Designation: D 3300 – ~~94~~00

Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Under Impulse Conditions[1]

This standard is issued under the fixed designation D 3300; 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 in a highly divergent field under impulse conditions.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility ~~of whoever uses~~ the user of this standard to ~~consult and~~ establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* ~~See X1.2.3.~~

2. Referenced Documents

2.1 *ASTM Standards:*

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[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 D27.05 on Electrical Test.

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D ~~923 Test Method~~ 923 Practices for Sampling Electrical Insulating Liquids[2]
D 2864 Terminology Relating to Electrical Insulating Liquids and Gases[2]

2.2 *IEEE Documents:*

IEEE ~~C57.12.90 Test Code~~ Standard 4-1995 Techniques for ~~Liquid Immersed Distribution, Power and Regulating Transformers~~ High-Voltage Testing[3]
~~IEEE C57.98 Guide for Transformer Impulse Tests~~[3]

3. Significance and Use

3.1 This test method is most commonly performed using a negative polarity point opposing a grounded sphere (NPS). The NPS breakdown voltage of fresh unused oils measured in the highly divergent field in this configuration depends on oil composition~~;~~, decreasing with increasing concentration of aromatic, particularly polyaromatic, hydrocarbon molecules.

3.2 This test method may be used to evaluate the continuity of composition of an oil from shipment to shipment. The NPS impulse breakdown voltage of an oil can also be substantially lowered by contact with materials of construction, by service aging, and by other impurities. Test results lower than those expected for a given fresh oil may also indicate use or contamination of that oil.

3.3 Although polarity of the voltage wave has little or no effect on the breakdown strength of an oil in uniform fields, polarity does have a marked effect on the breakdown voltage of an oil in nonuniform electric fields.

3.4 Transient voltages may also vary over a wide range in both the time to reach crest value and the time to decay to half crest or to zero magnitude. The IEEE standard lightning impulse test (see 2.2) specifies a 1.2 by 50-μs negative polarity wave.

4. Apparatus

4.1 *Impulse Generator*, capable of producing a standard 1.2 by 50-μs full wave adjustable to positive or negative polarity. The generator shall have a nominal voltage rating of at least 300 kV adjustable in 10-kV steps. Generators having a capability of 1000 W·s (1000 J) at 300 kV have been found satisfactory.

4.2 *Voltage-Control Equipment*—The controls shall include a suitable measuring device for predetermining the crest voltage to within ±5 %. A voltage stabilizer is desirable at the input to the d-c power supply used for charging the impulse-generator capacitors.

4.3 *Electrodes*:

4.3.1 The electrodes shall consist of a polished steel or brass sphere~~s~~ of 0.5 in. (12.7 mm) diameter and a steel point. The point may be an ordinary steel phonograph needle with a 0.06 mm ± 20 % radius of curvature of point or a No. 18 Filter Point needle.[4] Needles with drawn tips are *not* recommended.

4.3.2 The effect of variation in the radius of curvature of point is subject to further investigation. Both electrodes shall be easily replaceable.

4.4 *Test Cell*:

4.4.1 The test cell shall be made of a material of high dielectric strength and of such dimensions that the electrical breakdown is restricted to the electrode gap. Test cell materials shall resist attack by, and be insoluble in, any of the cleaning or test liquids used. Test cells such as those shown in Fig. 1 and Fig. 2 have been found satisfactory.

4.4.2 The sphere electrode shall be rigidly fixed and the point electrode mounted such that the gap may be adjusted from zero to the required value.

5. Sampling

5.1 Obtain a sample of the liquid to be tested using appropriate ASTM sampling apparatus in accordance with ~~Test Methods~~ Practices D 923.

6. Adjustments and Care of Electrodes and Test Cell

6.1 *Electrode Spacing*:

6.1.1 For the cell shown in Fig. 1, reduce the electrode gap to zero spacing. Proceed very carefully to avoid damaging the point. The point of contact shall be established electrically with an ohmmeter. Open the gap to the specified spacing using a dial micrometer or other suitable method.

