C57.106™

IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment

IEEE Power Engineering Society

Sponsored by the
IEEE Transformers Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

6 June 2007

IEEE Std C57.106™-2006
(Revision of IEEE Std C57.106-2002)

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IEEE Std C57.106-2002)

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Approved 6 December 2006

IEEE-SA Standards Board

Abstract: Recommendations regarding oil tests and evaluation procedures are made in this guide; references are made to methods of reconditioning and reclaiming conventional petroleum (mineral) dielectric insulating oils; the levels at which these methods become necessary; and the routines for restoring oxidation resistance, where required, by the addition of oxidation inhibitors. The intent is to assist the power equipment operator in evaluating the serviceability of oil received in equipment, oil as received from the supplier for filling new equipment at the installation site, and oil as processed into such equipment; and to assist the operator in maintaining oil in serviceable condition. The mineral oil covered is used in transformers, reactors, circuit breakers, load tap changers, and voltage regulators.

Keywords: insulation testing, load tap changers, oil circuit breakers, oil insulation, power distribution maintenance, power transformer insulation, reactors, transformers, voltage regulators

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The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Print: ISBN 0-7381-5331-1 SH95621
PDF: ISBN 0-7381-5332-X SS95621

Introduction

This introduction is not part of IEEE Std C57.10-2006, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

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IEEE Guide for Maintenance and Acceptance of Insulating Oil in Equipment

1. Overview

The reliable performance of oil in insulation systems depends on the basic characteristics of the oil that can affect overall apparatus characteristics. These oil characteristics are integral parts of the equipment design of the manufacturer. Certain properties of mineral insulating oil have been determined as important for proper electrical equipment performance. A description of these properties and their recommended value ranges for new oil and for continued use of service-aged oils are included in this guide.

Mineral insulating oil that is received in electrical equipment will exhibit different characteristics from new oil received in bulk, which has not been in contact with apparatus construction materials.

Oil in service may contain dissolved gases that are useful in assessing the continued serviceability of certain types of transformers. It is not the intent of this guide to cover this subject, as that information is available in IEEE Std C57.104™.[1]

This guide reflects the current state of the art and may differ from information contained in IEEE Std 62™, which was authored by the Power System Instrumentation and Measurements (PSIM) Committee.

Should instructions or product standards given by the manufacturer differ from recommendations made in this guide, the instructions of the manufacturer are to be given preference.

1.1 Scope

This guide applies to mineral oil used in transformers, load tap changers, voltage regulators, reactors, and circuit breakers. The guide discusses the following:

a) Analytical tests and their significance for the evaluation of mineral insulating oil.

b) The evaluation of new, unused mineral insulating oil before and after filling into equipment.

c) Methods of handling and storage of mineral insulating oil.

d) The evaluation of service-aged mineral insulating oil.

e) Health and environmental care procedures for mineral insulating oil.

[1] Information on references can be found in Clause 2.

The characteristics of the oils discussed in this guide do not include oil that is in factory fill lines, nor does this guide cover reclaimed oil installed in new equipment. The qualities of such oil, if used, should be agreed upon by the manufacturer and the user of the equipment.

1.2 Purpose

The purpose of this guide is to assist the user of the equipment in evaluating the serviceability of new, unused oil being received in equipment; oil as received for filling new equipment at the installation site; and oil as processed into equipment. It also assists the operator in maintaining the oil in serviceable condition.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D88, Standard Test Method for Saybolt Viscosity.[2]

ASTM D92, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester.

ASTM D97, Standard Test Method for Pour Point of Petroleum Products.

ASTM D445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity).

ASTM D611, Standard Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents.

ASTM D664, Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration.

ASTM D877, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

ASTM D923, Standard Practice for Sampling Electrical Insulating Liquids.

ASTM D924, Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.

ASTM D971, Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method.

ASTM D974, Standard Test Method for Acid and Base Number by Color-Indicator Titration.

ASTM D1275, Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils.

ASTM D1298, Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method.

ASTM Dl500, Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale).

[2] ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

ASTM D1524, Standard Test Method for Visual Examination of Used Electrical Insulation Oils of Petroleum Origin in the Field.

ASTM D1533, Standard Test Methods for Water in Insulating Liquids by Coulometric Karl Fischer Titration.

ASTM Dl816, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.

ASTM D2112, Standard Test Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Pressure Vessel.

ASTM D2l6l, Standard Practice for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity.

ASTM D2285, Standard Test Method for lnterfacial Tension of Electrical Insulating Oils of Petroleum Origin Against Water by the Drop-Weight Method.

ASTM D2300, Standard Test Method for Gassing of Insulating Liquids Under Electrical Stress and Ionization (Modified Pirelli Method).

ASTM D2440, Standard Test Method for Oxidation Stability of Mineral Insulating Oil.

ASTM D2668, Standard Test Method for 2,6-Di-Tert-Butyl-P-Cresol and 2,6-Di-Tert-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption.

ASTM D2945, Standard Test Method for Gas Content of Insulating Oils.

ASTM D3284, Standard Test Method for Combustible Gases in the Gas Space of Electrical Apparatus Using Portable Meters.

ASTM D3300, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Under Impulse Conditions.

ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

ASTM D3612, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

ASTM D3613, Standard Practice for Sampling Insulating Liquids for Gas Analysis and Determination of Water Content.

ASTM D4059, Standard Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography.

ASTM D4768, Standard Test Method for Analysis of 2,6-Ditertiary-Butyl Para-Cresol and 2,6-Dietertiary-Butyl Phenol in Insulating Liquids by Gas Chromatography.

ASTM D5837, Standard Test Method for Furanic Compounds in Electrical Insulating Liquids by High-Performance Liquid Chromatography (HPLC).

IEEE Std 62™, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power Transformers, Regulators, and Reactors.[3,4]

[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

IEEE Std 637™, IEEE Guide for the Reclamation of Insulating Oil and Criteria for its Use.

IEEE Std 980™, IEEE Guide for Containment and Control of Oil Spills in Substations.

IEEE Std C37.010™, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C57.93™, IEEE Guide for Installation of Liquid-Immersed Power Transformers.

IEEE Std C57.104™, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers (withdrawn).[5]

IEEE Std C57.121™, IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers.

IEEE Std C57.131™, IEEE Standard Requirements for Load Tap Changers.

Title 40 Code of Federal Regulations (CFR), Part 110, Discharge of Oil.[6]

Title 40 CFR, Part 112, Oil Pollution Prevention.

Title 40 CFR, Part 112.7, General Requirements for Spill Prevention, Control, and Counter Measure Plans.

Title 40 CFR, Part 761, Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions.

3. Definitions

For the purposes of this guide, the following terms and definitions apply. The *Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B3],[7] should be referenced for terms not defined in this clause.

The various tests conducted on the insulating oil are defined and described in Clause 5.

