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INTERNATIONAL STANDARD

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Mineral insulating oils in electrical equipment – Supervision and maintenance guidance

Huiles minérales isolantes dans les matériels électriques – Lignes directrices pour la maintenance et la surveillance

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MINERAL INSULATING OILS IN ELECTRICAL EQUIPMENT – SUPERVISION AND MAINTENANCE GUIDANCE

FOREWORD

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International Standard IEC 60422 has been prepared by IEC technical committee 10: Fluids for electrotechnical applications.

This fourth edition cancels and replaces the third edition, published in 2005, and constitutes a technical revision.

The main changes with respect to the previous edition are as follows:

This new edition represents a major revision of the third edition, in order to bring in line this standard with latest development of oil condition monitoring, containing new limits for oil parameters, suggested corrective actions in the tables and new test methods.

The action limits for all oil tests have been revised and changes made where necessary to enable users to use current methodology and comply with requirements and regulations affecting safety and environmental aspects.

In addition, this standard incorporates changes introduced in associated standards since the third edition was published.

The text of this standard is based on the following documents:

FDIS	Report on voting
10/894/FDIS	10/896/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

• reconfirmed,
• withdrawn,
• replaced by a revised edition, or
• amended.

The contents of the corrigendum of December 2013 have been included in this copy.

INTRODUCTION

Insulating mineral oils are used in electrical equipment employed in the generation, transmission, distribution and use of electrical energy, so that the amount of oil in service, worldwide, amounts to hundreds of millions of kilograms.

Monitoring and maintaining oil quality is essential to ensure the reliable operation of oil-filled electrical equipment. Codes of practice for this purpose have been established by electrical power authorities, power companies and industries in many countries.

A review of current experience reveals a wide variation of procedures and criteria. It is possible, however, to compare the value and significance of standardized oil tests and to recommend uniform criteria for the evaluation of test data.

If a certain amount of oil deterioration (by degradation or contamination) is exceeded, there is inevitably some erosion of safety margins and the question of the risk of premature failure should be considered. While the quantification of the risk can be very difficult, a first step involves the identification of potential effects of increased deterioration. The philosophy underlying this standard is to furnish users with as broad a base of understanding of oil quality deterioration as is available, so that they can make informed decisions on inspection and maintenance practices.

Unused mineral oils are limited resources and should be handled with this in mind. Used mineral oils are, by most regulations, deemed to be controlled waste. If spills occur this may have a negative environmental impact especially if the oil is contaminated by persistent organic pollutants such as polychlorinated biphenyls (PCBs).

This International Standard, whilst technically sound, is mainly intended to serve as a common basis for the preparation of more specific and complete codes of practice by users in the light of local circumstances. Sound engineering judgement will have to be exerted in seeking the best compromise between technical requirements and economic factors.

Reference should also be made to instructions from the equipment manufacturer.

General caution

This International Standard does not purport to address all the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to use.

The mineral oils and oil additives which are the subject of this standard should be handled with due regard to personal hygiene. Direct contact with the eyes may cause slight irritation. In the case of eye contact, irrigation with copious quantities of clean running water should be carried out and medical advice sought. For more information, refer to the safety data sheet provided by the manufacturer. Some of the tests specified in this standard involve the use of processes that could lead to a hazardous situation. Attention is drawn to the relevant standard for guidance.

Environment

This standard is applicable to mineral oils, chemicals and used sample containers.

Attention is drawn to the fact that, at the time of writing this standard, some mineral oils in service are known to be contaminated to some degree by PCBs.

Because of this, safety countermeasures should be taken to avoid risks to workers, the public and the environment during the life of the equipment, by strictly controlling spills and emissions. Disposal or decontamination of these oils should be carried out strictly according to local regulations. Every precaution should be taken to prevent release of mineral oil into the environment.

MINERAL INSULATING OILS IN ELECTRICAL EQUIPMENT – SUPERVISION AND MAINTENANCE GUIDANCE

1   Scope

This International Standard gives guidance on the supervision and maintenance of the quality of the insulating oil in electrical equipment.

This standard is applicable to mineral insulating oils, originally supplied conforming to IEC 60296, in transformers, switchgear and other electrical apparatus where oil sampling is reasonably practicable and where the normal operating conditions specified in the equipment specifications apply.

This standard is also intended to assist the power equipment operator to evaluate the condition of the oil and maintain it in a serviceable condition. It also provides a common basis for the preparation of more specific and complete local codes of practice.

The standard includes recommendations on tests and evaluation procedures and outlines methods for reconditioning and reclaiming oil and the decontamination of oil contaminated with PCBs.

NOTE   The condition monitoring of electrical equipment, for example by analysis of dissolved gases, furanic compounds or other means, is outside the scope of this standard.

2   Normative references

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

IEC 60156, *Insulating liquids – Determination of the breakdown voltage at power frequency – Test method*

IEC 60247, *Insulating liquids – Measurement of relative permittivity, dielectric dissipation factor (tan δ) and d.c. resistivity*

IEC 60296:2012, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60475, *Method of sampling liquid dielectrics*

IEC 60666:2010, *Detection and determination of specified additives in mineral insulating oils*

IEC 60814, *Insulating liquids – Oil-impregnated paper and pressboard – Determination of water by automatic coulometric Karl Fischer titration*

IEC 60970, *Insulating liquids – Methods for counting and sizing particles*

IEC 61125:1992, *Unused hydrocarbon based insulating liquids – Test methods for evaluating the oxidation stability*

IEC 61619, *Insulating liquids – Contamination by polychlorinated biphenyls (PCBs) – Method of determination by capillary column gas chromatography*

IEC 62021-1, *Insulating liquids – Determination of acidity – Part 1: Automatic potentiometric titration*

IEC 62021-2, *Insulating liquids – Determination of acidity – Part 2: Colourimetric titration*

IEC 62535:2008, *Insulating liquids – Test method for detection of potentially corrosive sulphur in used and unused insulating oils*

ISO 2049, *Petroleum products – Determination of colour (ASTM scale)*

ISO 2719, *Determination of flash point – Pensky-Martens closed cup method*

ISO 3016, *Petroleum products – Determination of pour point*

ISO 3104, *Petroleum products – Transparent and opaque liquids – Determination of kinematic viscosity and calculation of dynamic viscosity*

ISO 3675, *Crude petroleum and liquid petroleum products – Laboratory determination of density – Hydrometer method*

ISO 4406:1999, *Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles*

EN 14210, *Surface active agents – Determination of interfacial tension of solutions of surface active agents by the stirrup or ring method*

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

ASTM D1275:2006, *Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils*

DIN 51353: *Testing of insulating oils; Detection of corrosive sulphur; Silver strip test*

3   Terms and definitions

For the purposes of this document, the following definitions apply.

3.1
local regulations
regulations pertinent to the particular process in the country concerned

Note 1 to entry: Such regulations may be defined by local, regional or national legislation or even the owner or operator of the equipment itself. They are always to be considered as the most stringent of any combination thereof. It is the responsibility of each user of this standard to familiarize themselves with the regulations applicable to their situation. Such regulations may refer to operational, environmental or health and safety issues. A detailed risk assessment will usually be required.

3.2
routine tests (Group 1)
minimum tests required to monitor the oil and to ensure that it is suitable for continued service

Note 1 to entry: If the results obtained from these tests do not exceed recommended action limits usually no further tests are considered necessary until the next regular period for inspection but, under certain perceived conditions, complementary tests may be deemed prudent.

3.3
complementary tests (Group 2)
additional tests, which may be used to obtain further specific information about the quality of the oil, and may be used to assist in the evaluation of the oil for continued use in service

3.4
special investigative tests (Group 3)
tests used mainly to determine the suitability of the oil for the type of equipment in use and to ensure compliance with environmental and operational considerations

3.5
reconditioning
process that eliminates or reduces gases, water and solid particles and contaminants by physical processing only

3.6
reclamation
process that eliminates or reduces soluble and insoluble polar contaminants from the oil by chemical and physical processing

3.7
PCB decontamination
process that eliminates or reduces PCB contamination from mineral oil

4   Properties and deterioration/degradation of oil

The reliable performance of mineral insulating oil in an insulation system depends upon certain basic oil characteristics that can affect the overall performance of the electrical equipment.

