Designation: D2413 − 16 (Reapproved 2022)

Standard Practice for Preparation of Insulating Paper and Board Impregnated with a Liquid Dielectric[1]

This standard is issued under the fixed designation D2413; 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 practice covers the preparation of insulating paper and board impregnated with a liquid dielectric. Where this practice states only "paper," the same procedure shall apply to board.

1.2 This practice has been found practicable for papers having nominal thickness of 0.05 mm (2 mil) and above. It has been used successfully for insulating board as thick as 6 mm (¼ in.) when care is taken to ensure the specimen geometry necessary for valid measurement of dielectric properties. Suitable geometry depends on the electrode system used. Rigid solid opposing electrodes require flat specimens that have essentially parallel surfaces.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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]

D117 Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Liquids
D149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
D150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation
D202 Test Methods for Sampling and Testing Untreated Paper Used for Electrical Insulation
D257 Test Methods for DC Resistance or Conductance of Insulating Materials
D924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
D1711 Terminology Relating to Electrical Insulation
D1816 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes
D1933 Specification for Nitrogen Gas as an Electrical Insulating Material
D3394 Test Methods for Sampling and Testing Electrical Insulating Board
D3426 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Using Impulse Waves

3. Terminology

3.1 *Definitions*—Use Terminology D1711 for definitions of terms used in this practice and associated with electrical or electronic materials.

4. Summary of Practice

4.1 The paper is heated and vacuum dried and the liquid dielectric degassed. The paper may be dried in loose form or assembled between electrodes. The liquid dielectric may be heated and degassed prior to introducing it into the chamber containing the dried paper or it may be degassed as it is introduced into the evacuated chamber containing the dried paper. A sufficient length of time is allowed for the impregnating process depending on the apparent density of the paper and method of impregnation. The impregnated specimens are subsequently tested for various selected electrical properties.

5. Significance and Use

5.1 *Dissipation Factor and Relative Permittivity*—Knowledge of these properties is important in the design of electrical equipment such as cables, transformers, insulators, and so forth. The numerical product of these two properties of a dielectric system is proportional to the energy loss converted to heat, and is called its loss index (see Terminology D1711).

[1] This practice is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.01 on Electrical Insulating Products.

Current edition approved May 1, 2022. Published May 2022. Originally approved in 1965. Last previous edition approved in 2016 as D2413 – 16. DOI: 10.1520/D2413-16R22.

[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.

The energy loss reduces the efficiency of electrical equipment. The heat produced tends to chemically degrade the dielectric material and may even lead to thermal runaway. Test results of impregnated specimens can disclose significant differences between combinations of papers and oils that appear similar when the papers and the oils are tested separately. Dissipation factor, particularly at elevated temperatures, is often changed significantly by the presence of a small quantity of impurities in either the liquid or the paper. This practice is useful in the comparison of materials and in evaluating the effects of different papers on a given liquid. Judicious analysis of results with respect to time, temperature, and field strength are useful in predicting the performance and capabilities of systems using the paper and the liquid. For additional information on the significance of dissipation factor and relative permittivity, see Test Methods D150.

5.2 *Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies:*

5.2.1 A comprehensive discussion of the significance of the dielectric strength test as applied to solid, semi-solid, and liquid materials is given in Appendix X1 of Test Method D149. Other factors peculiar to high-quality composite insulations, such as oil-impregnated papers, are considered in the following:

5.2.2 In tests involving high electrical stresses, immersion of critical parts of a test circuit in oil is a widely used technique for inhibiting corona. However, it has limitations that must be recognized when using the submerged electrode option of this practice (Note 1). Attack on the paper by corona generated in the surrounding fluid at electrode edges can occur whether the fluid is air or oil. Corona occurs at considerably higher voltages in oil than in air. Thick and dense papers are more likely to cause discharge-initiated breakdowns. For interpretation of breakdown measurements consider the number of edge breakdowns, implying discharge-initiated breakdowns.

