.

6. Test Cup

6.1 Construct the cup of a material having high dielectric strength, that is inert to any of the cleaning or test liquids. The cup material shall not absorb moisture or the cleaning and test liquids. The vector sum of the resistive and capacitive current of the cup, when filled with oil meeting the requirements of Specification D3487, shall be less than 200 µA at 20 kV, at power frequency. Construct the cup so that no part is less than 12.7 mm [0.5 in.] from any part (the side, back or edge) of the electrode disk. The cup shall be designed to permit easy removal of the electrodes for cleaning and polishing, verification that the sharp edge is within the specified tolerance, and to permit easy adjustment of the gap spacing. The top of the cup shall be maintained at least 25.4 mm [1.0 in.] above the top of the electrodes.

7. Adjustment and Care of Electrodes and Test Cup

7.1 *Daily Use*—At the beginning of each day's testing examine the electrodes for scratches, pitting, and contamination. If pitting or scratches of the disk faces are found, polish in accordance with 7.5. For severe problems resurfacing may be required. The electrodes should be examined quarterly in accordance with 7.4 for the proper sharp edge, if there is apparent edge damage, or upon return from resurfacing. The gap shall be reset in accordance with 7.2. Clean and prepare the cup in accordance with 7.3.

7.2 *Electrode Spacing*—Gauges shall be used to set the spacing of the electrodes during tests to 2.54 mm [0.100 in.] + 0.0254 mm [0.001 in.]. The gap should be set with "go" and "no-go" gauges such that the spacing is no less than 2.51 mm [0.0990 in.] for a "go" measurement and no larger than 2.57 mm [0.1010 in.]. If the "no-go" gauge can enter the gap, the gap must be reset. Alternatively, if the cup is supplied with a vernier scale for setting the gap, it can be used following the manufacturer's instructions. Vernier scales are to be verified at least monthly with gauges. Recheck the spacing following any disturbance of the cup or electrodes and at operation in the beginning of each day's testing.

7.3 *Cleaning*—Wipe the electrodes and the cup clean with dry, lint-free tissue paper or a clean dry chamois. It is important to avoid touching the electrodes or the cleaned gauge 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, the cup shall be rinsed with a dry solvent. A low-boiling solvent should not be used as its rapid evaporation may cool the cup, causing moisture condensation. If this occurs, the cup should be warmed slightly to evaporate any moisture before use. Take care to avoid touching the electrodes or the inside of the cup after cleaning. Flush the cup using part of the sample. Fill the cup with a specimen from a sample with a known breakdown voltage. Make a voltage breakdown test as specified in this test method. If the breakdown voltage is judged in the proper range for the sample with a known breakdown value, the test cup is prepared for testing other samples. If a value lower than expected is obtained, flush or clean the cup as necessary until test results meet the expected value for the known sample.

7.4 *Electrode Edge Verification*—Using a 0.254-mm [0.010-in.] equivalent radius gauge[5] or an optical comparator, verify that the radius of the edge of the electrode, on the gap side, is less than 0.254 mm [0.010 in.]; verify the face of the electrodes are at 90 ± 1° to the side edge of the electrode. If the edge radius is no greater than the value specified and the sides are at 90°, the electrodes are satisfactory for continued use. Check the disk in at least four locations for each criteria. If the radius exceeds the tolerance or the edges are not at 90°, the electrodes shall be resurfaced to the specified values. Refer to Annex A1 for illustrations of measuring edge radius.

7.5 *Polishing of Electrodes*—When examination of electrodes shows minor scratching or pitting, the electrodes should be removed from the test cup and polished by buffing with jeweler's rouge using a soft cloth or soft buffing wheel. (Resurfacing may be necessary in order to remove deep pit marks or edge damage.) Care must be taken in resurfacing or in polishing to ensure that the electrode faces remain perpendicular to the axis and the edges' radius does not exceed the value specified in 7.4. All residue from the buffing must be removed before the electrodes are reinstalled in the test cup. This can be accomplished by repeated wiping with lint-free tissue paper saturated with a suitable solvent (such as petroleum ether), followed by solvent rinsing or ultrasonic cleaning. After the electrodes have been reinstalled in the test cup, clean and adjust spacing in accordance with 7.2 and 7.3.

