INTERNATIONAL

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

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

1. Scope

1.1 This specification covers new 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,~~ 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

[1] This specification is under the jurisdiction of ASTM Committee D-27 on Electrical Insulating Liquids and Gases and is the direct responsibility of Subcommittee D27.01 on ~~Mineral Oils.~~ Mineral.

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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.

2. Referenced Documents

2.1 *ASTM Standards:*

D 88 Test Method for Saybolt Viscosity[3]

D 92 Test Method for Flash and Fire Points by Cleveland Open Cup[4]

D 97 Test Method for Pour Point of Petroleum Products[4]

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids ~~(and the Calculation of Dynamic Viscosity)~~ [4]

D 611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents[4]

D 877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes[5]

D 923 Test Method for Sampling Electrical Insulating Liquids[5]

D 924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids[5]

D 971 Test Method for Interfacial Tension of Oil Against Water by the Ring Method[5]

D 974 Test Method for Acid and Base Number by Color-Indicator ~~Titration [4], [5]~~ Titration[4]

D 1275 Test Method for Corrosive Sulfur in Electrical Insulating Oils[5]

D ~~1298 Practice~~ 1298 Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[4,5]

D ~~1473 Test~~ 1500 Test Method for ~~2,6-Ditertiary-Butyl Para-Cresol in Electrical Insulating Oils [6]~~ ASTM Color of Petroleum Products (ASTM Color Scale)[4]

D 150~~0~~24 Test Method for ~~ASTM Color~~ Visual Examination of Used Electrical Insulating Oils of Petroleum ~~Products (ASTM Color Scale) [4]~~ Origin in the Field[5]

D 15~~24~~33 Test Methods for ~~Visual Examination of Used Electrical Insulating Oils of Petroleum Origin~~ Water in ~~the Field~~ Insulating Liquids (Karl Fischer Reaction Method)[5]

D 1~~533~~816 Test Method~~s~~ for ~~Water in~~ Dielectric Breakdown Voltage of Insulating ~~Liquids (Karl Fischer Reaction Method)~~ Oils of Petroleum Origin Using VDE Electrodes[5]

D ~~1816 Test~~ 1903 Test Method for ~~Dielectric Breakdown Voltage~~ Coefficient of Thermal Expansion of Electrical Insulating ~~Oils~~ Liquids of Petroleum ~~Origin Using VDE Electrodes~~ Origin, and Askarels[5]

D ~~1903 Test~~ 2112 Test Method for ~~Coefficient~~ Oxidation Stability of ~~Thermal Expansion of Electrical~~ Inhibited Mineral Insulating ~~Liquids of Petroleum Origin, and Askarels~~ Oil by Rotating Bomb[5]

D ~~2112 Test~~ 2300 Test Method for ~~Oxidation Stability~~ Gassing of ~~Inhibited Mineral~~ Insulating ~~Oil by Rotating Bomb~~ Oils Under Electrical Stress and Ionization (Modified Pirelli Method)[5]

D 23~~0~~44~~0~~0 Test Method for ~~Gassing~~ Oxidation Stability of Mineral Insulating ~~Oils Under Electrical Stress and Ionization (Modified Pirelli Method)~~ Oil[5]

D ~~2440 Test~~ 2668 Test Method for ~~Oxidation Stability of Mineral~~ 2,6-Ditertiary-Butyl Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption[5]

D ~~2668 Test~~ 2717 Test Method for ~~2,6-Ditertiary-Butyl Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption [5]~~ Thermal Conductivity of Liquids[6]

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[2] Refer to American National Standard ~~C 59.131.~~ C 57.106. Guide for Acceptance and Maintenance of Insulating Oil in Equipment (IEEE Standard 64). Available from the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

[3] *Annual Book of ASTM Standards*, Vol 04.04.

[4] *Annual Book of ASTM Standards*, Vol 05.01.

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

~~[6] Discontinued; see *1987 Annual*~~

[6] *Annual Book of ASTM Standards*, Vol ~~10.03.~~ 05.02.

D 27~~17~~66 Test Method for ~~Thermal Conductivity~~ Specific Heat of Liquids ~~7~~ and Solids[6]

D ~~2766 Test~~ 3300 Test Method for ~~Specific Heat~~ Dielectric Breakdown Voltage of ~~Liquids and Solids 7~~ Insulating Oils of Petroleum Origin Under Impulse Conditions[5]

D ~~3300 Test~~ 4059 Test Method for ~~Dielectric Breakdown Voltage~~ Analysis of Polychlorinated Biphenyls in Insulating ~~Oils of Petroleum Origin Under Impulse Conditions~~ Liquids by Gas Chromatography[5]

D ~~4059 Test~~ 4768 Test Method for Analysis of ~~Polychlorinated Biphenyls~~ 2,6-Ditertiary-Butyl Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Insulating ~~Liquids~~ Fluids by Gas Chromatography[5]

D 5837 Test Method for Furanic Compounds in Electrical Insulating Liquids by High Performance Liquid Chromatography (HPLC)[5]

3. Terminology Definitions

3.1 *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.