In order to accomplish its multiple roles of dielectric, coolant and arc-quencher, the oil needs to possess certain properties, in particular:

- high dielectric strength to withstand the electric stresses imposed in service
- sufficiently low viscosity so that its ability to circulate and transfer heat is not impaired
- adequate low-temperature properties down to the lowest temperature expected at the installation site
- resistance to oxidation to maximize service life

In service, mineral oil degrades due to the conditions of use. In many applications, insulating oil is in contact with air and is therefore subject to oxidation. Elevated temperatures accelerate degradation. The presence of metals, organo-metallic compounds or both may act as a catalyst for oxidation. Changes in colour, the formation of acidic compounds and, at an advanced stage of oxidation, precipitation of sludge may occur. Dielectric and, in extreme cases, thermal properties may be impaired.

In addition to oxidation products, many other undesirable contaminants, such as water, solid particles and oil-soluble polar compounds can accumulate in the oil during service and affect its electrical properties. The presence of such contaminants and any oil degradation products are indicated by a change of one or more properties as described in Table 1.

Deterioration of other constructional materials, which may interfere with the proper functioning of the electrical equipment and shorten its working life, may also be indicated by changes in oil properties.

5 Oil tests and their significance

5.1 General

A large number of tests can be applied to mineral insulating oils in electrical equipment. The tests listed in Table 1 and discussed in 5.2 to 5.19 are considered sufficient to determine whether the condition of the oil is adequate for continued operation and to suggest the type of corrective action required, where applicable. The tests are not listed in order of priority.

Table 1 – Tests for in-service mineral insulating oils

Property	Group [a]	Subclause	Method
Colour and appearance	1	5.2	ISO 2049
Breakdown voltage	1	5.3	IEC 60156
Water content	1	5.4	IEC 60814
Acidity (neutralization value)	1	5.5	IEC 62021-1 or IEC 62021-2
Dielectric dissipation factor (DDF) and resistivity	1	5.6	IEC 60247
Inhibitor content [b]	1	5.7.3	IEC 60666
Sediment Sludge	2	5.8	Annex C of this standard
Interfacial tension (IFT) [c]	2	5.9	ASTM D971 EN 14210
Particles (counting and sizing) [c]	2	5.10	IEC 60970
Oxidation stability [c]	3	5.7	IEC 61125
Flash point [d]	3	5.11	ISO 2719
Compatibility [d]	3	5.12	IEC 61125
Pour point [d]	3	5.13	ISO 3016
Density [d]	3	5.14	ISO 3675
Viscosity [d]	3	5.15	ISO 3104
Polychlorinated biphenyls (PCBs)	3	5.16	IEC 61619
Corrosive sulphur [c]	3	5.17	IEC 62535 ASTM D1275, Method B DIN 51353
Dibenzyl disulfide (DBDS) content	3	5.18	IEC 62697-1
Passivator content [b]	3	5.19	Annex B of IEC 60666:2010

[a] Group 1 are routine tests, Group 2 are complementary tests, Group 3 are special investigative tests.

[b] Restricted to inhibited and or passivated oils.

[c] Only needed under special circumstances, see applicable subclause.

[d] Not essential, but can be used to establish type identification.

5.2 Colour and appearance

The colour of an insulating oil is determined in transmitted light and is expressed by a numerical value based on comparison with a series of colour standards. It is not a critical property, but it may be useful for comparative evaluation. A rapidly increasing or a high colour number may be an indication of oil degradation or contamination.

Besides colour, the appearance of oil may show cloudiness or sediment, which may indicate the presence of free water, insoluble sludge, carbon particles, fibres, dust, or other contaminants.

5.3 Breakdown voltage

Breakdown voltage is a measure of the ability of oil to withstand electric stress and has primary importance for the safe operation of electrical equipment. It is strongly dependent on the sampling temperature (5.4.3 and 5.4.4).

Dry and clean oil exhibits an inherently high breakdown voltage. Free water and solid particles, the latter particularly in combination with high levels of dissolved water, tend to migrate to regions of high electric stress and reduce breakdown voltage dramatically. The measurement of breakdown voltage, therefore, serves primarily to indicate the presence of contaminants such as water or particles. A low value of breakdown voltage can indicate that one or more of these are present. However, a high breakdown voltage does not necessarily indicate the absence of all contaminants.

The values of breakdown voltage are only significant when the oil has been sampled at the operating temperature of the transformer. Samples taken at < 20 °C may give an optimistic view of the state of the transformer when analysed at room temperature. The breakdown voltage of spare units that have been long out of service and are again energized should be monitored more often until the transformer has reached a steady state.

5.4 Water content

5.4.1 General

Depending on the amount of water, the temperature of the insulating system and the status of the oil, the water content of insulating oils influences

- the breakdown voltage of the oil,
- the solid insulation,
- the ageing tendency of the liquid and solid insulation.

The water content in the liquid and solid insulation thus has a significant impact on the actual operating conditions and the lifetime of the transformer.

There are two main sources of water increase in transformer insulation:

- ingress of moisture from the atmosphere;
- degradation of insulation.

Water is transferred in oil filled electrical equipment by the insulating liquid. Water is present in oil in a dissolved form and may also be present as a hydrate adsorbed by polar ageing products (bonded water). Particles, such as cellulose fibres may bind some water.

5.4.2 Water in oil

The solubility of water in oil (W_s), given in mg/kg, depends on the condition of the oil, the temperature and type of oil. The absolute water content (W_{abs}) is independent of the temperature, type and condition of the oil and the result is given in mg/kg. W_{abs} can be measured according to IEC 60814. The relative water content (W_{rel}) is defined by the ratio W_{abs}/W_s and the result is given in per cent. The relative water content can be evaluated by use of a suitable method such as that in BS 6522 [1][1] or on-line by means of capacitive sensors [2]. Water solubility (W_s) should be determined at the same temperature as that of

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[1] Figures in square brackets refer to the bibliography.

the oil sample when taken. By way of a guide, the condition of cellulosic insulation in relation to oil percentage saturation is given in Table A.1.

At water contents in oil above the saturation level, i.e. when $W_{abs} > W_s$ (or $W_{rel} > 100 \%$), the excess water cannot remain dissolved and free water may be seen in the form of cloudiness or droplets.

Usually, the temperature is determined directly in the oil stream of the sample taken. In cases where top oil indicator readings or corrections for ONAN (natural oil or natural air) or OFAF (forced oil or forced air) cooling mode are used, this should be explicitly noted.

The water content in oil is directly proportional to the relative water concentration (relative saturation) up to the saturation level. The temperature dependence of the solubility of water in oil (W_S) is expressed by:

$$W_s = W_{oil} e^{(-B/T)}$$

(1)

where T is the temperature of the oil at the point of sampling in Kelvin and W_{0il} and B are constants that are similar for many transformer oils but may be different for some products, mainly due to differences in aromatic content. Where present, some free water may transfer into dissolved water at elevated temperatures.

