



Standard Test Methods for Relative Permittivity (Dielectric Constant) and Dissipation Factor by Fluid Displacement Procedures¹

This standard is issued under the fixed designation D 1531; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

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

1. Scope

1.1 These test methods provide techniques for the determination of the relative (Note 1) permittivity and the dissipation factor of solid insulating materials by fluid (Note 2) displacement.

NOTE 1—In common usage, the word “relative” is frequently dropped.

NOTE 2—The word “fluid” is a commonly used synonym for “liquid” and yet a gas is also a fluid. In these test methods the words fluid and liquid appear as synonyms, but the word fluid is also used to show that liquid is not all that is meant.

1.2 Test Method A is especially suited to the precise measurements on polyethylene sheeting at 23°C and at frequencies between 1 kHz and 1 MHz. It may also be used at other frequencies² and temperatures to make measurements on other materials in sheet form.

1.3 Test Method B is limited to the frequency range of available guarded bridges. It is especially suited to measurements on very thin films since it does not require determination of the thickness of the specimen. The test method provides an estimate of the thickness of thin films which is more accurate and precise than thickness measurements obtained by other means.

1.4 Test Method B is also useful for measurements of polymer sheeting up to 2 mm thickness.

1.5 These test methods permit calculation of the dissipation factor of the specimens tested.

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.* For a specific precautionary statement, see Note 3.

1.7 The values stated in SI units are to be regarded as the standard.

2. Referenced Documents

2.1 ASTM Standards:

D 150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials³

D 374 Test Methods for Thickness of Solid Electrical Insulation³

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing⁴

D 831 Test Method for Gas Content of Cable and Capacitor Oils⁵

D 924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids⁵

D 1711 Terminology Relating to Electrical Insulation³

E 1 Specification for ASTM Thermometers⁶

3. Terminology

3.1 Definitions—Definitions are in accordance with Terminology D 1711.

3.2 Description of a Term Specific to This Standard:

3.2.1 *compatibility, n*—A fluid is considered compatible with a test specimen if, during the time required to complete a test of the specimen in the fluid at the specified temperature and frequency, the calculated permittivity of the specimen does not change by more than 0.1 %, and the dissipation factor change is less than 0.0001.

4. Summary of Test Methods

4.1 Test Method A—The single fluid technique:

4.1.1 Measurements are made with a fixed-plate, two-terminal self-shielded test cell assembly. By two measurements, one with the cell filled with the fluid (which in this case is a liquid) only and the second one with the solid specimen immersed in the liquid, a change in capacitance is determined. This capacitance difference is used with the approximate thickness of the specimen, the plate spacing, and the precisely known permittivity of the liquid to calculate the permittivity of

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² Coutlee, K. G., “Liquid Displacement Test Cell for Dielectric Constant and Dissipation Factor up to 100 Mc,” 1959 Annual Report, Conference on Electrical Insulation, National Research Council, Publication 756, Washington, DC.

³ *Annual Book of ASTM Standards*, Vol. 10.01.

⁴ *Annual Book of ASTM Standards*, Vol. 08.01.

⁵ *Annual Book of ASTM Standards*, Vol. 10.03.

⁶ *Annual Book of ASTM Standards*, Vol. 14.03.

the specimen. The dissipation factor of the test specimen is calculated from measurements of the cell with the liquid alone and with the specimen immersed in it. Precision and accuracy are made high by limiting the proportion of fluid to solid, limiting the difference in permittivity between the fluid and the solid, and designing the cell so that both the stray capacitance and the sensitivity limit of the measuring instrument are very small relative to that part of the capacitance due to the specimen. Also, due to its bulk, the measuring system is insensitive to mechanical and thermal disturbances. Since it is not necessary to know the thickness of the specimen accurately and it is not necessary to apply electrodes, there is an overall saving in testing time.

4.2 Test Method B—This is a two fluid technique that uses a rigidly constructed, fully shielded, temperature controlled cell.