3.2 *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.

NOTE 1—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 and 2,6-ditertiary-butyl phenol, 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:

	Minimum Pressure	
Temperature, °C	Pa	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.

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

3.4 *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.

4. Sampling and Testing

4.1 Take all oil samples in accordance with Test Methods D 923.

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 2—Because of the different needs of the various users, items relating to packaging, labeling, and inspection are considered to be subject to buyer-seller agreement.

NOTE 3—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.

~~*Annual Book*~~

[7] Mulhall, V. R., "The Significance of ~~ASTM Standards~~ the Density of Transformer Oils,'' *IEEE Transactions on Electrical Insulation*, Vol ~~05.02.~~ 15, No. 6, December 1980, pp. 498–499.

TABLE 1 Property Requirements

Property	Limit Type I	Limit Type II	ASTM Test Method
Physical:			
Aniline point, °C	(63–84) [A]	(63–84) [A]	D 611
Aniline point, °C	(63–84)[A]	(63–84)[A]	D 611
Color, max	0.5	0.5	D 1500
Flash point, min, °C	145	145	D 92
Interfacial tension at 25°C, min, dynes/cm	40	40	D 971
Pour point, max, °C	−40 [B]	−40 [B]	D 97
Specific gravity, 15°C/15°C max	0.91	0.91	D 1298
Viscosity, max, cSt (SUS) at:			
100°C	3.0 (36) [C]	3.0 (36) [C]	D 445 or D 88
100°C	3.0 (36)	3.0 (36)	D 445 or D 88
40°C	12.0 (66) [C]	12.0 (66) [C]	
40°C	12.0 (66)	12.0 (66)	
0°C	76.0 (350)	76.0 (350)	
Visual examination	clear and bright	clear and bright	D 1524
Electrical:			
Dielectric breakdown voltage at 60 Hz:			
Disk electrodes, min, kV	30	30	D 877
VDE electrodes, min, kV 0.040-in. (1.02-mm) gap	28 [D]	28 [D]	D 1816
0.080-in. (2.03-mm) gap	56 [D]	56 [D]	
VDE electrodes, min, kV 0.040-in. (1.02-mm) gap	20[C]	20[C]	D 1816
0.080-in. (2.03-mm) gap	35[C]	35[C]	
Dielectric breakdown voltage, impulse conditions			D 3300
25°C, min, kV, needle negative to sphere grounded, 1-in. (25.4-mm) gap	145 [A,E]	145 [A,E]	
25°C, min, kV, needle negative to sphere grounded, 1-in. (25.4-mm) gap	145[D]	145[D]	
Gassing tendency, [F,G] max, μL/min	+ 15	+ 15	D 2300 (Procedure A)
	+ 30	+ 30	D 2300 (Procedure B)
Gassing tendency,	+30	+30	D 2300
Dissipation factor (or power factor), at 60 Hz max, %:			D 924
25°C	0.05	0.05	
100°C	0.30	0.30	
Chemical:			
Chemical:[E]			
Oxidation stability (acid-sludge test)			D 2440
72 h:			
% sludge, max, by mass	0.15	0.1 [A]	
Total acid number, max, mg KOH/g	0.5	0.3 [A]	
% 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 [A]	
Total acid number, max, mg KOH/g	0.6	0.4 [A]	
% sludge, max, by mass	0.3	0.2	
Total acid number, max, mg KOH/g	0.6	0.4	
Oxidation stability (rotating bomb test), min, minutes	—	195	D 2112
Oxidation inhibitor content, max, % by mass	0.08	0.3	D 1473 or D 2668 [H]
Oxidation inhibitor content, max, % by mass	0.08	0.3	D 4768 or D 2668[F]
Corrosive sulfur	noncorrosive		D 1275
Water, max, ppm	35	35	D 1533
Neutralization number, total acid number, max, mg KOH/g	0.03	0.03	D 974
PCB content, ppm	not detectable	not detectable	D 4059

[A] The value shown represents current knowledge. Work is in progress to reaffirm the validity of this value.

[B] In certain sections of the United States and Canada, it is common practice to specify a lower or higher pour point, depending upon climatic conditions.

[C] At t The tse limperaiturs by Tes pt Method D 1816 arev applicable ousnly u to as received f new orinsulat (see Appendix X2.2.1.2). A ngew processed oil vi sehosityuld haveter minatimum breakdown s,these values correspondgths o 3.1 cSt (36.5 SUS) atf 210°F (98.9°C) kV and t 56 kV fo 13r a 0.0 cSt4 in. (71.0 SUS2 mm) at 1 or 0.0°F8 in. (372.8°C03 mm) gap respectively.