As oils become very oxidized with increasing amounts of polar ageing by-products, their water solubility characteristics, which are also dependent on the type of the oil, also increase. The solubility of water in very aged oils may be much higher than that in unused oils (Figure 1). Each oil should be considered separately and no universal formula is available.
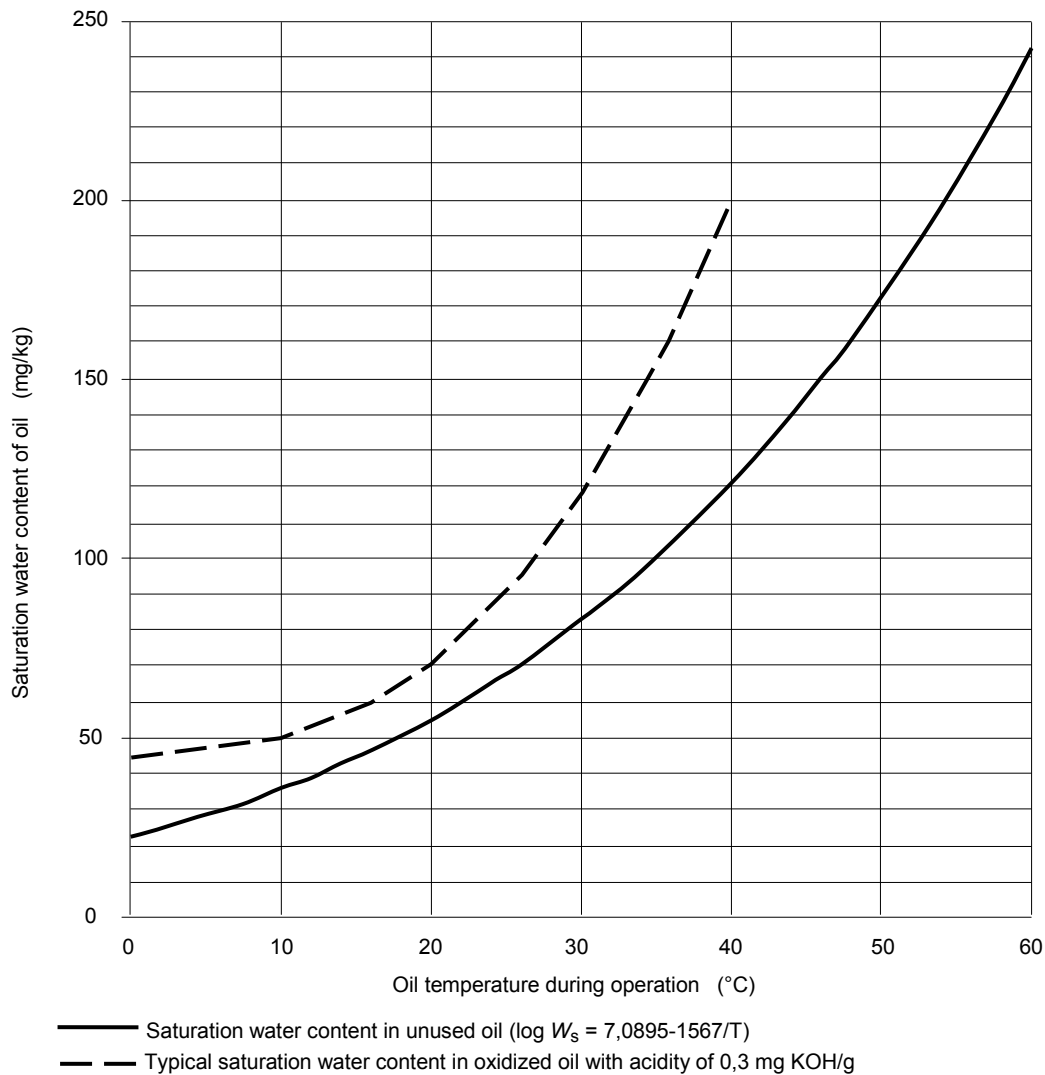
Figure 1 – Example of variation in saturation water content with oil temperature and acidity for insulating oil originally conforming to IEC 60296

5.4.3   Water content in the oil/paper-system

Transformers are dried during the manufacturing process until measurements or standard practices yield a moisture content in the cellulosic insulation of less than 0,5 % to 1,0 % depending upon purchaser's and manufacturer's requirements. After the initial drying, the moisture content of the insulation system increases depending on the environmental and/or operating conditions.

In a transformer, the total mass of water is distributed between the paper and the oil such that the bulk of the water is in the paper. Small changes in temperature significantly change the dissolved water content of the oil but only slightly change the water content of the paper.

When oil in a transformer is operating at a constant, relatively elevated temperature for a long period, thermodynamic equilibrium between water absorbed by cellulose and water dissolved in oil is closely approached. This equilibrium is temperature dependent so that at elevated temperatures more water diffuses from the paper into the oil. However, if the oil temperature is not high enough, such equilibrium is not reached because of the lower rate of diffusion of water to the oil from the cellulose insulation.

The determination of the water content in the paper of a transformer by the measurement of the water in oil has been frequently described, but practical results are often not in line with the theoretical predictions. The drying process of the paper may not take out as much water as calculated.

All calculations and correlations of the water content in oil and the water content in the oil/paper-system depend on the equilibrium state between the insulating oil and the oil/paper-system and vice versa. The equilibrium is influenced by many factors, such as the difference in the temperature between oil and the cellulose/oil-system. The calculation of the water content of the paper/pressboard by determination of the water in the oil has been examined in several studies and publications (see Annex A).

5.4.4 Interpretation of results

Breakdown voltage and water content are strongly interrelated. Both of them are temperature dependent, therefore it is most informative to measure them at different transformer temperatures in order to obtain a reliable assessment of humidity in the combined oil-paper insulation system. The interpretation of water content in oil is strongly related to the sampling temperature determined by measuring the temperature directly in the oil stream. In cases where the top oil temperature indicator (OTI) temperature corrections for ONAN or OFAF cooling mode are used, this should be explicitly noted.

For transformers with a relatively steady load, a normalizing calculation of the water content for 20 °C may be helpful for trending. The procedure is described in Annex A.

5.5 Acidity

The acidity (neutralization value) of oil is a measure of the acidic constituents or contaminants in the oil.

The acidity of a used oil is due to the formation of acidic oxidation products. Acids and other oxidation products will, in conjunction with water and solid contaminants, affect the dielectric and other properties of the oil. Acids have an impact on the degradation of cellulosic materials and may also be responsible for the corrosion of metal parts in a transformer.

The rate of increase of acidity of oil in service is a good indicator of the ageing rate. The acidity level is used as a general guide for determining when the oil should be replaced or reclaimed.

Generally, inhibited oil should show no significant increase in acidity from its original value provided that the inhibitor is present in sufficient amount.

5.6 Dielectric dissipation factor (DDF) and resistivity

These parameters are very sensitive to the presence of soluble polar contaminants, ageing products or colloids in the oil. Changes in the levels of the contaminants can be monitored by measurement of these parameters even when contamination is so slight as to be near the limit of chemical detection.

Acceptable limits for these parameters depend largely upon the type of equipment. However, high values of DDF, or low values of resistivity, may deleteriously affect the dielectric losses and/or the insulation resistance of the electrical equipment.

There is generally a relationship between DDF and resistivity, with resistivity decreasing as DDF increases. It is normally not necessary to conduct both tests on the same oil and generally DDF is found to be the more common test. Resistivity and DDF are temperature and moisture dependent and Figure 2 illustrates typical changes of resistivity with temperature and moisture for insulating oils that are virtually free from solid contamination.

Useful additional information can be obtained by measuring resistivity or DDF at both ambient temperature and a higher temperature such as 90 °C.

In the case of very high voltage (VHV) and ultra high voltage (UHV) instrument transformers, special attention shall be paid to DDF as it has been reported that a higher value of DDF may lead to thermal runaway leading to failure.

Oils classified as 'good' (see 9.4) will have characteristics similar to curves A and B in Figure 2 and will result in satisfactory test results being obtained at both the higher and lower temperatures.

Oils classified as 'poor' (see 9.4) will have characteristics similar to curve C and will result in a satisfactory test result at 90 °C coupled with an unsatisfactory value at the lower temperature. This is an indication of the presence of water or degradation / deterioration products precipitable in the cold without any significant amount of chemical degradation or general contamination. Unsatisfactory results at both temperatures indicate a greater extent of contamination and that it may not be possible to restore the oil to a satisfactory condition by reconditioning.

The measurement of resistivity is also considered to be of value for monitoring oils in service, as it has been shown to be reasonably proportional to oxidation acids and to be affected by undesirable contaminants such as metal salts and water. Other compounds present in used oils, which can affect resistivity, include aldehydes, ketones and alcohols. An increase in temperature reduces the resistivity, as does water when precipitated at low temperature due to the saturation point being reached.