6.1.2 For the cell shown in Fig. 2, the gap may be set with a go-no-go gage.

6.1.3 The gap spacings shall be 1.0 in. (25.4 mm) for point-to-sphere and 0.15 in. (3.8 mm) for sphere-to-sphere electrode configuration.

6.2 *Cleaning*—Degrease the cell and electrodes by rinsing them with reagent grade petroleum ether, washing with detergent and hot water, rinsing thoroughly in hot tap water, and then rinsing them with distilled water. Dry the cell and hardware in an oven

[2] *Annual Book of ASTM Standards*, Vol 10.03.
[3] Available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331.
[4] The following steel needle has been found satisfactory for this method: Dean No. 18 Filter Point Needle, available from John Dean, Inc., 20 Mechanic St., Putnam, CT 06260.

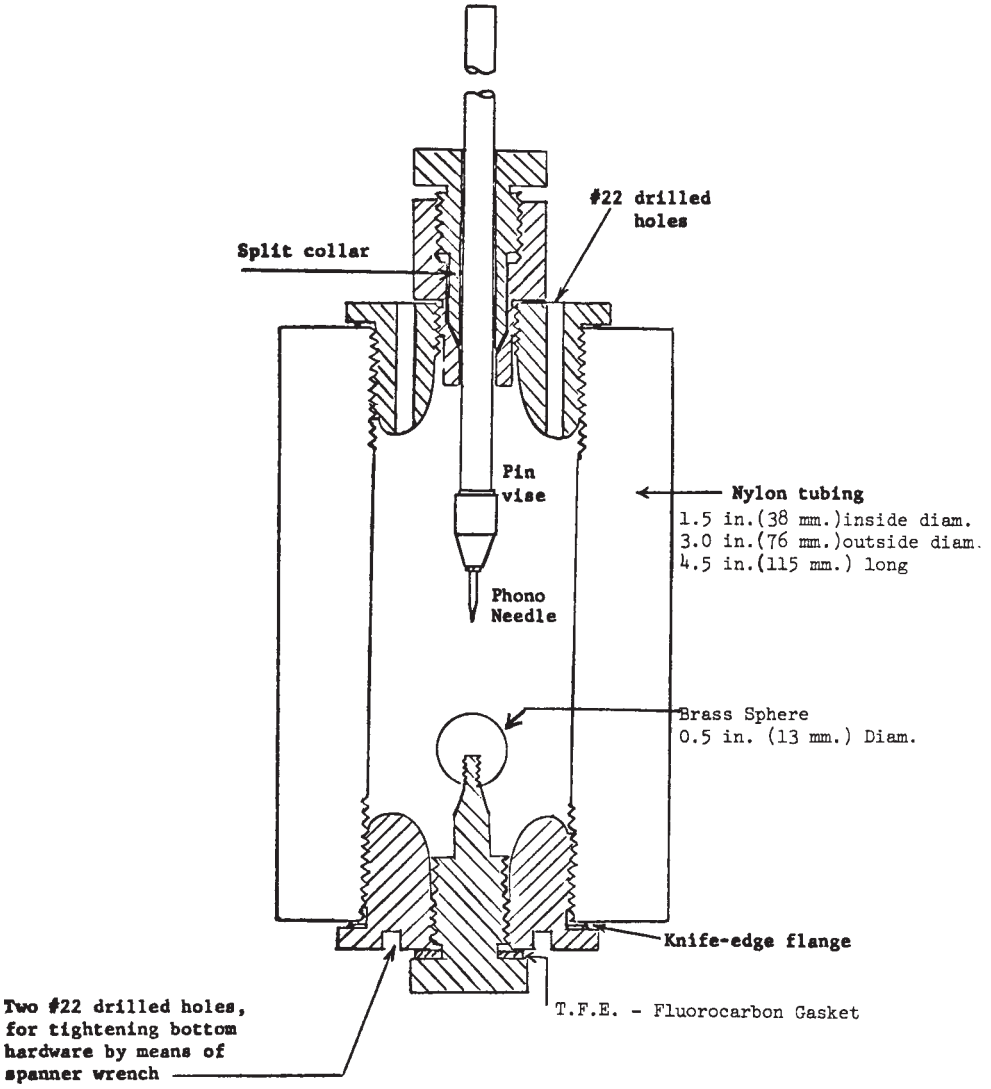

FIG. 1 Test Cell

for 2 h at approximately 105 to 110°C, remove, and store in a desiccator until needed.