4.2.1 The fluids are:

4.2.1.1 Two liquids, or

4.2.1.2 One liquid and a gas such as air or nitrogen.

4.2.2 Observations of capacitance and dissipation factor from the four following conditions are used to compute relative permittivity, dissipation factor, and the thickness of the specimen:

4.2.2.1 Without a solid specimen but with a single fluid in the cell,

4.2.2.2 Without a solid specimen but with a fluid different from that in 4.2.1.1,

4.2.2.3 With a solid specimen and with the single fluid of 4.2.1.1, and

4.2.2.4 With a solid specimen and with the different fluid of 4.2.1.2.

TEST METHOD A—LIQUID DISPLACEMENT METHOD USING A SINGLE FLUID

5. Significance and Use

5.1 Permittivity:

5.1.1 Polyethylene and Materials of Permittivity within 0.1 of that of Polyethylene—Since the permittivity of benzene or 1 cSt silicone fluid is very close to that of polyethylene, these fluids are recommended for highly accurate and precise testing of polyethylene or other materials with permittivity close to that of polyethylene. These properties of the test method make it a suitable tool to determine batch to batch uniformity of a polyethylene compound in order to meet precise requirements of high capacitance-uniformity and capacitance-stability in electronic apparatus. It also serves as a means to detect impurities, as well as changes resulting from prolonged exposure to high humidity, water immersion, weathering, aging, processing treatments, and exposure to radiation.

5.1.2 Other Materials—The test method may provide advantages for routine testing of materials with a poorer match in permittivity between these liquids and the specimen than that required above, because of the ease of testing, and the dilution of errors due to inaccurate thickness. Correction factors can be calculated to account for the bias introduced by the permittivity mismatch. Also, other compatible liquids of appropriate and known dielectric properties different from the two mentioned above are available.

5.2 Dissipation Factor—Normally, polyethylene has a very low dissipation factor, and a test specimen exhibiting an abnormally high dissipation factor would be suspected of containing impurities or being contaminated. The reproducibility of dissipation factor by this test method is somewhat better than that obtainable with the more conventional methods, but is limited by the sensitivity of commercially available measuring apparatus.

6. Apparatus

6.1 Measuring Circuits—Any low-voltage bridge or resonant-circuit method conforming to the requirements of Test Methods D 150 is suitable when the parallel substitution method is employed. A capacitance sensitivity and readability of about 0.01 pF and a dissipation factor sensitivity and readability of at least 0.00001 is needed. One means for obtaining this sensitivity at 100 kHz and above is by using commercially available resonant circuit apparatus and high Q coils (500 minimum).

6.2 Leads and Connectors—Low-loss coaxial connectors and leads are recommended for connecting the cell to bridges equipped with guard circuits for frequencies from 1000 Hz to 1 MHz. Terminate the guard as close as possible to the cell.

6.3 A rigid lead construction is necessary for connecting the cell to unguarded circuits including resonant circuits. Such construction stabilizes stray capacitance. Bare #10 AWG (2.5 mm dia) copper is suitable if rigidly mounted and maintained in the same position throughout the tests. At frequencies of 1 MHz and higher, lead resistance and contact resistance become important because they affect dissipation factor measurements of 0.0001 or less. Contact resistance can be minimized by use of bright solid copper clips for connections. Such clips should be small in size to minimize the effect that placement of the clip has on the measured capacitance. Take care to keep the variations in capacitance between leads and surrounding objects to less than 0.01 pF during measurements.

6.4 The measuring cell in which the test specimens are immersed in the liquid is shown in Fig. 1. It is a two-terminal, self-shielded type cell consisting of a rectangular 6.35 mm ($\frac{1}{4}$ in.) thick gold-plated brass center electrode having parallel and flat faces, each 58.06 cm² (9.00 in.²) in area. This electrode is supported by 5 polytetrafluoroethylene post insulators, and is located midway between two gold-plated brass electrodes which form an integral part of the walls of the cell. The standard spacing between the plates is 1.52 ± 0.05 mm (0.060 ± 0.002 in.); however, other spacings may be used to accommodate test specimens of thicknesses other than 1.27 mm (0.050 in.), such as 1.6 and 3.2-mm ($\frac{1}{16}$ and $\frac{1}{8}$ -in.) test specimens. The center electrode slides in grooves and can be removed readily to permit easy cleaning. The cell is equipped with an overflow pipe in order to maintain a constant level of the liquid with the test specimens either in or out. The cooling effect resulting from the evaporation of the liquid is small at the specified test temperature due to the large mass of metal and the small area of liquid exposed to the air, so that under normal testing conditions the required stability of capacitance and temperature can be obtained without the use of a ccover.