It has been observed in instrument transformers that some types of oil may experience a huge increase in DDF after a very short oxidation time, leading to failure of the equipment. It is therefore recommended to measure the DDF of the unused oil after subjecting it to a short oxidation period according to IEC 61125:1992, Method C to verify that the oil is suitable for this application.
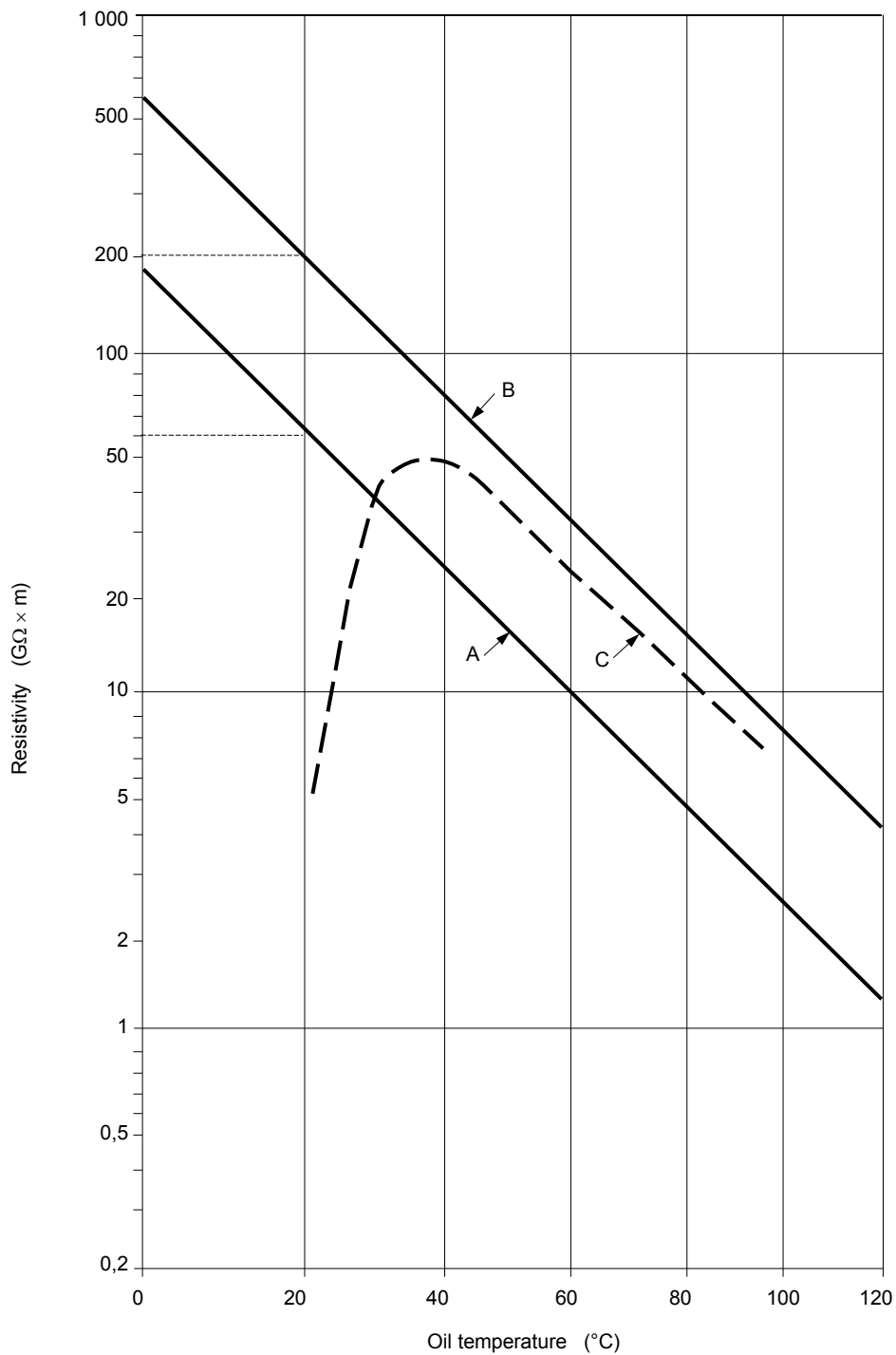
Line A: Dry oil having a resistivity of 60 GΩ×m at 20 °C.
Line B: Dry oil having a resistivity of 200 GΩ×m at 20 °C.
Line C: Wet oil that is 100 % saturated at 35 °C.

NOTE   In transformers in service, the behaviour of line C is unlikely to occur in the windings, but rather along tank walls or other very cold surfaces.

Figure 2 – Example of variation of resistivity with temperature for insulating oils

5.7 Inhibitor content and oxidation stability

5.7.1 Oxidation stability

The ability of unused mineral insulating oil to withstand oxidation under thermal stress and in the presence of oxygen and a copper catalyst is called oxidation stability. It gives general information about the life expectancy of the oil under service conditions in electrical equipment. The property is defined as resistance to formation of acidic compounds, sludge and compounds influencing the dielectric dissipation factor (DDF) under given conditions. For oils complying with IEC 60296, these conditions are detailed in IEC 61125:1992, Method C and the limits of acceptable performance in IEC 60296.

The property depends mainly on the refining process and how it is applied to a given feedstock. Refined mineral oils contain, to a varying degree, natural compounds acting as oxidation inhibitors. These are known as natural antioxidants. Oils containing only natural antioxidants are designated as uninhibited oils.

Synthetic oxidation inhibitors can be added to enhance the oxidation stability. In transformer oils, mainly the phenolic type is used and the common and generally accepted compounds are 2,6-di-tert-butyl-paracresol (DBPC) and 2,6-di-tert-butyl-phenol (DBP). The efficacy of added inhibitors will vary with the chemical composition of the base oil.

To determine the oxidation stability, tests specified in IEC 61125:1992 Method C may be used. As this ageing protocol is designed for unused oils, interpretation of test results may be difficult when ageing is performed with oil in service. However, this oxidation stability test is occasionally used to evaluate oil in new electrical equipment prior to energizing.

5.7.2 Monitoring of uninhibited oils

Oxidation of uninhibited oils is normally monitored by the formation of acidic compounds and oil soluble and insoluble sludge. An increase in DDF and reduction in IFT are also signs of oxidation of insulating oils (see 5.5, 5.6 and 5.9).

5.7.3 Monitoring of inhibited oils

Inhibited oils have a different oxidation pattern compared to uninhibited oils. At the beginning of service life, the synthetic inhibitor is consumed with little formation of oxidation products. This is referred to as the induction period. After the inhibitor is consumed, the oxidation rate is determined mainly by the base oil oxidation stability.

A decrease of IFT in inhibited oils may also be an early indication of initial formation of oxidation products.

The common and easy way to monitor the inhibitor consumption is to measure the inhibitor concentration according to IEC 60666.

The inhibitor content should be monitored at regular intervals the frequency of which will depend upon operational temperature and load levels.

5.8 Sediment and sludge

This test distinguishes between sediment and sludge.

Sediment is insoluble material present in the oil.

Sediment includes:

- insoluble oxidation or degradation products of solid or liquid insulating materials;
- solid products arising from the conditions of service of the equipment; carbon and metal particles, metallic oxides and sulfides;

- fibres and other foreign matter of diverse origins.

Sludge is a polymerized degradation product of solid and liquid insulating material. Sludge is soluble in oil up to a certain limit, depending on the oil solubility characteristics and temperature. At sludge contents above this, the sludge is precipitated, contributing as an additional component to the sediment.

The presence of sediment and/or sludge may change the electrical properties of the oil, and in addition, deposits may hinder heat-exchange, thus encouraging thermal degradation of the insulating materials.

Sediment and sludge should be measured according to the method described in Annex C.

5.9 Interfacial tension (IFT)

The interfacial tension between oil and water provides a means of detecting soluble polar contaminants and products of degradation. This characteristic changes fairly rapidly during the initial stages of ageing but levels off when deterioration is still moderate.

The rate of decrease of IFT is strongly influenced by the type of oil; uninhibited oils usually show higher IFT rates of decrease than inhibited oils.