6.3 *Daily Use*—Use new or polished sphere electrodes at the beginning of each day's testing. Discard the point electrode and replace it after each breakdown; replace the sphere electrodes after every five breakdowns when testing point-to-sphere. More frequent replacement may be necessary when testing sphere-to-sphere. Sphere electrodes may be cleaned and polished for reuse in point-to-sphere testing. However, the use of polished spheres is not recommended for sphere-to-sphere testing. When not in use, clean and store the cell in accordance with 6.2.

7. Test Temperature

~~7.1 Adjust~~

7.1 Conduct the ~~temperature of~~ tests with the ~~sample when tested the same as that of the room, but the~~ specimen at room temperature ~~shall~~ as defined in ~~no case be less than 20°C.~~ Terminology D 2864. Testing liquids at temperatures lower than that of the room may give variable and unsatisfactory results. Record the test temperature.

8. Procedure

8.1 Set the electrode spacing to the desired value.

8.2 Rinse the test cell with a ~~sample~~ portion of the ~~liquid to be tested~~ sample and discard this liquid. Slowly fill the cell with the test liquid, being careful to avoid entraining air bubbles. Allow it to set undisturbed for 2 min prior to testing.

8.2.1 For the test cell shown in Fig. 1, unscrew the upper electrode holding assembly to fill it with the sample oil while holding the cell at an angle to prevent splashing, which could create air bubbles. Screw the top portion down until the metal flange seats firmly.