3.1 reclamation of oil: The restoration of usefulness by the removal of contaminants and products of degra¬dation such as polar, acidic, or colloidal materials from used electrical insulating liquids by chemical or adsorbent means such as Fuller’s earth.

3.2 reconditioning of oil: The removal of insoluble contaminants, moisture, and dissolved gases from used, electrical insulating liquids by mechanical means, such as vacuum processing or filtering.

[4] The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.
[5] IEEE Std C57.104 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).
[6] CFR publications are available from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA (http://www.access.gpo.gov/).
[7] The numbers in brackets correspond to those in the bibliography in Annex A.

4. Evaluation of mineral insulating oil

4.1 General

This guide uses several different terms to identify insulating oil of a petroleum origin, for example, as defined in ASTM D3487. The terms *mineral insulating oil*, *liquid*, and *dielectric fluid* are all equivalent to *insulating oil* in the context of this guide.

4.2 New oil properties

New mineral insulating oils as delivered must conform to the property requirements listed in ASTM D3487. Newly supplied oils have many characteristics related to their chemical and molecular structure that are directly measured by test methods such as viscosity, flash and fire points, pour point, aniline point, relative density (specific gravity), oxidation stability, gassing tendency, and dielectric strength.

Many characteristics not necessarily related to the functional performance of mineral insulating oils are evaluated because of their sensitivity to the presence of harmful contaminants. The following characteristics are sensitive to contamination in the oil: interfacial tension, dissipation factor (power factor), dielectric breakdown voltage, color, water content, and neutralization number (acidity).

4.2.1 New oil properties—as supplied

New mineral insulating oils as supplied must have properties so that new oils meet the standard specification of ASTM D3487 and Clause 5 of this guide when received, prior to any processing.

4.2.2 Test limits: new oil properties—as received from the supplier

When mineral insulating oil specified to conform to ASTM D3487 is received, it should be tested to verify conformance with ASTM D3487. Testing of the oil for full conformance of all property requirements of ASTM D3487 is only justified under circumstances determined by the purchaser. As a minimum, it is recommended that the purchaser require the supplier to provide a certified set of tests for the oil that demonstrate that the oil, as shipped, met or exceeded the property requirements of ASTM D3487. For those circumstances where a full set of tests according to ASTM D3487 are not justified, it is recommended that, at a minimum, the tests shown in Table 1 of this guide be considered. The purchaser of the oil should conduct tests sufficient to satisfy concerns regarding conditions of shipment that might result in nonconformance to ASTM D3487 property requirements. Table 1 lists several of the more important tests with values that should help in the decision regarding acceptance of the new mineral insulating oil.

Insulating oil is ordinarily shipped in three types of containers: drums or totes, tank trailers, and rail cars. Rail cars are usually under the control of the supplier and dedicated to insulating oil shipment, so they tend to be the cleanest. Highway trailers are used to transport many different chemical products as well as insulating oil; these trailers are therefore subject to chemical contamination. Special cleaning and drying procedures may be necessary. If problems are encountered, check the history of the shipping containers to see that they have been cared for properly. It is recommended that the purchaser require the delivery of oil in containers that are properly cleaned to guarantee delivery of oil conforming to ASTM D3487.

Drums and totes are the least desirable method of insulating oil transport but may be necessary for small purchases. Drums and totes should be stored under cover to prevent contamination by moisture. Before processing, it is necessary to check the quality of the oil in each drum or tote or after blending the oil in a large tank. Each tank load or each shipping unit of oil as received at the customer's site should undergo a check test to determine that the electrical characteristics have not been impaired during transit or storage. Table 1 contains a list of recommended acceptance tests for shipments of mineral insulating oil as received from the supplier. Some users may not wish to perform all these tests; however, as a minimum, dielectric strength and dissipation factor (power factor) as listed in Table 1 should be performed. It is satisfactory to accept oils that exhibit characteristics other than those described by the values in Table 1, providing that the users and the suppliers are in agreement.

Table 1—Test limits for shipments of new mineral insulating oil as received from the supplier

Test and method	Limit value
Dielectric strength ASTM D1816 kV minimum 1 mm gap[b] 2 mm gap[b]	 20 35
Dissipation factor (power factor) ASTM D924 25 ºC, % maximum 100 °C, % maximum	 0.05 0.30
Interfacial tension ASTM D971 mN/m minimum	 40
Color ASTM D1500 ASTM units maximum	 0.5
Visual examination ASTM D1524	 Bright and clear
Neutralization number (acidity) ASTM D974 mg KOH/g maximum	 0.015[c]
Water content ASTM D1533 mg/kg maximum[d]	 25[c]
Oxidation inhibitor content when specified ASTM D2668 Type I oil, % maximum Type I oil, % minimum Type II oil, % maximum Type II oil, % minimum	 0.08 0.0 0.3 >0.08
Corrosive sulfur ASTM D1275	 Not corrosive
Relative density (specific gravity) ASTM D1298 15 °C/15 °C maximum	 0.91

[a] Oil dielectric testing in accordance with ASTM D877 has been replaced by ASTM D1816 in Table 1. See 5.2.1.
[b] Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[c] This value is more stringent than the ASTM D3487 requirement.
[d] Equivalent measurement is parts per million (ppm).

4.3 New oil properties—oil received in new equipment rated less than 230 kV

Mineral insulating oil that has been shipped in new equipment from the manufacturing plant may be evaluated by obtaining a sample from the equipment at the job site. Note that the new oil characteristics will have changed. The oil may have been filtered and dried at the factory. The more sensitive dielectric breakdown test, ASTM Dl816, is a recommended test. Properties, such as interfacial tension (IFT), dielectric strength, and dissipation factor, which are sensitive to certain dissolved or particulate contaminants, will reflect the exposure to normal equipment construction materials. Recommended test limits for mineral insulating oil received in new equipment rated less than 230 kV prior to energization are given in Table 2. Table 2 allows for change due to oil contacting transformer materials.

Table 2—Test limits for new mineral insulating oil received in new equipment, below 230 kV, prior to energization

Test and method	Value for voltage class	
	≤69 kV	>69 – <230 kV
Dielectric strength,[a] ASTM D1816, kV minimum 1 mm gap[b] 2 mm gap[b]	 25 45	 30 52
Dissipation factor (power factor) ASTM D924 25 °C, % maximum 100 °C, % maximum	 0.05 0.40	 0.05 0.40
Interfacial tension, ASTM D971 mN/m minimum	38	38
Color, ASTM D1500, ASTM units maximum	1.0	1.0
Visual examination, ASTM D1524	Bright and clear	Bright and clear
Neutralization number (acidity), ASTM D974, mg KOH/g maximum	0.015[c]	0.015[c]
Water content, ASTM D1533, mg/kg maximum[d]	20	10
Oxidation inhibitor content when specified ASTM D2668 Type I oil, % maximum Type I oil, % minimum Type II oil, % maximum Type II oil, % minimum	 - - 0.3 >0.08	 0.08 0.0 0.3 >0.08

[a]Oil dielectric testing in accordance with ASTM D877 has been replaced by ASTM D1816 in Table 2. See 5.2.1.
[b]Alternative measurements of 1.0 mm (0.04 in.) and 2.0 mm (0.08 in.), respectively, for gaps.
[c]This value is more stringent than the ASTM D3487 requirement.
[d]Equivalent measurement is parts per million (ppm). From a dielectric strength point of view the moisture in oil limits given could be excessive at low temperatures due to high moisture in oil percent saturation levels. See 4.5.