A rapid decrease of IFT may also be an indication of compatibility problems between the oil and some transformer materials (varnishes, gaskets), or of an accidental contamination when filling with oil. However, oils with interfacial tension values at or near the lower limit value given in Table 5 should be further investigated.

With overloaded transformers, the deterioration of materials is rapid and IFT is a tool for detection of deterioration.

5.10 Particle count

Particles in insulating oil in electrical equipment may have numerous possible sources. The equipment itself may contain particles from manufacturing and the oil may contain particles from storage and handling if not properly filtered. Metal wear and the ageing of oil and solid materials may produce particles during the service life of equipment. Localized overheating over 500°C may form carbon particles. The carbon particles produced in the on-load tap-changer diverter switch may migrate by leakage into the bulk oil compartment to contaminate the oil-immersed parts of the transformer. A typical source of metallic particles is wear of bearings of the pumps.

The effect of suspended particles on the dielectric strength of insulating oil depends on the type of particles (metallic, fibres, sludge, etc.) and on their water content.

Historically, some failures on HV transformers have been associated with particle contamination. Traditional dielectric breakdown voltage tests are not sufficient to identify the problem and particle counting methods have been advised as monitoring tools [3], [4] (see Table B.1).

5.11 Flash point

Breakdown of the oil caused by electrical discharges or prolonged exposure to very high temperatures may produce sufficient quantities of low molecular weight hydrocarbons to cause a lowering of the flash point of the oil.

A low flash point is an indication of the presence of volatile combustible products in the oil. This may result from contamination by a solvent but, in some cases, the cause has been observed to be extensive sparking discharges.

5.12 Compatibility of insulating oils

Unused oil complying with IEC 60296 and with the same classification (class, group and LCSET as stated in IEC 60296) as that already in service should be used for topping up and/or refilling electrical equipment.

Field experience indicates that problems are not normally encountered when unused oil is added in small percentage, e.g. less than 5 %, to used oils classified as 'good' (see 9.4), though larger additions to heavily aged oil may cause sludge to precipitate.

A compatibility test may be needed to determine the feasibility of mixing unused oils of different origins with oil in service. For mixing used oils, a compatibility study is strongly recommended. Reference to the oil supplier is recommended if any doubts concerning compatibility arise.

In the compatibility study, as described below, the characteristics of the mixture should not be less favourable than those of the worse individual oil.

Oils should be mixed in the same proportions as in the application, or if not known in a 50/50 ratio.

The following functional tests are recommended for each individual oil and for the mixture:

- foaming;
- oxidation stability according to IEC 61125:1992, Method C, including acidity, sludge and DDF after ageing. Test time should be according to the oil group as stated in IEC 60296;
- corrosive sulphur and/or potential corrosivity after ageing according to IEC 61125:1992 Method C.

Experience is very limited regarding the use of oil containing pour point depressants to top-up naturally low pour point oils. However, laboratory investigations suggest that no significant deterioration of low temperature behaviour is likely to occur.

Compatibility tests are particularly necessary in the case of oils containing additives. Again, reference to the oil supplier or to the equipment manufacturer is recommended.

5.13 Pour point

Pour point is a measure of the ability of the oil to flow at low temperature. There is no evidence to suggest that this property is affected by normal oil deterioration. Changes in pour point can normally be interpreted as the result of topping-up with a different oil.

5.14 Density

In cold climates, the density of oil may be important in determining its suitability for use. For example, ice crystals formed from separated water may float on oil of high density and lead to flashover on subsequent melting. However, density is not significant in comparing the quality of different samples of oil. There is no evidence that density is affected by normal oil deterioration.

Density may be useful for discriminating mineral insulating oil from other fluid types.

5.15 Viscosity

Viscosity is an important controlling factor in the dissipation of heat. Ageing and oxidation of the oil tend to increase viscosity. Viscosity is also affected by temperature. Normal ageing and oxidation of the oil will not significantly affect its viscosity. Only under extreme conditions of corona discharges or oxidation may this occur.

5.16 Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a family of synthetic chlorinated aromatic hydrocarbons, which have good thermal and electrical properties. These properties combined with excellent chemical stability made them useful in numerous commercial applications. However, their chemical stability and resistance to biodegradation has given cause for concern in terms of environmental pollution. This increasing concern over the environmental impact of PCBs has progressively restricted their use since the early 1970s and their use in new plant and equipment was banned by international agreement in 1986. Unfortunately, the use of common handling facilities has led to widespread contamination of mineral insulating oil.

The PCB content of oil in new equipment should be measured to confirm that the oil is PCB free. Thereafter, whenever there is a risk of potential contamination (oil treatment, transformer repairs, etc.) the oil should be analysed and if PCB content is found to exceed defined limits appropriate action should be taken (see 11.4).

NOTE   Limits will be as defined by local regulations.

5.17 Corrosive sulphur

Table 1 identifies three methods for assessment of corrosive sulphur in oil. The IEC method is considered to be more exacting than the ASTM method and shall be passed by all oils. The ASTM method is easier to perform and may be used as an initial test but negative results may require further investigation. The DIN method is considered complementary and shall be passed in addition to either the ASTM or IEC method to be considered 'non-corrosive' in Table 5.

The amount of sulphur in oil depends on oil refining processes, degree of refining and crude oil type; it is normally present as organo-sulphur, but elemental sulphur contamination can also occur. The presence of reactive compounds causing corrosion at normal operating temperatures is due to poor refining or contamination.

At relatively high temperatures, sulphur-containing oil molecules may decompose and react with metal surfaces to form metal sulphides. Such reactions may take place in switching equipment and will impact the conductivity of contacts. DIN 51353, using a silver strip at 100 °C, provides a sensitive test for such type of problem.

Some sulphur containing molecules may also cause the formation of copper sulphide (Cu_2S) deposition in the paper insulation of electrical equipment. This phenomenon leads to a reduction of the electrical insulation properties and has resulted in several equipment failures in service [5].

Cu_2S deposition occurs preferentially in paper insulated electrical equipment where corrosive sulphur compounds are present in oil, unvarnished or unprotected copper is used, operating or/and ambient temperatures are high and the amount of oxygen in oil is limited. One group of substances in oil causing this effect are disulphides, e.g. dibenzyl disulphide.

IEC 60296 provides specifications to ensure that Cu_2S deposition in paper will not occur in service as a result of unused oil. The tests used for that purpose (IEC 62535 and ASTM D1275:2006, Method B) apply to oils that do not contain a metal passivator additive; Clause A.3 of IEC 60296:2012 provides a method for removal of passivators where they are present. The tests will give a positive indication if corrosive sulphur compounds are present in the oil.

Strongly aged insulating oils (e.g. with high acidity), or oils with poor oxidation stability, may give ambiguous results on the paper strip under the conditions of IEC 62535, because of heavy sludge formation. In this case SEM-EDX analysis (described in Annex B of IEC 62535:2008) may be helpful to solve ambiguous cases. False positives tests can also be avoided by carrying out the test only with insulating paper, without copper strip and comparing the paper's appearance by testing with copper.

A combination of several factors not only the potential oil corrosivity may lead to a failure in electrical equipment. In this case a risk assessment including design and operating conditions should be performed.

5.18 Dibenzyl disulphide (DBDS)

DBDS is potentially corrosive to copper surfaces at normal transformer operating temperatures and may form copper sulphide under certain conditions.

Among corrosive sulphur compounds DBDS appears to play a predominant role in the problem of corrosion. Identified as a major sulphur compound in several mineral insulating oils, it is present in most corrosive insulating oils produced and blended after 1988-1989 (although they passed the corrosivity tests of their time). There seem to be very few oils introduced or produced after 2006 that contain DBDS in detectable amounts [5].

It should be noted that there are also oils in service that are corrosive despite the absence of DBDS.

NOTE Dibenzyl disulphide is a sulphur compound used as an antioxidant additive in rubber compounds, a stabilizer for petroleum fractions and an additive for silicon oils.