8.3 Connect the fixed electrode to ground and the movable electrode to the impulse generator.

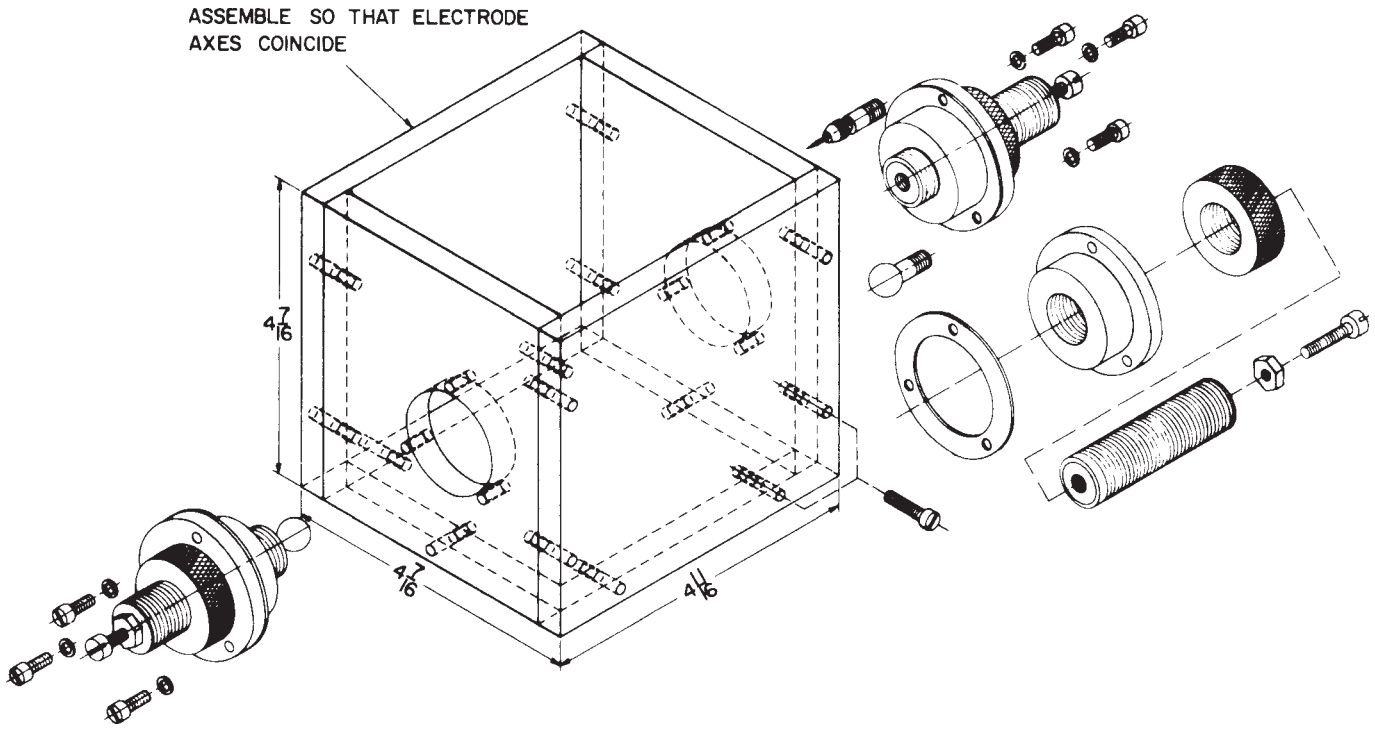

FIG. 2 Test Cell

8.4 Apply the impulse wave of specified polarity starting approximately 40 kV below the expected breakdown level. Apply three impulse waves at each voltage level. Allow a minimum of 30 s between each test.

8.5 Increase the voltage level in steps of 10 kV or less until breakdown occurs, noting the crest voltage level at breakdown. It is necessary to have at least three withstand levels prior to breakdown.

~~8.5.1 The measurement of~~

8.5.1 Measure the ~~voltage at~~ breakdown ~~is very critical. For suggested measuring~~ voltage using techniques ~~refer to Appendix X1.~~ specified in IEEE Standard 4.

8.6 After each breakdown, change the point electrode and follow 8.1 and 8.2.

8.7 Make five breakdown tests ~~of each sample of liquid. Examine the~~ on five ~~breakdowns for statistical consistency, and if they meet~~ specimens from the ~~criterion described~~ same sample. Maintain at least two significant digits in ~~8.9, use their average to determine~~ the ~~impulse breakdown voltage of the sample.~~

~~8.8 If the spread from maximum to minimum is more than 30 kV, it is necessary to obtain breakdowns for five additional fillings.~~

~~NOTE 1—This is a temporary statement and refers only to point-to-sphere electrodes and a 1.2 by 50-μs negative test wave. This statement will be expanded when more test data are obtained.~~

~~8.8.1 Retain and report all test data.~~

~~8.9~~ results.

8.8 *Criterion for Statistical Consistency* :

8.~~9~~8.1 Calculate the mean and standard deviation of the five breakdowns as follows:

$$\overline{X} = \frac{1}{5}\sum_{i=1}^{5} X_i \text{ and } s = \sqrt{\frac{1}{4}\sum_{i=1}^{5} X_i^2 - 5\overline{X}^2} \quad (1)$$

$$\overline{X} = n^{-1}\,(\sum_{i=1}^{n} X_i) \quad (1)$$

~~5~~

where:

$\overline{X}$ = mean of the five individual values,

X_i = ith breakdown voltage, and

~~s = standard deviation, and~~

~~n~~

~~5~~ = ~~the upper limit~~number of ~~the summation.~~ breakdowns either 5 or 10.

~~If~~

8.8.2 Using the ~~ratio $s/\overline{X}$ exceeds 0.1, it is probable~~ impulse crest voltage breakdown values determined in 8.7, calculate the

mean value using the equation in 8.8.1. Determine that the standard deviation range of the five breakdowns is excessive and therefore that the probable error no greater than 33.3 % of their mean value. If the range is also excessive.