4.4 New oil properties—after filling into new equipment rated at 230 kV or higher

Prior to filling equipment rated 230 kV and above with mineral insulating oil at the installation site, manufacturers generally require rigorous processing of the oil to remove all moisture, particulate matter, and gas that dissolved during shipment. The object is to fill high-voltage equipment with oil that contains the very least amount of particulate (see also IEEE Std 62) material and water, recognizing that a slight reduction in quality due to contact with the equipment insulation and other materials will occur. In this procedure, oil samples are taken after the oil enters into the electrical equipment.

When mineral insulating oil is received in bulk shipping containers, it is processed according to the instructions of the manufacturer and then introduced into the equipment. Table 3 contains test limits that ensure that the insulating oil, in equipment after the processing and standing time before energization, is dry, contains no excess particulate matter, and contains a minimum amount of dissolved gas.

Table 3—Test limits for new mineral insulating oil processed for equipment, 230 kV class and above, prior to energization

Test and method	Value for voltage class	
	≥230 kV – <345 kV	345 kV and above
Dielectric strength ASTM D1816 kV minimum 1 mm gap[a] 2 mm gap[a]	 32 55	 35 60
Dissipation factor (power factor) ASTM D924 25 °C, % maximum 100 °C, % maximum	 0.05 0.30	 0.05 0.30
Interfacial tension ASTM D971 mN/m minimum	 38	 38
Color ASTM D1500 ASTM units maximum	 1.0	 0.5
Visual examination ASTM D1524	Bright and clear	Bright and clear
Neutralization number (acidity) ASTM D974 mg KOH/g maximum	 0.015[b]	 0.015[b]
Water content ASTM D1533 mg/kg maximum[d]	 10	 10
Total dissolved gas ASTM D2945	0.5% or per manufacturer's requirements[c]	0.5% or per manufacturer's requirements[c]

[a] Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[b] This value is more stringent than the ASTM D3487 requirement.
[c] This value should be obtained from a sample collected 24 h to 48 h after the transformer is filled and applies only to transformers with diaphragm conservator systems.
[d] Equivalent measurement is parts per million (ppm.) From a dielectric strength point of view the moisture in oil limits given could be excessive at low temperatures due to high moisture in oil percent saturation levels. See 4.5.

4.5 Water in oil versus water in paper insulation and thermodynamic equilibrium

Equilibrium curves predict that moisture will be transported between the paper and the oil in a transformer. With increasing temperature, the moisture in oil goes up, and with decreasing temperature, it goes down. However, for the reasons given below, it is not recommended that these curves be used to determine moisture in paper levels in an operating transformer. Since the publication of moisture equilibrium curves for paper-oil systems (Bruce et al. [B1], Oommen [B5]) cautions have been issued to *not* use these curves to determine the dryness level of the solid insulation in an operating transformer (Oommen [B6]). One estimate of error is placed at ±200% (Ward et al. [B8]). It is important to note that these equilibrium curves are based on thermodynamic equilibrium and are not intended to correlate water concentrations in oil to water in paper concentrations for operating transformers. This result is due to (1) changing electrical loads, (2) changing ambient temperatures, (3) temperature gradients within a transformer (even with constant load and ambient temperatures), and (4) the relatively slow diffusion of moisture in the paper/pressboard.

As a result, the thermodynamic "states" (temperatures and moisture concentrations) of the operating transformer are too far from equilibrium. For example, a computation of diffusion time constants at various temperatures and moisture levels in 0.635 sm (0.25 in) thick pressboard (Thompson [B7]) shows that the time constants are in weeks not hours, which means that the actual measured moisture changes will not reach 70% of the total changes at equilibrium for weeks.

Even when a power transformer undergoes a constant load and ambient temperature for a relatively long time compared with the diffusion times, there are temperature gradients within the transformer. Again thermodynamic equilibrium, required for the use of these curves, is not achieved. In fact, the moisture equilibrium curves predict that the temperature gradients will result in a relatively wide range of moisture levels in the paper at various locations within the transformer paper due to moisture migration. Even though various constructed equilibrium curves may vary due to different solubilities of moisture in oil, they probably will all predict that the paper at the highest temperatures will contain significantly less moisture than the paper with the lowest temperatures within the same transformer.

With regard to oil moisture levels, solubility equations have been used to assess the solubility limit of moisture in oil. The solubility limit is the maximum amount of moisture that is soluble in the oil at a specific temperature. It is also referred to as the moisture in oil saturation limit or simply 100% saturation and is determined when the calculation of the percent saturation equals 100%. The equation is [(mg/kg water in oil)/(mg/kg of water in oil at saturation)] × 100.

WARNING

Once the moisture in oil reaches the solubility limit (or 100% saturation), free water droplets will form, which adversely affects the dielectric strength of the oil and may result in transformer failure.

In addition, from a dielectric strength point of view, reduced oil temperatures in a deenergized transformer could increase the moisture in oil percent saturation level enough to significantly reduce the dielectric breakdown strength of the oil, even at percent saturation levels below 100%. Consequently when energizing a new transformer or reenergizing any transformer during cold weather, caution should be taken so that the dielectric breakdown strength of the oil, which is referenced to the actual temperature of the oil in the deenergized transformer, is sufficient for service. Equations for moisture percent saturation values at various temperatures and for various oils are found in the following references: Bruce et al. [B1] and Du et al. [B2]. These references indicate that the moisture solubility can vary somewhat between new oil types as well as between a new and service aged oil.

In summary, as the changing electrical loads and ambient temperatures contribute significant temperature changes throughout a transformer, then the moisture levels in both the paper and the oil then move toward new thermodynamic equilibrium values. Consequently, the moisture values are too far from equilibrium to use these curves. Although the estimation of moisture in paper is beyond the scope of this guide, commercial methods are currently available regarding on-line modeling systems (using computer models and temperature probes) to model moisture in paper in various temperature zones within a transformer. The most direct method of estimating the moisture in paper is an off-line solid insulation test method.

4.6 Mixtures of mineral insulating oil

Although conventional mineral oils from different suppliers may differ in their characteristics, these oils, as well as blends of these oils, should all meet the specifications of ASTM D3487.