6.5 Thermometer—An ASTM Engler Viscosity Thermometer having a range from 18 to 28°C and conforming to the

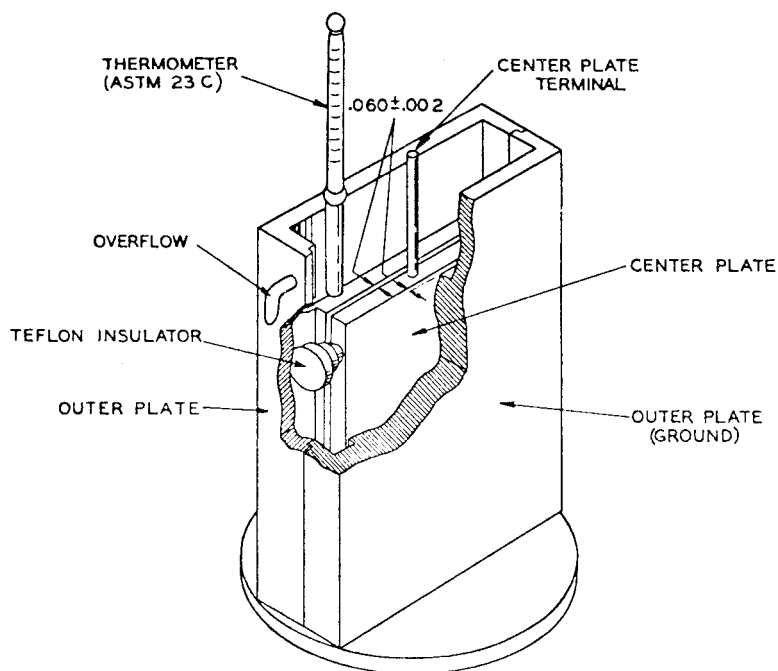


Plate assembly shall be a sliding fit in the cell subassembly; if necessary the polytetrafluoroethylene post insulators may be modified very slightly to accomplish this. The tolerances on the component parts have been apportioned so as to provide a spacing of 1.52 ± 0.05 mm (0.060 ± 0.002 in.).

FIG. 1 Measuring Cell For Test Method A

requirements for Thermometer 23°C in Specification E 1 can be used.

7. Standard Liquid Dielectrics

7.1 Silicone Liquid—Use a 1.0 cSt (1×10^{-6} m²/s) silicone fluid. The permittivity of the liquid changes with temperature and has to be measured to determine the exact value for each lot of material. Use the three-terminal measuring cells and procedures of Test Method D 924 for this purpose. The values of silicone liquid are quite similar to those of dry ACS grade benzene as shown in Table 1. The dissipation factor of 1.0 cSt silicone liquid is less than 0.000005 from 100 kHz to 1 MHz and therefore can be considered zero over this frequency range. The liquid can be used a number of times or until an increase in dissipation factor is observed.

7.2 Benzene—Use certified ACS reagent-grade (thiophene-free) benzene having a permittivity as specified in Table 1 as the referee liquid. As the permittivity of a liquid is a function of temperature, measure the temperature of the cell to an accuracy of $\pm 0.1^\circ\text{C}$ both with the test specimens in and out. The permittivity values shown in Table 1 are for benzene that has been dried over powdered calcium hydride for 3 months. U.S. commercial certified ACS reagent-grade benzene has been

found generally satisfactory. However, in case of a dispute, dry the benzene as above, or measure the permittivity of the benzene, or both. The dissipation factor of the benzene shall not exceed 0.00001 during test. From 100 kHz to 1 MHz, the dissipation factor of ACS reagent-grade benzene is consistently less than 0.000005. The benzene can be used a number of times or until an increase in dissipation factor is observed.

NOTE 3—Precaution: Observe proper precautions due to the toxicity and flammability of benzene. Minimize benzene fumes from test specimens by dropping the specimens in a beaker and covering it at once. A portable hood placed near the cell will also remove benzene fumes.

7.3 Other liquids may be used. Those selected should have a permittivity which is approximately the same as that of the specimen, and is known precisely; that is to the fourth decimal place at the test frequency.

7.4 Avoid liquids that dissolve any constituents of the specimen, result in swelling of the specimen, or are absorbed within the body of the specimen.

7.5 Avoid liquids that exhibit peaks in dissipation factor in excess of 0.00005 in the frequency range $\pm 50\%$ of the test frequency.

8. Sampling

8.1 Take samples according to the applicable material specification, and observe the following precautions in handling.

8.1.1 Handle specimens with tweezers so that no fingerprints or other contamination is introduced onto the specimen. This precaution is very important for polyethylene, and is expected to be very important for other materials also.

8.1.2 Note the handling precautions of Test Method B which relate to removing surface contamination and maintaining a clean surface between sampling and test, not only to improve

TABLE 1 Permittivity Values for Dry Benzene

Temperature, °C	Permittivity	Temperature, °C	Permittivity
21.8	2.2802	23.2	2.2775
22.0	2.2798	23.4	2.2771
22.2	2.2794	23.6	2.2768
22.4	2.2790	23.8	2.2764
22.6	2.2787	24.0	2.2760
22.8	2.2783	24.2	2.2756
23.0	2.2779	24.4	2.2752