7.6 *Storage of Test Cup*—When not in use, the cup, if used for referee tests, shall be stored filled with a new, dry, filtered liquid of the type being tested, and tightly covered.

8. Sampling

8.1 Obtain a sample of the liquid to be tested in accordance with Practices D923. Record on the label of the sample container identification of the device from which the sample was obtained, the date, and temperature of the sample at the time of collection (Note 1). Prior to starting the test, the sample

[5] The sole source of supply of the apparatus known to the committee at this time is www.starrett.com, (Radius Gauge, 0.010 in. Part 167-010). If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

shall be inspected for the presence of moisture, sludge, metallic particles, or other foreign matter. If the sample shows evidence of free water, the dielectric breakdown test should be waived, and the sample shall be reported as unsatisfactory.

NOTE 1—It is suggested that 2 L of sample be made available when Procedure B is used, and 1 L of sample be made available when Procedure A is used.

9. Test Temperature

9.1 Make the temperature of the test specimen about the same as the test cup, then equilibrate the specimen and test cup temperature by rinsing the cup with part of the sample and filling the cup with the specimen within 15 s of rinsing the cup. Record the temperature of the sample and ambient temperature. Tests conducted in a laboratory shall be done at room temperature (20 to 30°C). See Terminology D2864 for definitions.

10. Voltage Application to the Specimen

10.1 Start with the voltage across the electrodes at zero. Apply the test voltage as specified in Section 4 until operation of the interrupting equipment. Record the maximum voltage reached prior to the breakdown. If no breakdown takes place record the highest value reached and report "no breakdown" occurred.

11. Procedure

11.1 The dielectric breakdown voltage of liquids may be seriously impaired by the migration of impurities through the liquid. In order that a representative test specimen containing the impurities may be obtained, invert and swirl the sample container several times before filling the test cup (Note 2). 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 cup. The cup shall then be filled slowly with the liquid to be tested in a manner that will avoid entrapment of air. It should be filled to a level not less than 20.3 mm [0.8 in.] above the top of the electrodes. In order to permit the escape of air, allow the liquid to stand in the cup for not less than 2 min and not more than 3 min before voltage is applied.

NOTE 2—It is impractical to handle liquids having viscosities ranging from 10 to 22 mm^2/s (cSt) (60 to 100 SUS) at 100°C [212°F] in the manner outlined in 11.1. When testing high-viscosity liquids in this range, the sample should be allowed to stand until it reaches room temperature. The sample container should not be swirled as prescribed in 11.1, but should be inverted for at least 30 min before the test, and then reinverted and opened just prior to filling the test cup. Refer to 1.3.3.

11.2 *Procedure A*—When it is desired to determine the dielectric breakdown voltage of a liquid on a routine basis, five breakdowns may be made on one cup filling with 1-min intervals between each breakdown and the next voltage application. The mean of the five breakdowns shall be considered the dielectric breakdown voltage of the sample, provided the range criteria of 11.4.2 are met. Retain all breakdown test values. If a second series of five breakdowns is required fill the cup with a new specimen in accordance with 11.1. During testing, maintain at least two significant digits for each breakdown.

11.3 *Procedure B*—When testing dielectric liquids described in 1.4.2.1 to determine dielectric breakdown or when comparing breakdown results with other test facilities, make one breakdown on each of five successive fillings of the test cup. The mean of the five breakdowns may be reported as the breakdown voltage, provided the range criteria of 11.4.2 are met. Retain all breakdown values. During testing maintain at least two significant digits for each breakdown.

11.4 *Criteria for Statistical Consistency :*

11.4.1 Calculate the mean of the 5 or 10 breakdowns using the following equation:

$$\bar{X} = n^{-1}\left(\sum_{i=1}^{n} X_i\right) \quad (1)$$

where:

$\bar{X}$ = mean of the n individual values,
X_i = ith breakdown voltage, and
n = number of breakdowns either 5 or 10.

11.4.2 *Acceptable Range Criteria*—Using the breakdown values determined in 11.2 or 11.3, calculate the mean breakdown value using the equation in 11.4.1. Determine the range of the breakdown voltages as follows:

$$\text{Range} = X_{\text{Highest}} - X_{\text{Lowest}} \quad (2)$$

where:

X_{Highest} = the highest breakdown voltage of the readings, and
X_{Lowest} = the lowest breakdown voltage of the readings.