Although mineral insulating oil is miscible with some types of less flammable and nonflammable dielectric liquids, it is advisable to use dedicated processing and handling systems for each type of fluid to avoid even traces of cross-contamination, particularly even trace contamination between petroleum-based and non-petroleum-based fluids.

Mixtures of less-flammable (see IEEE Std C57.121) or nonflammable dielectric fluids with conventional mineral insulating oil will alter the flammability characteristics of the less-flammable fluid. Differences in the dielectric constant of the fluids may cause localized voltage stresses in equipment. It is undesirable to mix different types of dielectric fluids.

4.7 Sampling

Accurate sampling methods are extremely important due to their effect on the reliability of the test results for the sampled oil. Careless sampling procedures will result in contamination of the sample, which will lead to erroneous conclusions concerning the quality of the oil. To minimize the possibility of obtaining a nonrepresentative sample, the procedures and precautions outlined in the latest revision of ASTM D923 and/or ASTM D3613 should be followed.

WARNING

Caution should be taken when extracting an oil sample from energized equipment. Taking samples from equipment under negative pressure (vacuum) may cause an air bubble to be drawn into the tank. If this occurs, it can cause catastrophic failure and death.

5. Oil tests and their significance

Many established ASTM tests of practical significance can be applied to insulating oil. Some of these tests are more applicable to new oils than to service-aged oils; some are more useful in the analysis of service-aged oils than oils received in new condition, particularly trace contamination between petroleum-based and non-petroleum-based fluids.

Each of the tests and its significance are described in the subclauses of this guide, as listed in Table 4. The number after the name of the test is the number of the ASTM standard/method.

Table 4—Pertinent ASTM tests for mineral insulating oil

Subclause	Test	ASTM standard/method
5.1 Physical tests		
5.1.1	Aniline point	ASTM D611
5.1.2	Color	ASTM D1500
5.1.3	Flash and fire points	ASTM D92
5.1.4	Interfacial tension	ASTM D971 ASTM D2285
5.1.5	Pour point	ASTM D97
5.1.6	Relative density (specific gravity)	ASTM D1298
5.1.7	Viscosity	ASTM D88 ASTM D445 ASTM D2161
5.1.8	Visual examination	ASTM D1524
5.2 Electrical tests		
5.2.1	Dielectric breakdown voltage	ASTM D877 ASTM D1816
5.2.2	Dielectric breakdown impulse voltage	ASTM D3300
5.2.3	Dissipation factor (power factor)	ASTM D924
5.2.4	Gassing of insulating oils under electrical stress and ionization	ASTM D2300
5.3 Chemical tests		
5.3.1	Gas content	ASTM D2945 ASTM D3284 ASTM D3612
5.3.2	Polychlorinated biphenyls	ASTM D4059
5.3.3	Corrosive sulfur	ASTM D1275
5.3.4	Neutralization number (acidity)	ASTM D664 ASTM D974
5.3.5	Oxidation inhibitor content	ASTM D2668 ASTM D4768
5.3.6	Oxidation stability (inhibited oil only, Pressure Vessel) Oxidation stability	ASTM D2112 ASTM D2440
5.3.7	Water in insulating liquids	ASTM D1533
5.3.8	Furans in insulating liquids	ASTM D5837

5.1 Physical tests

5.1.1 Aniline point—ASTM D611

The aniline point (temperature) of a mineral insulating oil indicates the solvency of the oil for some materials that are in contact with the oil. A high aniline point indicates a lower degree of aromaticity and a lower solvency for some material (rubber, for example).

5.1.2 Color—ASTM D1500

Insulating oil should have a light color and be optically clear so that it permits visual inspection of the assembled apparatus inside the equipment tank. Any change in the color of an oil over time is an indication of deterioration or contamination of the oil.

5.1.3 Flash and fire points—ASTM D92

The flash point of an oil is the temperature to which the material must be heated (under prescribed conditions of test) in order to give off sufficient vapor to form a flammable mixture with air. The fire point is the temperature that provides sufficient oil vapors to ignite and sustain a fire for 5 s (under the same test conditions). A low flash point indicates the presence of volatile combustible contaminants in the insulating oil.

5.1.4 Interfacial tension—ASTM D971 and ASTM D2285

This method covers the measurement, under nonequilibrium conditions, of the surface tension that an insulating fluid maintains against water. Interfacial tension is a measurement of the forces of attraction between molecules of the two fluids. It is expressed in milli-Newtons per meter (mN/m). The test is an excellent means of detecting oil-soluble polar contaminants and oxidation products in insulating oils.

5.1.5 Pour point—ASTM D97

The pour point is the temperature at which oil ceases to flow under prescribed testing conditions. The pour point has little significance as a test for contamination or deterioration of the oil. It may be useful for oil identification and determination of suitability for a particular climate.

5.1.6 Relative density (specific gravity)—ASTM D1298

The relative density of oil is the ratio of the weights of equal volumes of the oil and water, tested at 15 °C. The relative density is significant in determining the suitability for use in certain applications; in cold climates, ice may form in equipment exposed to temperatures below freezing. When considered along with other oil properties, relative density can be an indicator of the quality of the oil.

5.1.7 Viscosity—ASTM D88, ASTM D445, and ASTM D2161

The viscosity of insulating oil is measured by timing the flow of a known volume of oil through a calibrated tube. Viscosity is not significantly affected by oil contamination or deterioration, but it may be useful for identifying certain types of service-aged insulating oils. Viscosity has an important influence on the heat transfer characteristics of oil. High viscosity decreases the cooling efficiency of the oil. High viscosity will also affect the movement of parts in electrical equipment, such as circuit breakers, switchgear, tap changers, pumps, and regulators. Viscosity is a factor in determining the conditions for oil processing and cellulose impregnation time.

5.1.8 Visual examination—ASTM D1524

This test indicates the color and degree of turbidity of oil, which may indicate the presence of free water or contaminating solid particles. The source of insoluble solid contaminants may be determined by filtrating the particles and examining them. This test may be used to suggest the need for additional laboratory tests, as it may permit a determination of whether the sample should be sent to a central laboratory for a full evaluation.

5.2 Electrical tests

5.2.1 Dielectric breakdown voltage—ASTM D877 and ASTM D1816

The dielectric breakdown voltage of insulating oil is a measure of its ability to withstand voltage stress without failure. It is the voltage at which breakdown occurs between two electrodes under prescribed test conditions. The test serves primarily to indicate the presence of electrically conductive contaminants in the oil, such as water, dirt, moist cellulosic fibers, or particulate matter. A high dielectric breakdown voltage does not indicate the absence of all contaminants, however.

