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Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus[1]

This standard is issued under the fixed designation D3487; 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.

ε[1] NOTE—In X1.1, for Thermal conductivity, W/ was added before (m·°C) editorially in December 2017.

1. Scope

1.1 This specification covers unused mineral insulating oil of petroleum origin for use as an insulating and cooling medium in new and existing power and distribution electrical apparatus, such as transformers, regulators, reactors, circuit breakers, switchgear, and attendant equipment.

1.2 This specification is intended to define a mineral insulating oil that is functionally interchangeable and miscible with existing oils, is compatible with existing apparatus and with appropriate field maintenance,[2] and will satisfactorily maintain its functional characteristics in its application in electrical equipment. This specification applies only to new insulating oil as received prior to any processing.

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:*[3]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D117 Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Oils of Petroleum Origin
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents
D923 Practices for Sampling Electrical Insulating Liquids
D924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
D971 Test Method for Interfacial Tension of Oil Against Water by the Ring Method
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1275 Test Method for Corrosive Sulfur in Electrical Insulating Liquids
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)
D1524 Test Method for Visual Examination of Used Electrical Insulating Liquids in the Field
D1533 Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration
D1816 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes
D1903 Practice for Determining the Coefficient of Thermal Expansion of Electrical Insulating Liquids of Petroleum Origin, and Askarels
D2112 Test Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Pressure Vessel
D2300 Test Method for Gassing of Electrical Insulating Liquids Under Electrical Stress and Ionization (Modified Pirelli Method)

[1] This specification is under the jurisdiction of ASTM Committee D27 on Electrical Insulating Liquids and Gasesand is the direct responsibility of Subcommittee D27.01 on Mineral.

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[2] Refer to the Institute of Electrical and Electronic Engineers, Inc. (IEEE) C 57.106, Guide for Acceptance and Maintenance of Insulating Oil in Equipment. Available from IEEE Operations Center, 445 Hoes Lane, Piscataway, NJ 08854-4141, USA.

[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.

D2440 Test Method for Oxidation Stability of Mineral Insulating Oil
D2668 Test Method for 2,6-*di-tert*-Butyl- *p*-Cresol and 2,6-*di-tert*-Butyl Phenol in Electrical Insulating Oil by Infrared Absorp
D2717 Test Method for Thermal Conductivity of Liquids
D2766 Test Method for Specific Heat of Liquids and Solids
D2864 Terminology Relating to Electrical Insulating Liquids and Gases
D3300 Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Under Impulse Conditions
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4059 Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography
D4768 Test Method for Analysis of 2,6-Ditertiary-Butyl Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Insulating Liquids by Gas Chromatography
D5837 Test Method for Furanic Compounds in Electrical Insulating Liquids by High-Performance Liquid Chromatography (HPLC)
D5949 Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method)
D5950 Test Method for Pour Point of Petroleum Products (Automatic Tilt Method)

2.2 *IEEE Standard*[2]

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

3. Terminology

3.1 *Definitions:*

3.1.1 *Type I Mineral Oil*—an oil for apparatus where normal oxidation resistance is required. Some oils may require the addition of a suitable oxidation inhibitor to achieve this.

3.1.2 *Type II Mineral Oil*—an oil for apparatus where greater oxidation resistance is required. This is usually achieved with the addition of a suitable oxidation inhibitor.

3.1.2.1 *Discussion*—During processing of inhibited mineral oil under vacuum and elevated temperatures, partial loss of inhibitor and volatile portions of mineral oil may occur. The common inhibitors, 2,6-ditertiary-butyl para-cresol (DBPC/BHT) and 2,6-ditertiary-butyl phenol (DPB), are more volatile than transformer oil. If processing conditions are too severe, oxidation stability of the oil may be decreased due to loss of inhibitor. The selectivity for removal of moisture and air in preference to loss of inhibitor and oil is improved by use of a low processing temperature.

Conditions that have been found satisfactory for most inhibited mineral oil processing are:

Temperature, °C	Minimum Pressure Pa	Minimum Pressure Torr, Approximate
40	5	0.04
50	10	0.075
60	20	0.15
70	40	0.3
80	100	0.75
90	400	3.0
100	1000	7.5

If temperatures higher than those recommended for the operating pressure are used, the oil should be tested for inhibitor content and inhibitor added as necessary to return inhibitor content to its initial value. Attempts to dry apparatus containing appreciable amounts of free water may result in a significant loss of inhibitor even at the conditions recommended above.