5.19 Passivator

The addition of a metal passivator is the mitigation technique that has been used to the largest extent in order to minimize the risk of corrosive sulphur. In particular a toluyltriazole derivative has been used[2]. Typically 100 mg/kg (0,01 % by weight) of this substance is added to inhibit the reactions of copper with corrosive sulphur.

Metal passivators, have a long history of use in mineral oil, mainly in lubricating oil but also, to a more limited extent, in insulating oil. They have been used not only to counteract corrosion, but also to improve oxidation stability and to suppress streaming electrification.

It is essential to monitor the passivator content during service.

6   Sampling of oil from equipment

It is essential that every effort be made to ensure that samples are representative of the insulating oil in equipment. Experience indicates that oil is sometimes rejected unjustifiably because inadequate care has been taken whilst sampling. Careless sampling procedures or contamination in the sample container will lead to erroneous conclusions concerning quality and incur waste of time, effort and expense involved in obtaining, transporting and testing the sample.

Whenever possible, sampling from equipment shall be at normal operating conditions or very shortly after de-energization.

Sampling should be performed by an experienced person, who has received adequate training, in accordance with IEC 60475.

Where available, manufacturer's instructions should be followed.

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2   This is commercially available under the name of Irgamet 39®.

7 Categories of equipment

In order to take account of different user requirements, equipment has been placed in various categories as shown in Table 2 below.

Table 2 – Categories of equipment

Category	Type of equipment
Category O	Power transformers/reactors with a nominal system voltage of 400 kV and above
Category A	Power transformers/reactors with a nominal system voltage above 170 kV and below 400 kV. Also power transformers of any rated voltage where continuity of supply is vital and similar equipment for special applications operating under onerous condition
Category B	Power transformers/reactors with a nominal system voltage above 72,5 kV and up to and including 170 kV (other than those in Category A)
Category C	Power transformers/reactors for MV/LV application e.g. nominal system voltages up to and including 72,5 kV and traction transformers (other than those in Category A). Oil-filled circuit breakers with a nominal system voltage exceeding 72,5 kV. Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage greater than or equal to 16 kV
Category D	Instrument/protection transformers with a nominal system voltage above 170 kV
Category E	Instrument/protection transformers with a nominal system voltage up to and including 170 kV
Category F	Diverter tanks of on-load tap-changers, including combined selector/diverter tanks
Category G	Oil-filled circuit breakers with a nominal system voltage up to and including 72,5 kV. Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage less than 16 kV

NOTE 1   Separated selector tanks of on-load tap-changers belong to the same category as the associated transformer.

NOTE 2   Oil-impregnated paper bushings and other hermetically sealed equipment may be placed in Category D or E if a routine monitoring programme is desired. The manufacturer's instructions should be referred to.

NOTE 3   Regardless of size or voltage, a risk assessment may justify condition-monitoring techniques usually appropriate to a higher classification.

NOTE 4   For practical and economical reasons, some electrical utilities may decide that their small transformers up to 1 MVA and 36 kV are not included in this classification. Routine monitoring programmes may not be considered economical for this type of equipment. Where a monitoring programme is required for these transformers, the guidelines given for category C should be adequate.

8 Evaluation of mineral insulating oil in new equipment

A substantial proportion of electrical equipment is supplied to the final user already filled with mineral oil. In such cases, as the oil has already come into contact with insulating and other materials, it can no longer be considered as "unused oil" as defined in IEC 60296. Therefore its properties shall be regarded as those applicable to oil in service, even though the electrical equipment itself may not have been energized.

Oil properties should be appropriate to the category and functions of the equipment (see Table 3).

The extent of the changes in properties may vary with the type of equipment due to the different types of material and ratios of liquid-to-solid insulation, and should be within the limits of Table 3. Properties not included in Table 3 (with the exception of oxidation stability for which no in service limits have been established) should be within the limits of IEC 60296.

As the characteristics of oil in new equipment are an integral part of that equipment design, the user may request these characteristics to be better than the minimum standards suggested in Table 3, which are based on the experience of many years of operating practice.

**Table 3 – Recommended limits for mineral insulating oils after filling
in new electrical equipment prior to energization**

Property	Highest voltage for equipment kV		
	< 72,5	72,5 to 170	> 170
Appearance	Clear, free from sediment and suspended matter		
Colour (on scale given in ISO 2049)	Max. 2,0	Max 2,0	Max. 2,0
Breakdown voltage (kV)	> 55	> 60	> 60
Water content (mg/kg) [a]	20 [b]	< 10	< 10
Acidity (mg KOH/g)	Max. 0,03	Max. 0,03	Max. 0,03
Dielectric dissipation factor at 90 °C and 40 Hz to 60 Hz [c]	Max. 0,015	Max. 0,015	Max. 0,010
Resistivity at 90 °C (GΩ×m)	Min. 60	Min. 60	Min. 60
Corrosive sulphur	Non-corrosive		
DBDS content (mg/kg)	< 5		
Interfacial tension (mN/m)	Min. 35	Min. 35	Min. 35
Total PCB content (mg/kg)	Not detectable (< 2 mg/kg total)		
Particles	–	–	See Table B.1 [d]

[a] The values are not corrected for temperature since not enough time may have elapsed to reach an equilibrium between oil and cellulose insulation.

[b] For use in transformers under 72,5 kV class, the maximum water content should be agreed between supplier and user depending upon local circumstances.

[c] Higher dielectric dissipation factor values may indicate excessive contamination, or the misapplication of solid materials used in manufacture, and should be investigated.

[d] A determination of particle size and quantity should be made as a baseline for future comparison in transformers >170 kV.

9   Evaluation of oil in service

9.1   General

Insulating oil in service is subjected to heat, oxygen, water and other catalysts, all of which are detrimental to the properties of the oil. In order to maintain the quality of the oil in service, regular sampling and analysis should be performed.

Often the first sign of oil deterioration may be obtained by direct observation of the oil clarity and colour through the sight glass of the conservator. From an environmental point of view, this simple and easy inspection can also be used to monitor leakage and spills of oil.

The interpretation of results, in terms of the functional deterioration of the oil, should be performed by experienced personnel based on the following elements of risk management and life cycle management:

- characteristic values for the type and family of oil and equipment, developed by statistical methods;

- evaluation of trends and the rate of variation of the values for a given oil property;

- normal, or typical values, for "fair" or "poor" for the appropriate type and family of equipment.

In the case of oil contaminated with PCBs, environmental impact is a critical factor to consider, as are local regulations. If it is suspected that oil has become contaminated with PCBs specific analyses should be undertaken and interpretation of the results should be used in risk assessment to take into account prevention and mitigation of potential damage to the environment and to avoid unreasonable risks for staff and the public.

9.2   Frequency of examination of oils in service

It is impossible to lay down a general rule for the frequency of examination of oils in service which will be applicable to all possible situations that might be encountered.

The optimum frequency will depend on the type, function, voltage, power, construction and service conditions of the equipment, as well as the condition of the oil as determined in the previous analysis. A compromise will often have to be found between economic factors and reliability requirements.

Much greater difficulties exist in deciding frequency of testing and permissible oil deterioration levels which are acceptable for all applications of insulating oil in relation to differences in operating policies, reliability requirements and types of electrical system. For example, large power companies may find the full application of these recommendations to distribution transformers uneconomical. Conversely, the industrial user, whose activities depend on the reliability of his power supply, may wish to institute more frequent and stricter controls of oil quality as a means of guarding against power failures.

By way of a guide, a suggested frequency of tests suitable for different types of equipment is given in Table 4. However, some equipment is designed having systems that are designed to control exposure of the oil to atmosphere. Where such systems are maintained in good condition, less frequent testing may be appropriate based on life cycle analysis (LCA) and/or life cycle management (LCM) and risk assessment (RA).