The electrodes described in ASTM D877 are thin flat disks, which are not representative of the electrodes in transformers. Although the rounded electrodes described in ASTM D1816 do not duplicate the characteristics of insulated electrodes in transformers, they more closely approximate transformer applications. However, the electrodes described in ASTM D1816 are more responsive to particles and dissolved water in oil, both of which are detrimental to the electrical strength of oil in transformers. Therefore, test results in ASTM D1816 furnish a better evaluation of changes that may occur in the oil from transformers.

Two methods are recognized for measuring the dielectric breakdown voltage of insulating oils, as follows:

a) ASTM D877 is recommended for the routine acceptance of new, unprocessed oil from a supplier for use in circuit breakers. This test method uses thin flat-faced cylindrical electrodes with a 2.5 mm gap. The sensitivity of this method, to the general population of contaminates present in a liquid sample, decreases as applied test voltages used in this method become greater than 25 kV rms.

b) ASTM D18l6 is recommended for testing fluid that is being processed into transformers or contained in transformers and load tap changers. This method uses spherically shaped electrodes. The fluid sample is circulated continuously in the test cell throughout the test. The gap distance standard settings are 1 mm and 2 mm.

5.2.2 Dielectric breakdown impulse voltage—ASTM D3300

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.

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

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

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 standard lightning impulse test described in IEEE Std C57.12.90™-1999 [B4] specifies a 1.2 × 50 µs negative polarity wave.

5.2.3 Dissipation factor (power factor)—ASTM D924

The dissipation factor is a measure of the power lost when an electrical insulating liquid is subjected to an ac field. The power is dissipated as heat within the fluid. A low-value dissipation factor means that the fluid will cause little of the applied power to be lost. The test is used as a check on the deterioration and contamination of insulating oil because of its sensitivity to ionic contaminants.

5.2.4 Gassing of insulating oils under electrical stress and ionization—ASTM D2300

This test measures whether insulating oils are gas absorbing or gas evolving when subjected to electrical voltage. For certain applications, when insulating oils are stressed at high voltage gradients, it is desirable to know the rate at which gas is absorbed or evolved from the oil. The absorption or evolution of gas by a liquid under electrical stress is a function of the aromatic character of the liquid molecules. Liquids that are significantly aromatic in character will absorb gas as they are electrically stressed. Liquids that have little or no aromatic character will evolve hydrogen gas upon application of an electrical voltage. Currently, however, correlation of these test results with equipment performance is limited. Numerical results obtained in different laboratories or by using two different procedures may differ significantly in magnitude, and the results of this method should be considered qualitative in nature.

5.3 Chemical tests

5.3.1 Gas content—ASTM D2945, ASTM D3284, and ASTM D3612

The gas content of an insulating fluid may be defined as the volume of dissolved gas per 100 volumes of oil, at standard pressure and temperature. Some types of equipment require the use of electrical insulating liquids of low gas content. In filling electrical apparatus, a low gas content reduces foaming and reduces the available oxygen, thereby increasing the service life of the insulating oil.

The amount and kind of gases dissolved in oil can be used as a tool to aid in detecting and diagnosing faults and abnormal operating conditions in equipment.

The test is not intended for use in purchase specifications because the oil is customarily degassed immediately prior to use. The test can be used, however, as a factory control test and is more useful in evaluating the health of the transformer equipment. Overheating or arcing within the transformer will generate combustible and noncombustible gasses that will be dissolved in the oil. For dissolved gas analysis, reference IEEE Std C57.104 for more recommendations.

5.3.2 Polychlorinated biphenyls (PCBs)—ASTM D4059

U.S. regulations require that electrical apparatus and electrical insulating fluids containing polychlorinated biphenyls (PCBs) be handled and disposed of through the use of specific procedures. The procedure to be used for a particular apparatus or quantity of insulating fluid is determined by the PCB content of the fluid. The results of this analytical technique can be useful in selecting the appropriate handling and disposal procedures; refer to Title 40 CFR, Part 761.

5.3.3 Corrosive sulfur—ASTM D1275

This test is designed to detect the presence of free sulfur and combined corrosive sulfur by how the liquid affects polished copper strips in prescribed conditions. The test indicates the possibility of corrosion inside of electrical equipment resulting from the presence of sulfur-containing compounds. The source of sulfur present in insulating oil is usually the crude oil from which it is refined. The sulfur may come from rubber hoses used for oil processing or from replacement gasket materials.

5.3.4 Neutralization number (acidity)—ASTM D664 and ASTM D974

The neutralization number of an electrical insulating liquid is a measure of the acidic components of that material. In new oil, any acid present is likely residual from the refining process. In a service-aged liquid, the neutralization number is a measure of the acidic by-products of the oxidation of an oil. The neutralization number may be used as a general guide for determining when oil should be reprocessed or replaced. ASTM D974 is the traditional color-change indicator method of titrating the acids with a mild (0.1 N) KOH solution. ASTM D664 is a potentiometric titration method. On some service-aged liquids, the color may be so dark as to impair the ability of the technician to determine the indicator color change in ASTM D974, so ASTM D664 is used instead. The correlation between these two methods, however, has not been established.

5.3.5 Oxidation inhibitor content—ASTM D2668 by infrared spectrophotometry and ASTM D4768 by gas chromatography

Two synthetic oxidation inhibitors are commonly used in dielectric fluids. They are 2-6 ditertiary-butyl phenol (DBP) and 2-6 ditertiary-butyl para-cresol (DBPC). Their use provides added resistance to oxidation in systems that are partially or wholly exposed to air. The effectiveness of the oxidation inhibitor depends a great deal on the type of crude oil from which the insulating oil came. Certain new oils may contain naturally occurring antioxidant substances that may yield a false-positive indication in this test.

5.3.6 Oxidation stability, inhibited only (pressure vessel)—ASTM D2112 and ASTM D2440

Oxidation stability—ASTM D2112: This test method is a rapid test for evaluating the oxidation stability of a new mineral insulating oil that contains the synthetic oxidation inhibitor 2-6 DBPC or 2-6 DBP. The test measures the length of time required for the oil sample to react with a given volume of oxygen when a sample of oil is heated and oxidized under test conditions.

Oxidation stability—ASTM D2440: This test method determines the resistance of mineral insulating oils to oxidation under prescribed accelerated aging conditions. Oxidation stability is measured by the propensity of oils to form sludge and acid products during oxidation. This test method is applicable to new oils, both inhibited and uninhibited.