3.1.3 *additives*—chemical substances that are added to mineral insulating oil to achieve required functional properties.

3.1.4 *properties*—those properties of the mineral insulating oil which are required for the design, manufacture, and operation of the apparatus. These properties are listed in Section 5.

3.2 Other definitions of terms related to this specification are given in Terminology D2864.

3.3 More information on tests related to this specification can be found in Guide D117.

4. Sampling and Testing

4.1 Take all oil samples in accordance with Practices D923.

4.2 Make each test in accordance with the latest revision of the ASTM test method specified in Section 5.

4.3 The oil shall meet the requirements of Section 5 at the unloading point.

NOTE 1—Because of the different needs of the various users, items relating to packaging, labeling, and inspection are considered to be subject to supplier and user agreement.

NOTE 2—In addition to all other tests listed herein, it is sound engineering practice for the apparatus manufacturer to perform an evaluation of new types of insulating oils in insulation systems, prototype structures, or full-scale apparatus, or any combination thereof, to assure suitable service life.

4.4 Make known to the user the generic type and amount of any additive used, for assessing any potential detrimental reaction with other materials in contact with the oil.

5. Property Requirements

5.1 Mineral insulating oil conforming to this specification shall meet the property limits given in Table 1. The significance of these properties is discussed in Appendix X2.

TABLE 1 Property Requirements

Property	Limit Type I	Limit Type II	ASTM Test Method
Physical:			
Aniline point, min, °C	63[A]	63[A]	D611
Color, max	0.5	0.5	D1500
Flash point, min, °C	145	145	D92
Interfacial tension, min, mN/m	40	40	D971
Pour point, max, °C	−40[B]	−40[B]	D97, D5949, or D5950[B]
Relative Density (Specific gravity), 15°C/15°C, max	0.91	0.91	D1298 or D4052[C]
Viscosity, max, mm²/s at:			D445
100°C	3.0	3.0	
40°C	12.0	12.0	
0°C	76.0	76.0	
Visual examination	clear and bright	clear and bright	D1524
Electrical:			
Dielectric breakdown voltage at 60 Hz:			D1816
VDE electrodes, min, kV 1 mm gap	20[D]	20[D]	
2 mm gap	35[D]	35[D]	
Dielectric breakdown voltage, impulse conditions			D3300
negative polarity point, min, kV	145	145	
Gassing tendency, max, µL/minute	+30	+30	D2300
Dissipation factor (or power factor), at 60 Hz, max, %:			D924
25°C	0.05	0.05	
100°C	0.30	0.30	
Chemical:			
Oxidation stability (acid-sludge test)			D2440
72 h:			
sludge, max, % by mass	0.15	0.1	
Total acid number, max, mg KOH/g	0.5	0.3	
164 h:			
sludge, max, % by mass	0.3	0.2	
Total acid number, max, mg KOH/g	0.6	0.4	
Oxidation stability (pressure vessel test), min, minutes	—	195	D2112
Oxidation inhibitor content, max, % by mass	0.08[E]	0.30[F]	D4768 or D2668[G]
Corrosive sulfur	noncorrosive	noncorrosive	D1275
Water, max, mg/kg	35	35	D1533
Neutralization number, total acid number, max, mg KOH/g	0.03	0.03	D974
Furanic Compounds, max per compound, µg/L	25	25	D5837
PCB content, mg/kg	not detectable	not detectable	D4059

[A] The value shown represents current knowledge.
[B] In case of a dispute, D97 shall be used as the referee method.
[C] In case of a dispute, Test Method D1298 shall be used as the referee method.
[D] These limits by Test Method D1816 are applicable only to as received new oil (see Appendix X2.2.1.1).
[E] Provisions to purchase totally uninhibited oil shall be agreed upon between supplier and user.
[F] Minimum requirements of inhibitor for Type II oil shall be agreed upon between supplier and user.
[G] Both 2,6-ditertiary-butyl para-cresol (DBPC/BHT) and 2,6-ditertiary butylphenol (DBP) have been found to be suitable oxidation inhibitors for use in oils meeting this specification. Preliminary studies indicate both Test Methods D2668 and D4768 are suitable for determining concentration of either inhibitor or their mixture.