Generally, check measurements should be carried out on the basis of the following criteria, which apply particularly to transformer oils:

a)   Characteristics may be checked periodically, at intervals as suggested in Table 4, unless otherwise defined.

b)   The frequency of examination may be increased where any of the significant properties indicates that the oil is in fair or poor condition, or when trend analysis indicates significant changes.

c)   The oxidation of the oil will accelerate with increased temperature and in the presence of oxygen and water. Therefore heavily loaded transformers may need more frequent oil-sampling and complementary testing such as interfacial tension.

d)   The testing frequency should be established by means of a cost/benefit evaluation based on life cycle analysis and risk assessment. For some owners this approach may indicate different testing frequencies from those indicated in Table 4. For instance, some electrical utilities may prefer not to perform this programme on to this type of transformer and small industries may prefer to include this type of transformer even in a higher category.

Table 4 – Recommended frequency of testing [a]

Property [b]	Equipment category [c]							
	O	**A**	**B**	**C** [d]	**D** [e]	**E** [e]	**F**	**G**
Group 1 (routine tests) [f] – years	1 to 2	1 to 3	1 to 4	2 to 6	1 to 2	2 to 6	2 to 6	2 to 6
Group 2 (complementary tests)	[g]							
Group 3 (special investigative tests)	[h]							
Group 3 (passivator content)	6 months or less, depending on the rate of decrease and the absolute value.							

[a] These proposed periods refer to a normal routine maintenance programme. Should one or more of the measured properties indicate that the oil is in a fair or poor condition or if an abnormal ageing trend is observed, these periods should be shortened according to the importance of the equipment. These periods may also be shortened in the case of oils contaminated by PCB in order to minimize any potential environmental impact caused by malfunctioning equipment.

[b] Groups 1, 2 and 3 are defined in Clause 3 and as a footnote to Table 1.

[c] Equipment categories are defined in Table 2.

[d] See 9.2 d).

[e] Categories D and E. After the first sample has been taken, the user, after consultation with the manufacturer and/or laboratory, may decide to lengthen the sampling period.

[f] Group 1 tests shall be performed after filling or refilling the transformer, prior to energizing.

[g] These tests may be done periodically but less frequently than routine tests. The frequency will depend upon the type of oil, age and equipment. First (benchmark) measurements should be carried out in new or refurbished equipment prior to energization.

[h] These are very special tests that need be carried out only under special circumstances.

9.3 Testing procedures

9.3.1 General

The venue for testing and the number and type of tests that can be carried out on a given sample of oil may vary depending on local circumstances and economic considerations.

Oil in service varies widely in the extent of degradation and the degree of contamination. In general, a single type of test is insufficient to evaluate the condition of the oil sample.

Evaluation of the condition should preferably be based upon the composite evaluation of significant characteristics determined in suitably qualified and properly equipped laboratories. However, some users find it advantageous to carry out field screening tests.

9.3.2 Field tests

In some circumstances there is a need to perform tests closer to the point of sampling rather in the laboratory. These are typically chosen to meet the following requirements:

- obtain a prompt estimation of oil condition;
- establish the classification of service-aged oils (see 9.4);
- eliminate any changes to the oil sample's properties due to transportation to a laboratory and/or storage of oil samples.

Field tests may also be performed where there are on-site and on-line test instruments with an accuracy comparable to laboratory test instruments.

Some field tests are less accurate than laboratory tests. Field tests are usually limited to visual inspection (colour and appearance), breakdown voltage, water content and, with less accuracy, acidity. These tests may sometimes be used for the assessment of service-aged

oils in accordance with 9.4, though, more often, field tests are carried out to identify oil samples requiring laboratory evaluation.

Experience has shown that breakdown voltage and water content tests carried out on site may produce reliable results and may be used for acceptance tests.

9.3.3 Laboratory tests

A complete examination scheme includes all the tests listed in Table 1. However, these tests may be sub-divided into three groups and tests applicable to one or more groups may be required according to the specific requirements (see Tables 1 and 4).

9.4 Classification of the condition of oils in service

It is virtually impossible to set hard and fast rules for the evaluation of oil in service or recommend test limits for all possible applications of insulating oil in service. The classification and any consequent corrective action should only be taken after due consideration of the results of all tests. The trend of such results over a period of time is considered essential information when arriving at a final decision.

According to local or current industrial experience, oils in service may be classified as "good", "fair" or "poor" based on the evaluation of significant properties and their ability to be restored to the characteristics desired. Table 5 provides guidance to assist in this classification process.

- **Good**

  Oil in normal condition; continue normal sampling.

- **Fair**

  Oil deterioration detectable; more frequent sampling recommended (see Table 5).

- **Poor**

  Oil deterioration abnormal; schedule effective actions.

9.5 Corrective action

In general, two types of contamination/deterioration of the oil can be considered: physical and chemical. Each one requires a different remedial action as described in Table 5 below.

The following recommendations should also be noted:

a) Where a test result is outside the limits recommended in Table 5, it should be compared with previous results and, if appropriate, a fresh sample obtained for confirmation before any other action is taken.

b) If rapid deterioration or acceleration in the rate of deterioration is observed, more frequent tests (see Table 4) should be instituted promptly and appropriate remedial action should be taken. It may be desirable to consult the manufacturer of the equipment.

Table 5 – Application and interpretation of tests *(1 of 4)*

Property	Category [a]	Recommended action limits			Recommended action [b, c]	Notes
		Good	**Fair**	**Poor**		
Colour and appearance	All	Clear and without visible contamination		Dark and/or turbid	As dictated by other tests	Dark colour is a symptom of chemical contamination or ageing. Turbidity is a symptom of high water content
Breakdown voltage (kV)	O, A, D	> 60	50 to 60	< 50	Good: Continue normal sampling. Fair: More frequent sampling. Check other parameters, e.g. water, particle content and perhaps DDF/resistivity and acidity. Poor: Recondition the oil (see 11.2) or, alternatively, if more economical because other tests indicate severe ageing, replace (see Clause 12) or reclaim (see 11.3) the oil combined with subsequent drying procedures	
	B, E	> 50	40 to 50	< 40		
	C	> 40	30 to 40	< 30		
	F	< 30 kV for OLTC in star-point application. < 40 kV for OLTC in delta or line-end application				
	G			< 30		
Water content (mg/kg at transformer operating temperature)	O, A	< 15	15 to 20	> 20	Good: Continue normal sampling. Fair: More frequent sampling. Check other parameters e.g. breakdown voltage, particle content and perhaps DDF/resistivity and acidity. Poor: Check source of water, recondition the oil (see 11.2) or, alternatively, if more economical because other tests indicate severe ageing, replace (see Clause 12) or reclaim (see 11.3) the oil combined with subsequent drying procedures, although regard should be taken of the quantity of water that will still be retained in the solid insulation	The values of water content shall be always regarded together with the values for breakdown voltage. In case of a suspicion of a moisture problem, sampling at different equipment temperatures is recommended. In case of switching equipment without paper insulation (Category F), the values of breakdown voltage are of overriding importance. The listed limit values represent 90 % statistical values and are valid for transformer operating temperatures. The equilibrium between solid and liquid insulation under 40 °C is not reliable and for heavy loaded transformers with oil temperature over 70 °C an implementation of the correction procedure described in Annex A may be useful.
	B, D	< 20	20 to 30	> 30		
	C, E	< 30	30 to 40	> 40		
	F	Action necessity > 40				
	G	Not a routine test				