8.9.2 *Alternative Criterion*—Calculate acceptable, report this mean value as the impulse breakdown voltage. If the range exceeds 33.3 % of the mean value of the five breakdowns, then conduct five additional breakdowns (maximum breakdown voltage minus minimum breakdown voltage), and multiply this obtain a new mean breakdown value for the ten breakdowns. Determine the range by three. If of the value so obtained ten breakdowns and if the range is greater less than 54.6 % of the lowest breakdown, it indicates that the standard deviation mean of the five ten breakdowns, and, therefore, report this mean value as the impulse breakdobwn voltage. If the allowable range is exceeded, the error of their average, is excessive. too large. Investigate the cause of the error and repeat the tests.

NOTE 21—The criterion for statistical consistency specified in 8.9.1 and 8.9.2 apply only to negative polarity waves if point-to-sphere electrodes are used.

8.109 It may be necessary to partially immerse the test cell in oil to prevent external flashover. This is necessary with the cell shown in Fig. 1.

8.110 If a second insulating liquid is to be tested, thoroughly clean the test cell in accordance with 6.2.

9. Report

9.1 Report the following information:

9.1.1 Sample identification,

9.1.2 Electrode configuration, polarity, and electrode spacing,

9.1.3 Impulse crest voltage for each breakdown (do not discard any data),

9.1.4 Wave shape identification,

9.1.5 Starting voltage crest level, voltage steps, and highest voltage withstand level,

9.1.6 Sample and ambient temperature,

9.1.6 Mean impulse breakdown value,

9.1.7 Sample water content,

9.1.8 Barometric pressure, and

9.1.9 Date of test.

10. Precision and Bias

10.1 This precision statement applies to new oil received from a supplier. Using the point-to-sphere electrode configuration, the following precision statements are applicable to both positive and negative polarity:

10.1.1 *Repeatability*:

10.1.1.1 With 95 % confidence,Single Operator Precision —The single operator % coefficient of variance of a laboratory following this method and comparing single test result comprised of five breakdowns has been found to be 3.9 %. Therefore, results of two properly conducted tests by the savme operagtor on the same sample should not differ by more than 11 % of the average of the two successive tests. The maximum allowable range for the series of 5 five breakdowns on one sample comprising the test result should be less than 33.3 % of oil, can expect the two determinations to agree within 13 kV.

10.1.1.2 With 50 % confidence, average of the five breakdowns. In the case where a ten-breakdown average is used, the maximum allowable range of any two successive series the individual tests comprising the result should agree within 5 kV. be less than 54.6 % of the average of the ten breakdowns.

10.1.2 *Reproducibility*:

NOTE 3—Considerable workMultilaboratory Precision —The multilaboratory % coefficient of variance has been done by Committee D-27 and by IEC Subcommittee 10A in an attempt found to improve the precision be 5.43 %. Therefore, results of this test method. Items considered were oil pretreatment, test cell geometry, location of the ground plane, voltage measurement procedures, and small variations two properly conducted tests in different laboratories on the geometry same sample of the needle electrode. None oil should not differ by more than 15.4 % of these had any significant effect on the precision. It has become apparent that unknown factors determine the initiation average of breakdown under the impulse conditions used in this method.

10.1.2.1 With 95 % confidence, any two laboratories following this method, each making five determinations and reporting the average, can expect to agree within 45 kV.

10.1.2.2 With 50 % confidence, any two laboratories should agree within 15 kV. results.

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

11. Keywords

11.1 dielectric breakdown; impulse voltage; insulating oils

APPENDIX

(Nonmandatory Information)

X1. VOLTAGE MEASUREMENT TECHNIQUES

X1.1 Apparatus Requirements

X1.1.1 The accurate measurement of impulse voltages as applied to the test specimen requires the use of an accurately calibrated voltage divider, the high voltage end of which should be connected directly to the test piece using as short a lead as possible in order to keep the inductances to a minimum. The lower end of the divider circuit should likewise be connected with the shortest possible lead length to the grounded end of the test piece, which in turn should be solidly grounded. It is usually also desirable to connect the ground end of the impulse generator to this same ground point.