APPENDIXES

(Nonmandatory Information)

X1. SUPPLEMENTARY DESIGN INFORMATION

X1.1 The following values are typical for presently used mineral insulating oils. For oils derived from paraffinic or mixed-base crudes, the apparatus designer needs to know that these properties have not changed.

Property	Typical Values	ASTM Test Method
Coefficient of expansion,/°C from 25 to 100°C	0.0007 to 0.0008	D1903
Dielectric constant, 25°C	2.2 to 2.3	D924
Specific heat, J/(kg °C), 20°C	1800	D2766
Thermal conductivity, W/(m·°C), from 20 to 100°C	0.13 to 0.17	D2717

X2. SIGNIFICANCE OF PROPERTIES OF MINERAL INSULATING OIL

X2.1 Physical Properties

X2.1.1 *Aniline Point*—The aniline point of a mineral insulating oil indicates the solvency of the oil for materials that are in contact with the oil. It may relate to the impulse and gassing characteristics of the oil.

X2.1.2 *Color*—A low color number is an essential requirement for inspection of assembled apparatus in the tank. An increase in the color number during service is an indicator of deterioration of the mineral insulating oil.

X2.1.3 *Flash Point*—The safe operation of the apparatus requires an adequately high flash point.

X2.1.4 *Interfacial Tension*—A high value for new mineral insulating oil indicates the absence of undesirable polar contaminants. This test is frequently applied to service-aged oils as an indicator of the degree of deterioration.

X2.1.5 *Pour Point*—The pour point of mineral insulating oil is the lowest temperature at which the oil will just flow and many of the factors cited under viscosity apply. The pour point of −40°C may be obtained by the use of suitable distillates, refining processes, the use of appropriate long life additives, or any combination thereof. If a pour point additive is used, it is necessary to make known the amount and chemical composition.

X2.1.6 *Relative Density (Specific Gravity)*—The specific gravity of a mineral insulating oil influences the heat transfer rates and may be pertinent in determining suitability for use in specific applications. In extremely cold climates, specific gravity has been used to determine whether ice, resulting from freezing of water in oil-filled apparatus, will float on the oil and possibly result in flashover of conductors extending above the oil level. See, for example, "The Significance of the Density of Transformer Oils."[4]

X2.1.7 *Viscosity*—Viscosity influences the heat transfer and, consequently, the temperature rise of apparatus. At low temperatures, the resulting higher viscosity influences the speed of moving parts, such as those in power circuit breakers, switchgear, load tapchanger mechanisms, pumps, and regulators. Viscosity controls mineral insulating oil processing conditions, such as dehydration, degassification and filtration, and oil impregnation rates. High viscosity may adversely affect the starting up of apparatus in cold climates (for example, spare transformers and replacements).

X2.1.8 *Visual Examination*—A simple visual inspection of mineral insulating oil may indicate the absence or presence of undesirable contaminants. If such contaminants are present, more definitive testing is recommended to assess their effect on other functional properties.

X2.2 Electrical Properties

X2.2.1 *Dielectric Breakdown Voltage, 60 Hz*—The dielectric breakdown voltage of a mineral insulating oil indicates its ability to resist electrical breakdown at power frequencies in electrical apparatus.

X2.2.1.1 *Dielectric Breakdown—VDE Electrodes*—The VDE method (Test Method D1816) is sensitive to contaminants, such as water, dissolved gases, cellulose fibers, and conductive particles in oil. Processing involves filtering,

[4] Mulhall, V. R., "The Significance of the Density of Transformer Oils," *IEEE Transactions on Electrical Insulation*, Vol 15, No. 6, December 1980, pp. 498–499. DOI: 10.1520/D3487-09_WIP_#872079.

dehydration, and degassing, which generally improve the breakdown strength of the oil. As a general guide, the moisture and dissolved gas content by volume in processed oils should be less than 15 ppm and 0.5 % respectively. The minimum breakdown strength for as received oils is typically lower than that of processed oils because of higher levels of contaminants.