NOTE 1—Two techniques are in use in the industry for testing specimens for dielectric breakdown voltage. In one, the test is made with the electrodes and test specimen submerged in the impregnating liquid while in the other the electrodes are not submerged, that is, the specimen is tested in air. Much data has been accumulated using the latter technique. These techniques yield different values of breakdown voltage. Test Method D149 states preference for testing materials in the medium in which they are used. The use of submerged electrodes follows this preference. When testing thick insulating boards, the use of submerged electrodes is greatly preferred.

5.2.3 The results of power frequency tests on oil impregnated papers are useful for screening, research, and quality control, provided that considerable judgment is exercised in interpreting the results. The application of the test results to equipment design and service requires particular caution and skill (see Appendix X1 of Test Method D149).

5.3 *Dielectric Breakdown Voltage and Dielectric Strength Under Impulse Conditions*—Testing impregnated paper or board under impulse conditions can yield useful data for the designer of electrical equipment. The test results are useful in the comparison of materials and for research studies. For a more general treatise on the significance of impulse testing see Test Method D3426.

6. Apparatus

6.1 *Drying and Impregnating Equipment:*

6.1.1 *Impregnating Chamber*—The chamber shall be equipped with a thermal control unit capable of maintaining selected temperatures as high as 115 °C. The chamber shall have a connection, through a suitable vapor trap, to a vacuum pump capable of maintaining selected absolute pressures as low as 75 Pa (0.5 Torr), as measured by a suitable vacuum gage having a connection to the chamber separate from that of the vacuum pump. It shall be constructed of materials that will not contaminate either the liquid dielectric or the paper, and shall include an appropriately valved entry for the liquid plus a baffle for the purposes indicated in 9.3.

6.1.2 *Vacuum Drying Equipment*—For the liquid, if Procedure 1 (9.2.1) is to be used. This may be substantially a duplicate of the impregnating chamber except that a valved vacuum-tight line is required for transferring dried liquid to the impregnating chamber. Baffles may be used to expose thin films of incoming liquid to the drying and degassing effect of heat and vacuum.

6.2 *Equipment for Measuring Dissipation Factor (Power Factor) and Permittivity of Liquid Dielectric*—The equipment and test cell shall be any three-terminal system meeting the requirements set forth in Test Method D924.

6.3 *Equipment for Measuring Dielectric Strength at Commercial Power Frequencies:*

6.3.1 The equipment for measuring the dielectric strength of the paper shall be as described in Test Method D149, except that the electrodes shall be as specified in Test Methods D202 or D3394, as applicable.

6.3.2 The equipment for testing the dielectric strength of the liquid shall be as described in Test Method D1816.

6.4 Equipment for measuring impulse withstand strength and impulse breakdown dielectric strength shall be that which is specified in Test Method D3426.

7. General Considerations

7.1 When undertaking an investigation into the electrical properties of various papers that are to be impregnated with a specific liquid dielectric or a specific paper to be impregnated with various liquid dielectrics, the parties concerned shall agree to the following:

7.1.1 The identification of paper to be used.

7.1.2 The identification of the liquid dielectric to be used.

7.1.3 Whether the liquid dielectric shall be treated in a separate container or introduced directly into the evacuation chamber containing the treated paper.

7.1.4 The number of sheets or strips that shall comprise each test specimen for the respective tests.

NOTE 2—Two commonly used temperatures are 80 °C and 100 °C.

7.2 Determine the physical and electrical properties of the liquid dielectric in accordance with the applicable methods outlined in Guide D117 (see 6.3.2).

7.3 Use dry nitrogen in these procedures meeting the requirements of Type 1 listed in Table 1 of Specification D1933.

8. Test Specimens

8.1 Take great care to prevent either the untreated paper or the liquid dielectric from being contaminated or degraded by improper handling or from being subjected to laboratory fumes, dirt, oxidation, or ultraviolet light.

8.2 Before impregnation, cut the paper specimens to a size suitable to the geometry of the electrodes to be used. Test at least five specimens for each procedure used. Test at least five specimens for each procedure used.

9. Impregnating Procedure

9.1 *Vacuum Drying the Paper*—Two procedures are used for drying the paper: Procedure A, in which the paper is in loose form in either sheets or strips and Procedure B, in which the paper is assembled between electrodes.