X1.1.2 Wherever possible, a resistance divider should be used for steep front and full wave (1.2 × 50 μs) impulse testing, using noninductive resistors. A capacitance divider should be used only for switching surge impulse waves, where a high impedance is required. Capacitance dividers are susceptible to errors arising from stray capacitance to ground, which can vary if the position of the divider is changed relative to any ground plane or to any metal object which itself may be coupled either directly or capacitively to ground or to high voltage. If a capacitance divider is used, it should preferably be calibrated against a resistance divider.

X1.1.3 A suitable oscilloscope should be connected to the bottom end of the voltage divider by means of a coaxial cable, such as the RG11/U cable. It should be terminated in its characteristic impedance (75 Ω) [5] at the cathode ray oscilloscope. In the Tektronix 507 oscilloscope, which has been widely adopted for impulse testing, this terminating resistor (R_T) is provided with taps which change the voltage in 10 % steps over a 10 to 1 range. The vertical deflection plates of the oscilloscope are connected directly between ground and the tap on the attenuator, as shown in Fig. X1.1.

X1.1.4 With reference to Fig. X1.1, the overall ratio of the divider is:

$$\text{Overall ratio} = \left(\frac{R_D}{R_e} + 1\right) \text{(tap ratio)}$$

where:

R_e = $\dfrac{R_1 (R_T + R_c)}{R_1 + R_T + R_c}$,

Tap ratio = $\dfrac{R_T + R_c}{\text{tap resistance to ground}}$, and

R_c = series resistance of the cable.

X1.1.5 The resistance divider may be calibrated by measuring R_D, R_e, R_c and the tap resistances to ground using an accurate bridge, and then calculating the overall ratio for each position of the tap switch on the terminating resistor R_T.

X1.2 D-C Voltmeter Method of Calibrating Resistance Dividers

X1.2.1 An alternative method of calibration is shown in Fig. X1.2, in which a precision d-c differential voltmeter is used in conjunction with a precision d-c power supply (D-C Voltmeter Method).

X1.2.2 With the test circuit arranged as shown in Fig. X1.2, connect the differential voltmeter across the output of the d-c power supply. Set the differential voltmeter to 500.00 V and adjust the output of the d-c power supply until a good null reading is obtained on the differential voltmeter. Then turn off the power supply, disconnect the differential voltmeter and connect it across the input to the deflection plates of the cathode ray oscilloscope. Reapply 500 V dc to the top of the divider and adjust the differential voltmeter until the best null reading possible is obtained. Repeat the last step of this procedure for each tap position of the terminating resistor R_T. The overall ratio for each tap position is then the ratio of the applied d-c voltage (500 V in this case) divided by the voltage measured at the deflection plates of the oscilloscope.

X1.2.3 **CAUTION:** Extreme caution should be taken when working with the d-c power supply energized. It is desirable to work in an interlocked area whenever possible, so that the d-c power supply is deenergized when the interlock is broken.

X1.3 Method of Reading Voltage

X1.3.1 For accurate measurement of the peak or crest value of the impulse wave, it is necessary to calibrate the oscilloscope trace. This may be done by applying d-c voltages of various magnitudes directly to the deflection plates, using the precision d-c power supply. For greater accuracy, with the base line of the trace centered vertically on the CRO screen, a d-c bias voltage of opposite polarity to that of the impulse wave may be applied to the normally-grounded deflection plate. If the magnitude of the bias voltage is close to the nominal crest value of the deflection voltage, the crest of the impulse wave will be close to the unbiased base line near the center of the CRO screen, where the deflection is linear with respect to deflection voltage and hence may be read with a high degree of accuracy.

X1.3.2 The CRO tube should have a medium persistence screen so that sufficient time will be available for obtaining an accurate reading of the deflection.