5.3.7 Water in insulating liquids: Karl Fischer method—ASTM D1533

Water may be present in insulating liquids in several forms. The presence of free water may be indicated by visual examination. The oil will appear cloudy, or separated water drops will be observed, probably on the bottom surface. The presence of free water can be remedied by filtration or other means. Dissolved water cannot be detected visually and is normally quantified by physical or chemical means. Dissolved water may affect the dielectric breakdown of insulating oil; however, its significance is determined by several factors, including the percent of moisture saturation and the amount and type of contaminants. The method cited is suitable for the determination of water in insulating oil, and depending on the conditions of sample handling and the methods of analysis, it can be used to estimate total water as well as dissolved water in insulating oil. The units of measure of water are milligram/kilogram. New insulating oil received from the manufacturer normally contains less than 25 mg/kg moisture. New insulating oil should be tested for moisture content. If necessary, applicable measures should be taken to avoid introducing high moisture-content oil into electrical equipment.

5.3.8 Furans in insulating liquids—ASTM D5837

Furanic compounds are generated by the degradation of cellulosic materials used in the solid insulation systems of electrical equipment. Furanic compounds that are oil soluble to an appreciable degree will migrate into the insulating liquid. The presence of high concentrations of furanic compounds is significant in that this may be an indication of cellulose degradation from aging or incipient fault conditions. Testing for furanic compounds by high-performance liquid chromatography (HPLC) may be used to complement dissolved gas in oil analysis as performed in accordance with the test method in ASTM D3612.

6. Handling and storage

It is not intended that the recommendations given in this guide supersede U.S. federal or local regulations concerning storage, handling, or spill cleanup of insulating liquids.

6.1 Tanks

Direct transfer of the oil from on-site delivery containers into equipment, although recommended, is not always practical if the oil being delivered is to be tested before transfer into the equipment. It may be necessary, therefore, to store the oil in storage tanks temporarily. In these instances, all tanks should conform to applicable federal and local standards and codes. Tanks should be equipped with at least one manhole. The interior of the tanks should be sandblasted, primed, and coated with a coating that is compatible with insulating fluids. Storage tanks should be equipped with drains situated to allow complete emptying of the tank and with either a desiccant breather or a dry gas blanket. Such tanks are often coated internally to prevent rust. Before use, storage tanks should be thoroughly cleaned, wiped dry with clean rags, and flushed with clean insulating oil.

Collapsible or rubber fabric tanks may be used for short-time storage. Care should be taken to ensure that they are cleaned and thoroughly drained before filling with insulating oil. It is recommended that insulating oil not be held for more than three months in temporary storage tanks. Where that is unavoidable, tanks should be equipped with a dry inert (nitrogen) gas system with which to blanket the oil.

6.2 Oil quality protection in storage

All storage tanks should be equipped with a dry nitrogen gas supply or a desiccant vent dryer to minimize the introduction of moisture into the tank. Proper maintenance of the desiccant is essential.

The desiccant should be protected from outside contaminants and entry into the transformer. Filtration of the incoming air will prevent introduction of airborne particulate materials into the fluid during storage.

6.3 Dikes and curbs

Tanks for storage of insulating oil may be surrounded by dikes or curbs sufficient to contain the entire volume of oil in the tank should a spill occur. Refer to Title 40 CFR, Part 112.7, for general requirements for spill prevention, control and countermeasure plans (SPCC plans).

6.4 Processing oil for installation in apparatus

See IEEE Std C57.93. Processing systems consist of oil dehydration, degasifying, and filtration. The user should be advised that static charges can develop when insulating oil flows in pipes, hoses, and tanks. Oil leaving a filter press may be charged to a high potential. To accelerate dissipation of the charge in the oil, ground and bond together the filter press, the piping, the equipment tank, and all bushings or the winding leads during oil flow into any tank. Conduction through oil is slow; therefore, it is desirable to maintain these grounds for at least an hour after the oil flow has been stopped. Remove any explosive gas mixture from any container into which oil is flowing. Arcs can occur from the free surface of the oil even though the previous grounding precautions have been taken.

Equipment used for handling mineral insulating oils should be dedicated for that use, as these oils are very sensitive to contamination. Although mineral insulating oils may be miscible with other types of dielectric fluids, it is advisable to use dedicated processing and handling systems for each different type of fluid. See 4.5.

Before filling the electrical apparatus, a vacuum may be drawn on its tank. All insulating oil transfer lines should be flushed through with clean, processed oil. During the filling operations, flow rates should be controlled to the value specified by the manufacturer. The vacuum held on the tank should not exceed the design strength specified by the manufacturer.

The filling process may be varied to suit the capabilities of the equipment used and the recommendations of the manufacturer. Filling procedures used should comply with those that are recommended by the fluid and the equipment manufacturers in order to maintain eligibility of the equipment warranty.

7. Classification of service-aged insulating oil

7.1 General

This subject is treated in greater detail in IEEE Std 637. It is not practical to indicate the value of specific tests and recommended test limits for all possible existing applications of insulating oil in service. It should be recognized that, with the current state of knowledge, no single test can be used as the sole criterion to estimate the condition of service-aged oil. It is, possible, however, to summarize the value and importance of the current tests and to suggest methods of treatment for the oil being examined. Oils in service may be placed in the classifications described in 7.2.1 through 7.2.3, based on the composite evaluation of significant characteristics.

7.2 Classification

7.2.1 Class I

This group contains oils that are in satisfactory condition for continued use.

Suggested test limits by voltage class for Class I oils in electrical equipment to remain in continued service are given in Table 5. It is not intended that an oil be removed from service when a single property limit is exceeded or that the oil be left in service until all property values are outside the stated limits. It is difficult to quantify the risk of failure while in service with particular test values. The limits from Table 5 are intended to provide reference points for continued evaluation and testing. Each case should be examined individually, and the advice of the manufacturer may be considered.

7.2.2 Class II

This group contains oils that do not meet the dielectric strength and/or water content requirements of Table 5 and should be reconditioned by filter pressing or vacuum dehydration (see 4.5).

Table 5—Suggested limits for continued use of service-aged insulating oil

Test and method	**Value for voltage class**		
	≤69 kV	**>69 – <230 kV**	**230 kV and above**
Dielectric strength ASTM D1816 kV minimum 1 mm gap[a, c] 2 mm gap[a, c]	23 40	28 47	30 50
Dissipation factor (power factor) ASTM D924 25 º C, % maximum[c] 100 º C, % maximum[c]	0.5 5.0	0.5 5.0	0.5 5.0
Interfacial tension ASTM D971 mN/m minimum[c]	25	30	32
Neutralization number (acidity) ASTM D974 mg KOH/g maximum[c]	0.20	0.15	0.10
Water content ASTM D1533 mg/kg maximum (ppm)[b, c]	35	25	20
Oxidation inhibitor content ASTM D2668 Type II oil[c]	0.09% minimum, if in original oil.		

[a]Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[b]The ppm moisture values shown are based on consensus, which are also given in IEEE Std 637. These values should not be used to infer solid insulation dryness or dielectric integrity. The moisture in oil at a given time cannot be related to insulation moisture caused by nonequilibrium conditions. From a dielectric strength point of view, the moisture in oil limits given could be excessive at low temperatures because of high moisture in oil percent saturation levels. See 4.5. However, in operating units, the same moisture in oil levels might represent low moisture in oil percent saturation levels caused by increased oil temperatures.
[c]Any significant changes from previous test data should be investigated.