X2.2.2 *Dielectric Breakdown Voltage–Impulse*—The impulse strength of oil is critical in electrical apparatus. The impulse breakdown voltage of oil indicates its ability to resist electrical breakdown under transient voltage stresses (lightning and switching surges). The functional property is sensitive to both polarity and electrode geometry.

X2.2.3 *Dissipation Factor*—Dissipation factor (power factor) is a measure of the dielectric losses in oil. A low dissipation factor indicates low dielectric losses and a low level of soluble contaminants.

X2.2.4 *Gassing*—The gassing tendency of a mineral insulating oil is a measure of the rate of absorption or desorption of hydrogen into or out of the oil under prescribed laboratory conditions. It reflects, but does not measure, aromaticity of the oil.

X2.3 Chemical Properties

X2.3.1 *Oxidation Inhibitor Content*—Oxidation inhibitor added to mineral insulating oil retards the formation of oil sludge and acidity under oxidative conditions. It is important to know if an oxidation inhibitor has been added to the oil and the amount. 2,6-Ditertiary-butyl para-cresol and 2,6-ditertiary butylphenol have been found suitable for use in mineral insulating oils complying with this specification. It is anticipated that other oxidation inhibitors will be accepted.

X2.3.2 *Corrosive Sulfur*—The absence of elemental sulfur and thermally unstable sulfur-bearing compounds is necessary to prevent the corrosion of certain metals such as copper and silver in contact with the mineral insulating oil.

X2.3.3 *Water Content*—A low water content of mineral insulating oil is necessary to achieve adequate electrical strength and low dielectric loss characteristics, to maximize the insulation system life, and to minimize metal corrosion.

X2.3.4 *Neutralization Number*—A low total acid content of a mineral insulating oil is necessary to minimize electrical conduction and metal corrosion and to maximize the life of the insulation system.

X2.3.5 *Oxidation Stability*—The development of oil sludge and acidity resulting from oxidation during storage, processing, and long service life should be held to a minimum. This minimizes electrical conduction and metal corrosion, maximizes insulation system life and electrical breakdown strength, and ensures satisfactory heat transfer. The limiting values in accordance with Table 1, as determined by Test Methods D2112 and D2440, best achieve these objectives.

X2.3.6 Furanic Compounds provide a means to assess the cellulose degradation of an insulation system. The level of these compounds must be at or below the levels stated in Table 1 to ensure the baseline is known for new oil when delivered. Furanic Compounds are typically not found in highly refined oil but might be present due to contamination. The purpose is to ensure future work is not distorted by the presence of these compounds.

X2.3.7 *PCB Content*—Many regulations specify procedures to be followed for the use and disposal of electrical apparatus and electrical insulating fluids containing various PCBs (polychlorinated biphenyls) or aroclors. The procedure to be used for a particular apparatus or lot of insulating fluid is determined from its PCB content. New mineral insulating oil of the type covered by this specification should not contain any detectable PCBs. A non-detectable PCB concentration measured by Test Method D4059 provides documentation to permit the insulating oil and apparatus containing it to be used without the labeling, recordkeeping, and disposal restrictions required of PCB-containing materials.

X3. PETROLEUM SOURCES, REFINING PROCESSES, AND SHIPPING CONTAINERS

X3.1 *Petroleum Sources*—Mineral insulating oils are presently refined from predominantly naphthenic crude oils. Paraffinic crudes and new refining technology may be used to provide mineral insulating oil for use in electrical apparatus. As new petroleum sources are developed for this use, additional tests peculiar to the chemistry of these oils may need to be defined.

X3.2 *Refining Processes*—Distillates from crude oils may be refined by various processes such as solvent extraction, dewaxing, hydrotreating, hydrocracking, or combinations of these methods to yield mineral insulating oil meeting the requirements of this specification. The generic process should be specified upon request.

X3.3 *Shipping Containers*—Mineral insulating oil is usually shipped in rail cars, tank trucks (trailers), or drums. Rail cars used for shipping mineral insulating oil are usually not used for shipping other products and are more likely to be free of contamination. Tank trucks may be used for many different products and are more subject to contamination. Oil drums are most often used for shipping small quantities. All shipping containers, together with any attendant pumps and piping, should be cleaned prior to filling with oil and should be properly sealed to protect the oil during shipment.