[D] Th Curresently avaimlable oitls b vary T in impulse st Mrength. Sod D 1816me users prefer oil of a 145 kV minimum for certain applicabletions, whily te o nthewrs accept oil whieth has been f impultse stred, dehydrated, and degth as low as 130 kV for othed (see Ar appendlix, X2.2.3)cations.

[E] C Furrentlyavanilablec coilmpounds v, as deterymin impulsed by Testr Mength. Somd D 5837, are useful for as prsefer eossing the level of a 145 kV minim cellum flor ese degrtaindapplications, w thile oat hersas occurreptd in oil w ith impulsre sgnated paper systems. Specifyingth masximum allowable furan levels 130 kV in new oils for o theis pur appose shoulied be by agreementio between user and supplier.

[F] Specificati Bon requiresthat 2,6-dinsulating oils meert the gassingary-butendencylimits pas merasu cred by Test Methol and D 2300 e,6-dither Ptiarocedy burtylphe Anor B. Tl have sp becien ficatiound to be s not requirethable oxidation inhibitors for ulatse ing oils meet gassing this spendency limfitscas measured by both Test Methiod D 2300 Procedures A and B.

G In the gassing tendency test in Test Method D 2300Procedures A and B, the test temperature should be 80°C with a test voltage of 12 kV for Procedure A and a test voltage of 10 kV for Procedure B.

[H] Both 2,6-ditertiary-butyl para cresol and 2,6-ditertiary butylphenol have been found to be suitable oxidation inhibitors for use in oilsmeeting this specification. Preliminary studies indicate both Test Methods D 2668 i and D 4768 are s suitable for determining concentration of either inhibitor or their mixture. Test Method D 1473 is suitable for determining concentration of 2,6-ditertiary-butyl para cresol, but its applicability to 2,6-ditertiary butylphenol is still under investigation.

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	D 1903
Dielectric constant, 25°C	2.2 to 2.3	D 924
Specific heat, cal/g, 20°C	0.44	D 2766
Thermal conductivity, cal/ cm·s·°C, from 20 to 100°C	(0.30 to 0.40) $\times 10^{-3}$	D 2717

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.'' [8]~~ Oils."[7]

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—Disk Electrodes*—The test utilizing disk electrodes is useful in assessing the quality of the mineral insulating oil as received in tank cars, tank trucks, or drums. It is not sensitive enough to determine if an oil meets the minimum acceptable breakdown strength needed for processed oil used in some equipment.

X2.2.1.2 *Dielectric Breakdown—VDE Electrodes*—The VDE method ~~(D 1816), because of its sensitivity to contaminants,~~ (Test Method D 1816) is ~~used~~ sensitive to ~~de~~ cont~~er~~aminants, such as water, dissolved gases, cellulose fibers, and conductive particles in oil. Process~~ed~~ing involves fil~~m~~tering, dehydration, and degassing, which generally improve the ~~minimum acceptable~~ breakdown strength of ~~new oils, as required in apparatus. To obtain~~ the ~~limits shown in Section 5, oil must be filtered, dehydrated, and degassed. (As~~ oil. As a ~~guide for~~ general guide, the ~~user of this test procedure, acceptable processing should yield an oil that is essentially free of particulate matter, and with~~ moisture and dissolved gas content ~~levels of the order of~~ by volume in processed oils should be less 15 ppm and 0.5 % by volume, respectively.) This test respectively. The minimum breakdown strength for as received oils is not applicable to new unprocessed oil. 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 an 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 an oil. A low dissipation factor indicates low dielectric losses and a low level of soluble contaminants.

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 Section 5, Table 1, as determined by Test Methods D 2112 and D 2440, best achieve these objectives.

X2.3.6 *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. Most oil-filled transformers are blanketed with nitrogen or oxygen-depleted air. The gassing tendency of oil under nitrogen does not directly relate to its gassing tendency under hydrogen. No quantitative relationship has been established between the gassing tendency of an oil, as indicated by the results of Test Method D 2300, and the performance or life of that oil in service.

X2.3.7 *PCB Content*—United States regulations specify procedures to be followed for the use and disposal of electrical apparatus and electrical insulating fluids containing PCB (polychlorinated biphenyls). 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 PCB. A nondetectable PCB concentration measured by Test Method D 4059 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. CRUDE OILS, REFINING PROCESSES, AND SHIPPING CONTAINERS

X3.1 *Crude Oils*—Mineral insulating oils are presently refined from predominantly naphthenic crude oils. As the supply of such crude oils diminishes, paraffinic or mixed base crudes may be used to provide mineral insulating oil for use in electrical apparatus. As the new crudes are developed for this use, additional tests peculiar to the chemistry of these oils will need to be defined.

X3.2 *Refining Processes*—Distillates from crude oils may be refined by various processes such as acid treatment, solvent extraction, dewaxing, hydrogen treatment, 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.