Determine that the range of the five breakdowns is less than or equal to 92 % of the mean value. If the range is acceptable, report this mean value as the dielectric breakdown voltage. If the allowable range is exceeded, then conduct five additional breakdowns in accordance with 11.2 or 11.3. Obtain the new mean breakdown value for the ten breakdowns. Determine the range of the ten breakdowns and if the range is less than 151 % of the mean value of the ten breakdowns, report this mean value as the dielectric breakdown voltage for the sample. If the allowable range is exceeded, the error is too large. Investigate the cause of the error and repeat the tests.

12. Report

12.1 Report the following information:

12.1.1 ASTM designation of the test method used (D877),

12.1.2 If Procedure B was used, the report should so indicate,

12.1.3 The type of fluid tested,

12.1.4 Temperature of the sample recorded at collection when available and of the specimen when tested. If the temperature of the sample at sampling is not supplied, then the report should state the sampling temperature was not provided,

12.1.5 The mean breakdown, (Note 3).

12.1.6 If the sample was observed to contain free water, the report should so indicate, with a statement that the test was not made.

NOTE 3—Individual breakdown values should be retained and made available upon request.

13. Precision and Bias

13.1 *Single-Operator Precision*—The single-operator percent coefficient of variation of a single test result comprised of 5 breakdowns has been found to be 10.7 %. Therefore, results of two properly conducted tests by the same operator on the same sample should not differ by more than 30.3 % of the mean of the two tests. The maximum allowable range for the series of 5 breakdowns should not exceed 92 % of the mean of the 5 breakdowns. The maximum allowable range for the series of 10 breakdowns should not exceed 151 % of the mean of the 10 breakdowns.

13.2 *Multilaboratory Precision*—The multilaboratory percent coefficient of variation has been found to be 10.7 %. Therefore, results of two properly conducted tests in different laboratories on the same sample of oil should not differ by more than 30.3 % of the mean of the two results.

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

14. Keywords

14.1 breakdown voltage; dielectric strength; disk electrodes; electrical insulating liquids; test cup

ANNEX

(Mandatory Information)

A1. Examples for Measuring Electrode Edge Radius

A1.1 Annex A1 covers an example to use for checking Test Method D877 disk edge radius. The gray area represents the disk and the white area represents the gauge. See Figs. A1.1-A1.3.

NOTE 1—Fig. A1.1 illustrates the case where the edge radius of the disk exceeds the allowable radius. Both sides of the gauge are flush with the disk, and the edge of the disk does not fit into the gauge. This condition requires that the disk be machined back to a sharp edge. See Fig. A1.3 for a sharp edge.

FIG. A1.1 Unacceptable Electrode Edge Radius

NOTE 1—Fig. A1.2 illustrates the case where the edge has a radius equal to the gauge. Note both edges fit to the edge of the gauge and the disk edge fits in the radius with no gap as in Fig. A1.1. This disk is acceptable, however, consideration should be given to machining the disk to a sharp edge because any degradation will make it unacceptable.

FIG. A1.2 Marginally Acceptable Electrode Edge Radius

NOTE 1—Fig. A1.3 illustrates the condition of a sharp edge meeting the requirements of Test Method D877. Note the sharp edge fits into the radius gauge and only one side of the gauge fits up against the disk while the other side has considerable space.

FIG. A1.3 Acceptable Electrode Edge Radius

APPENDIX

(Nonmandatory Information)

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

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

X1.1.1 Water content of the oil,

X1.1.2 The temperature of the liquid as it affects the relative saturation level of moisture in solution,

X1.1.3 The degree of uniformity of the electric field,

X1.1.4 The area of the electrodes,

X1.1.5 Volume of the liquid under maximum stress,

X1.1.6 Insulation on the electrodes in electrical equipment,

X1.1.7 Size and number of particles in the oil,

X1.1.8 Length of time for which the liquid is under stress,

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.

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 previously listed, the average breakdown voltage of a liquid as determined by this test method cannot be used for design purposes. Alternate procedures utilizing electrode shapes and configurations similar to those in the apparatus and in Test Method D1816 should be used for oil-filled equipment utilizing well-rounded and insulated electrodes.