9.1.1 *Procedure A*—Pile the paper loosely in the impregnating chamber and thoroughly dry it at a temperature of 115 °C ± 5 °C and an absolute pressure of 75 Pa (0.5 Torr) or less for at least 16 h. This period has been found adequate for drying papers having an apparent density of up to 1.2 g/cm^3. For papers of greater apparent density, increase the drying time to at least 24 h. Procedure A is preferred for drying specimens of thick insulating board.

9.1.2 *Procedure B*—Assemble the paper insulation between the electrodes and place the assembly in the impregnating chamber. Connect shielded leads to the electrodes and bring them out of the chamber to permit measurements of dissipation factor or of resistivity to be made as an indication of the dryness of the paper during the treating process (see 9.2.2). Subject the assembly to the same treatment as that described in 9.1.1 except that the duration of the heating and vacuum treatment will be dependent on the results obtained when the electrical measurements are made. A constant value of dissipation factor or resistivity indicates that the moisture content of the paper is in equilibrium with the test chamber, but does not necessarily mean that the paper is dry. When resistivity is measured instead of dissipation factor, do so in accordance with Test Methods D257.

9.2 *Vacuum Treating the Liquid Dielectric*—Two procedures are used for drying and degassing the liquid: Procedure 1, in which the liquid is treated in a separate chamber before being introduced into the impregnating chamber containing the dried paper, and Procedure 2, in which the liquid is introduced directly into the impregnating chamber. Procedure 1 is recommended for referee testing and for use with low viscosity impregnants such as transformer oils.

9.2.1 *Procedure 1*—Maintain the separate container (6.1.2) at a temperature and absolute pressure suitable for the impregnating liquid to be used. For oil having a viscosity in the order of 50×10^{-6} m^2/s (50 cSt) or higher at 40 °C, as may be used with paper for cables, the same conditions as used for the paper drying have been found to be satisfactory. For transformer oils with a viscosity in the order of 12×10^{-6} m^2/s (12 cSt) at 40°C, conditions of 60 °C and 40 Pa (0.3 Torr) have been found to be adequate. Other liquids may require other conditions as learned by experience. To obtain good degassification, introduce the liquid, warmed to the temperature chosen, slowly into the separate container.

9.2.2 *Procedure 2*—Adjust the impregnating chamber containing the dried paper to conditions of pressure and temperature suitable for the impregnating liquid, as outlined in 9.2.1. To obtain good degassification, slowly introduce the liquid directly into the chamber.

9.3 *Impregnating Procedure*—When introducing the liquid into the chamber containing the paper it is generally considered good practice to arrange a baffle over the paper so that the liquid will impregnate the paper from the bottom. After the liquid has completely covered the paper, break vacuum with desiccated air or dry nitrogen. Allow 8 h or more at atmospheric pressure for the paper to become completely impregnated. To accelerate the process, positive pressure, using desiccated air or dry nitrogen, may be applied to the impregnating chamber. The time required for thorough impregnation is dependent on the rate of liquid penetration of the paper, which in turn is an inverse function of the paper density, the thickness, and the liquid viscosity. Loose pieces of paper impregnate more quickly than multiple layers tightly assembled in an insulation structure.

9.4 Do not remove impregnated specimens from immersion in the liquid dielectric even momentarily, where as moisture reabsorption will occur into the specimen. This is particularly important if dielectric tests are to be conducted.

10. Calculation

10.1 *Dissipation Factor and Permittivity*—Calculate the respective values in accordance with the applicable method given in Test Methods D150.

10.2 *Dielectric Strength at Commercial Power Frequencies*—Using the breakdown voltage and thickness of each test specimen, calculate the dielectric strength.

10.3 *Impulse Tests:*

10.3.1 Calculate the impulse withstand strength from the values of specimen thickness and the maximum level of impulse voltage that did not cause failure of the specimen.

10.3.2 Calculate the impulse breakdown dielectric strength from the values of specimen thickness and impulse dielectric breakdown voltage.

11. Keywords

11.1 board; dielectric strength; dissipation factor; drying; impulse strength; il impregnation; paper permittivity; pressboard; vacuum drying