7.2.3 Class III

This group contains oils in poor condition that should be reclaimed using Fuller's earth or an equivalent method.

Oils that do not meet the interfacial tension (IFT), dissipation factor, and neutralization number limits provided in Table 5 should be reclaimed. Oils should not be allowed to deteriorate such that the IFT is below

18, or to a point where oxidation inhibitor content is depleted. Under such conditions, considerably greater effort (i.e., more passes of treatment) is required.

For information and advice concerning the different techniques of reconditioning and reclaiming service-aged mineral insulating oils, refer to IEEE Std 637. Reconditioning or reclamation of mineral oils containing PCBs can be a violation of environmental regulations.

8. Insulating oil for circuit breakers

8.1 General

The requirements of insulating oil used in circuit breakers, as distinguished from insulating oil used in transformers, are uniquely different. Modern oil circuit breakers require low viscosity and low pour-point oil because a large percentage of them are used outdoors and, in many cases, at low temperatures. It should be noted that all circuit breakers are "free breathing" (open to the atmosphere through a breathing device). This does not prevent the admittance of humid air to the device. In the case of older oil circuit breakers where the use of higher viscosity oil is deemed necessary, caution and judgment must be exercised. The resultant effects of oil mixing and the addition of oxidation inhibitors upon thermal characteristics must be considered.

Reconditioning of circuit breaker oil is conducted in the same manner as transformer oil. The presence of dissolved heat and arc by-products is a significant problem in circuit breakers. In most transformers these products should not be present. Oil circuit breakers are usually designed with higher dielectric margins and thermal capacities compared with a transformer. In oil circuit breakers, by-products are created when the circuit breaker operates. These by-products, combining with moisture and oxygen in the breaker oil, will contribute to reduced dielectric strength in the circuit breaker. The accumulation of these substances results in the need for cleaning the breaker and reconditioning of the oil. For guidance in the application of circuit breakers, see IEEE Std C37.010.

8.2 Testing

Testing methods for circuit breaker oils are the same as those used for insulating oils. Samples are taken in the same manner as for insulating oil, at specified intervals, varying from a few months to annually. Some of the established ASTM tests applicable to mineral insulating oils are more significant to transformers than to circuit breakers, because a circuit breaker is essentially a free-breathing device that operates at ambient temperature.

8.2.1 New oil properties—as refined

New mineral insulating oils as received from the supplier must conform to certain qualifying functional requirements listed in ASTM D3487.

8.2.2 Test limits—shipments of new mineral insulating oil

When mineral insulating oil meeting the property requirements of ASTM D3487 is received in the field for installation in circuit breakers, it should be checked for certain key values that may be affected by shipment and storage. These values are shown in Table 6. Some users may wish to perform additional tests outlined in ASTM D3487; however, as a minimum, the tests listed in Table 6 should be performed.

Viscosity [12 cSt (12 mm^2/s) maximum at 40 °C—see ASTM D445] and pour point (–40 °C, maximum—see ASTM D97) should be checked in cold climates to ensure that the oil does not interfere with the free operation of the equipment.

Table 6—Test limits for shipments of new mineral insulating oil for circuit breakers

Test and method	Suggested limit
Dielectric strength ASTM D1816[a] kV minimum 1 mm, gap[b] 2 mm, gap[b]	 20 35
Dissipation factor (power factor) ASTM D924 25 °C, % maximum 100 °C, % maximum	 0.05 0.30
Interfacial tension ASTM D971 mN/m minimum	 40
Color ASTM D1500 ASTM units maximum	 0.5
Visual examination ASTM D1524	 Bright and clear
Neutralization number (acidity) ASTM D974 mg KOH/g maximum	 0.015
Water content ASTM Dl533 mg/kg maximum[c]	 25 [d]

[a] Oil dielectric testing in accordance with ASTM D877 has been replaced by ASTM D1816 in this table. See 5.2.1.
[b] Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[c] Equivalent measurement is parts per million (ppm).
[d] The value of water content is more stringent than the requirement specified in ASTM D3487.

8.2.3 New oil properties—oil shipped in new equipment

Oil circuit breakers are normally shipped from the factory without oil in the tank(s). New oil is processed on-site, and the equipment is filled with the oil. In cases such as these, refer to Table 7.

8.2.4 New oil properties—prior to energizing

When mineral insulating oil is received in bulk shipping containers, it is processed according to the instructions of the manufacturer and then introduced into the equipment. Table 7 gives test limits for mineral circuit breaker insulating oil after being processed, placed in equipment, and allowing for standing times before energizing.

Table 7—Test limits—new circuit breaker insulating oil after

Test and method	Suggested limit
Dielectric strength ASTM D1816 kV minimum 1 mm, gap[a] 2 mm, gap[a]	 30 60
Dissipation factor (power factor) ASTM D924 25 °C, % maximum	 0.10
Interfacial tension ASTM D971 mN/m minimum	 35
Color ASTM D1500 ASTM units maximum	 0.5
Visual examination ASTM D1524	 Bright and clear
Neutralization number (acidity) ASTM D974 mg KOH/g maximum	 0.015
Water content ASTM Dl533, mg/kg maximum[b]	 20

[a] Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[b] Equivalent measurement is parts per million (ppm).

8.2.5 Service-aged oil properties

Suggested limits for continued use of service-aged circuit breaker oils are shown in Table 8.

If additional tests are desired, they should be made in accordance with the guidelines given for insulating oil testing earlier in this guide. Some users of circuit breakers recondition or change their oils without testing them after a preset number of operations.

Table 8—Suggested limits for continued use of service-aged circuit breaker insulating oil

Test and method	Suggested limit
Dielectric strength ASTM D877 kV minimum	25
Dielectric strength ASTM D1816 kV minimum 1 mm, gap[a] 2 mm, gap[a]	 20 27
Dissipation factor (power factor) ASTM D924 25 °C, % maximum	1.0
Interfacial tension ASTM D971 mN/m minimum	25
Color ASTM D1500 ASTM units maximum	2.0
Visual examination ASTM D1524	No excessive carbon in oil.

[a]Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.

8.3 Reconditioning

The chief problem in circuit breaker oil maintenance is to keep the fluid free of water, arc decomposition products, and other contaminants. If visual examination shows the presence of these materials and the dielectric strength of the oil drops below an acceptable value, the oil can be reconditioned, provided it is free of chemical contaminants. The accepted means of reconditioning is by using blotter papers or paper cartridge filters. This subject is discussed in detail in IEEE Std 637.

9. Insulating oil for load tap changers (LTCs)

9.1 General

See IEEE Std C57.131. The requirements of insulating oils used in load tap changers (LTCs) are comparable with those of insulating oils used in power transformers. For LTCs where oil is used for arc-quenching, the arcing at the arcing switch or arcing tap switch contacts causes contact erosion and carbonization of the arcing switch oil. The degree of contamination depends on the operating current and step-voltage of the LTC, the number of operations, and to some degree, on the quality of the insulating oil (not relevant in the case of LTCs with vacuum interrupters).

If the LTC is a “free-breathing” design, the desiccant should be checked periodically to prevent the admittance of humid air.

Maintenance and inspection intervals depend on the type of LTC, the LTC rated through-current, the field experience, and the individual operating conditions. They are suggested as periodic measures with respect to a certain number of operations or after a certain operating time, whichever comes first. The recommended maintenance intervals for an individual LTC type are given in the operating and inspection manuals available for each LTC type. In general, at inspections the oil will be reconditioned or changed.

9.2 Testing methods

Testing methods for LTC oils are the same as those used for insulating oils of power transformers. Samples are taken in the same manner and at the same intervals as for insulating oils used in power transformers.

9.2.1 New oil properties—as supplied

New mineral insulating oils as received from the supplier must conform to certain qualifying functional requirements listed in ASTM D3487.

9.2.2 Test limits—shipment of new mineral insulating oil

When mineral insulating oil meeting the qualifications of ASTM D3487 is received in the field for installation in LTCs, it should be checked for certain key values that may be affected by shipment and storage (Table 1). Viscosity [12 cSt (12 mm^2/s) maximum at 40 °C] and pour point (–40 °C, maximum) should be checked in cold climates (below –25 °C and above –40 °C) to ensure that the oil does not interfere with the free operation of the equipment.

9.2.3 New oil properties—oil shipped in new equipment

LTCs are normally shipped from the factory without oil. If an LTC is filled with oil prior to shipping, refer to Table 9.

9.2.4 New oil properties—prior to energizing

When mineral insulating oil is received in bulk shipping containers, it is processed according to the instructions of the transformer manufacturer and then introduced into the equipment. Table 9 gives test limits for LTC mineral insulating oil after being processed, placed in equipment, and allowing for standing time before energizing.

9.2.5 Service-aged oil properties

Suggested limits for continued use of service-aged LTC oils are shown in Table 10.

9.3 Reconditioning

If the dielectric strength of the oil drops below the values given in Table 10, or the water content exceeds the values given in Table 10, the oil should be reconditioned or changed.

Table 9—Test limits of new mineral insulating oil for load tap changers, prior to energizing

Test and method	Suggested limit
Dielectric strength ASTM D1816 kV minimum 1 mm, gap[a] 2 mm, gap[a]	 35 55
Water content ASTM Dl533, mg/kg maximum[b]	10
Corrosive sulfur ASTM D1275	No corrosive sulfur in oil.

[a] Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[b] Equivalent measurement is parts per million (ppm).

Table 10—Limits for continued use of service-aged insulating oil for load tap changers

Test and method	Suggested limit		
	Neutral end	Line end	
		≤69 kV	>69 kV
Dielectric strength ASTM D1816 kV minimum 1 mm, gap[a] 2 mm, gap[a]	 20 27	 25 35	 28 45
Water content ASTM Dl533 mg/kg maximum[b]	40	30	25
Corrosive sulfur, ASTM D1275	No corrosive sulfur in oil.		

[a] Alternative measurements of 1.0 mm (0.04 in) and 2.0 mm (0.08 in), respectively, for gaps.
[b] Equivalent measurement is parts per million (ppm).

10. Health and environmental care procedures for mineral insulating oil

10.1 Health issues

Users should obtain an MSDS for each dielectric fluid in use. Where instructions differ from recommendations made here, the instructions of the manufacturer are to be followed. Although no special risk is involved in the normal handling of insulating fluids addressed in this guide, attention should be focused on the general need for personal hygiene or the practice of washing skin and clothing that may have come in contact with insulating oil. Personnel should avoid contact of the fluid with their eyes. When dielectric liquids have to be disposed of, certain precautions are necessary to comply with local, state, and federal requirements in the United States. These oils are generally classified as special, regulated, or hazardous waste depending on the individual state. The following procedures are not intended to supersede local, state, or federal regulations. Unless a PCB analysis has been performed, it is prudent to assume that the batch of oil contains PCBs and to act accordingly. The absence of PCBs in a volume of oil in or from a piece of equipment can be established only by analysis of that oil.

10.2 Leaks and spills

During equipment inspection or servicing, routine checks should be made of the equipment and surroundings for leaks. Areas to check and repair should include valves, bushings, gauges, tap changers, welds, sample ports, manhole covers, pipefittings, and pressure relief valves. The user is referred to IEEE Std 980.

New transformer oil as received from a refiner is very unlikely to contain PCBs. However, many older transformers and other pieces of electrical equipment in service are filled with mineral insulating oil that contains PCBs. Since 1977, various federal, state, and local environmental regulations have governed the handling and processing of mineral oils containing PCBs. Although these regulations can add substantially to the complexity of spill cleanup and disposal of oils, they should not be disregarded.

10.2.1 Minor spills

Minor spills, such as those occurring in the manufacture or repair of equipment, can be cleaned using absorbent rags or other materials.

10.2.2 Spills on soil

Soil acts as an absorbent and should not be allowed to become saturated with mineral insulating oil. Users should consult the applicable local, state, and federal guidelines (see Title 40 CFR, Part 112) in the United States for spills of mineral oil onto soil and the remedies available. Depending on state and local regulations, spills to soil may have to be reported to one or more regulatory agencies.

10.2.3 Spills on water

Because mineral insulating oils float on water, a spill can be contained by using floating booms or dikes. Section 311 of the Federal Water Pollution Control Act as amended, 33 U.S.C. 1251 *et seq*, also known as the Clean Water Act as found in Title 40 CFR, Part 110, imposes reporting requirements for petroleum oils that are spilled into navigable water ways. The requirement to report is triggered by discharges of oil that cause a film or sheen upon or discoloration of the surface of the water or adjoining shorelines or cause a sludge or emulsion to be deposited beneath the surface of the water or upon adjoining shorelines. The U. S. Coast Guard must be notified as well as the National Response Center.

Once the mineral oil has been concentrated, it can be removed from the surface of the water by systems that are normally used for petroleum spills. These systems include pumps, skimmers, physical absorbents, and fibers that are fabricated into floating ropes.

NOTE—If spilled mineral insulating oils are known or assumed to contain any concentration of PCBs, they must be treated as a PCB containing liquid. Also refer to the Spill Policy Guide of the Environmental Protection Agency (see Title 40 CFR, Parts 761.120 and 761.61).[8]

[8] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the guide.

Annex A

(informative)

Bibliography

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