Table 5 *(2 of 4)*

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Property	Category [a]	Recommended action limits			Recommended action [b, c]	Notes
		Good	**Fair**	**Poor**		
Acidity (mg$_{KOH}$/g$_{oil}$)	O, A, D	< 0,10	0,10 to 0,15	> 0,15	Good: Continue normal sampling.	
	B, E	< 0,10	0,10 to 0,20	> 0,20	Fair: More frequent sampling. Check the presence of sediment and sludge. An inhibited oil that reached fair values has possibly lost its oxidation protection.	
	C	< 0,15	0,15 to 0,30	> 0,30	Poor: Starting from a value of 0,15 a decision may then be made at which point to reclaim the oil (see 11.3) or, alternatively, if more economical and other tests indicate severe ageing, replace the oil (see Clause 12)	
	F, G	Not a routine test				
Dielectric dissipation factor at 40 Hz to 60 Hz at 90 °C	O, A	< 0,10	0,10 to 0,20	> 0,20	Good: Continue normal sampling.	
	B, C	< 0,10	0,10 to 0,50	> 0,50	Fair: More frequent sampling. Check other parameters. Poor: Reclaim oil (see 11.3) or, alternatively, if more economical because other tests indicate severe ageing, replace the oil (see Clause 12)	
	D	< 0,01	0,01 to 0,03	> 0,03	Refer to manufacturer's best practice	
	E	< 0,10	0,10 to 0,30	> 0,30	Refer to manufacturer's best practice	
	F, G	Not a routine test				
Resistivity (GΩm)	At 20 °C				Good: Continue normal sampling.	
	O, A	> 200	20 to 200	< 20	Fair: More frequent sampling. Check other parameters.	
	B, C	> 60	4 to 60	< 4	Poor: Reclaim the oil (see 11.3) or alternatively, if more economical because other tests indicate severe ageing, replace the oil (see Clause 12)	
	D	> 800	250 to 800	< 250		
	E	> 60	7 to 60	< 7		Not a routine test
	At 90 °C					
	O, A	> 10	3 to 10	< 3		
	B, C	> 3	0,2 to 3	< 0,2		
	D	> 50	10 to 50	< 10		
	E	> 3	0,4 to 3	< 0,4		Not routine test

Table 5 *(3 of 4)*

Property	Category [a]	Recommended action limits			Recommended action [b, c]	Notes
		Good	**Fair**	**Poor**		
Inhibitor content	All	> 60 % of original value	40 % to 60 % of original value	< 40 % of original value	Good: No action require if not indicated by other properties. Fair: (where acidity < 0,08 mgKOH/g and IFT > 28 mN/m). Consider re-inhibition to original base line level based on local experience. Poor: Continue to use and monitor as uninhibited oil, reclaim (see 11.3) or change the oil (see Clause 12)	Restricted to inhibited oils Consult oil supplier
Passivator content (mg/kg)	O, A, B, C, D, E, F	> 70 and stable, (rate of decrease < 10mg/kg/year)	50-70 mg/kg or < 70 mg/kg, with a significant rate of decrease of >10mg/kg/year	< 50 and decreasing at > 10mg/kg/year	Good: less frequent monitoring acceptable. Fair: maintain regular monitoring. Poor: remove the source of corrosivity by changing the oil (see Clause 12) or by removing corrosive compounds by mean of suitable oil treatments, *or* as a short-term solution, top up with new passivator, to at least 100mg/kg (see Clause 13)	Aged oil, especially uninhibited oil, runs a larger risk of rapid depletion of passivator
Sediment and sludge (%)	All	No sediment or precipitable sludge. Results below 0,02 % by mass may be neglected			Where sediment is detected, recondition oil (11.2). Where precipitable sludge is detected reclaim oil (see 11.3). Alternatively if more economical, or other tests dictate, replace the oil (see Clause 12)	Not a routine test. Perform only when acidity and dissipation factor values are near the limits
Interfacial tension (mN/m)	O, A, B, C, D Inhibited Uninhibited	> 28 > 25	22 to 28 20 to 25	< 22 < 20	Good: Continue normal sampling. Fair: More frequent sampling. Poor: Check the presence of sediment and sludge	Not a routine test. May be done as desired
	E	Not a routine test				
	F, G	Not applicable			Refer to manufacturer's best practice	

Table 5 *(4 of 4)*

Property	Category [a]	Recommended action limits			Recommended action [b, c]	Notes
		Good	**Fair**	**Poor**		
Corrosive sulfur	O, A, B, C, D, E, F	Non corrosive		Corrosive	For corrosive oil: - conduct risk assessment - reduce the corrosivity of the oil by adding a copper passivator (e.g. triazole derivates) *or* - remove the source of corrosivity by changing the oil (see Clause 12) or by removing corrosive compounds by mean of suitable oil treatments. See [d]	The necessity of corrective actions is to be carefully evaluated on the base of a risk assessment study (CIGRÉ Brochure no. 378, 2009 [5]). After passivation of the oil, regular monitoring the concentration of the passivator is necessary. In case of continuous depletion of concentration of the passivator remove the cause of corrosivity accordingly with recommended actions
Particles (counting and sizing)	O, A, B, C, D, E, F	See Table 9			If the breakdown voltage and water content are near or outside the limit for the appropriate equipment category and the particle number is higher than the limits for any of the size ranges, filter the oil (see 11.2)	Values for particles are based on statistical evaluation (Table 9). See [e]
	G	Not a routine test				
Flash point	All	Maximum decrease 10 %			Equipment may require inspection. Investigate	Not a routine test. May be required when an unusual odour is noticed, when an internal fault has occurred or when a transformer is refilled. In some countries health and safety legislation may preclude a higher limit
PCB	All	See NOTE to 5.16			See 11.4 and 12.3	See 5.16

[a] Category of equipment (see Table 2).

[b] Ensure sampling was properly done, sampling valve was properly cleaned before sampling (Clause 6) and transportation and storage periods in the laboratory were short.

[c] No action should be taken on the basis of one result and one property. All results shall be confirmed by a repeat sample especially if the result appears abnormal compared to the trend of the previous results obtained.

[d] If the oil test for corrosivity is positive and DBDS is present, follow the recommendations of CIGRÉ Brochure 378:2009 [3] for the appropriate mitigation actions.

[e] If there is a tendency for particles to increase, it may be necessary to make a determination of metals and other elements dissolved in the oil (see Table B.1).

Table 6 – Summary of typical actions

Key factors	Symptoms	Corrective actions
Physical	High water content Low breakdown voltage value High particles content Turbid (not clear)	Reconditioning (see 11.2)
Chemical	High colour value Low IFT High acidity value High dissipation factor value Presence of sediments or sludge, or both	Reclaiming (see 11.3): *or* Change the oil (see Clause 13)
	Low inhibitor content, for inhibited oil Low passivator content for passivator containing oil	Restore original additive concentration according to recommendations in Table 5
PCB	PCB contamination detectable	Refer to local regulations (see 11.4)
Corrosive sulphur	Oil corrosiveness	Perform risk assessment and correct as necessary: - passivation (see Clause 13) - oil change (see Clause 12) - reclaiming (see 11.3)
NOTE 1 In some cases, if the chemical contamination is extremely high, it may be more economical to replace the oil. A reclaiming viability test (see 11.3.3) is recommended.		
NOTE 2 The more aged the oil is at the time of passivation, and the more severe the operating conditions, the higher is the risk that passivation is not a sufficient long-term remedy. A more detailed scheme for dealing with corrosive sulphur and copper sulphide formation is proposed in CIGRÉ, Brochure no. 378, 2009 [5].		

It is emphasized that no action should be taken on the basis of one result and one property. Repeat samples are recommended where the result appears abnormal compared to the trend of the results previously obtained.

10   Handling and storage

CAUTION Safe drum handling and environmental procedures should be adopted according to local regulations. Special attention shall be paid to avoid cross contamination by PCBs.

To ensure satisfactory service, the utmost care in handling the oil is essential. Drums should be clearly marked to indicate whether they are for clean or for dirty oil, and should be reserved for the type indicated. Drums and bulk tankers used for oil awaiting reclamation should not be used for any other product.

Drums should be stored horizontally and placed in such a position that there is a head of oil on the stopper or plug. They should be stored under cover to minimize the ingress of water and to reduce solar thermal cycling due to exposure to sunlight. The use of plastic sheeting is not recommended unless great care is taken to avoid the drums "sweating" with condensation.

During transportation, drums should be in the vertical position for stability and covered to prevent the ingress of water.

In practice, difficulty may be experienced in maintaining the purity of oil when it is transferred from one vessel to another due to the possibility of introducing contamination. Such practice is not recommended without strict adherence to quality control.

It is recognized that storage of oil in damaged drums is not always satisfactory and the transfer of oil from such containers to electrical equipment should be through a suitable treatment plant to remove water and dissolved gases.

In locations with fixed oil-handling equipment, the pipe-work from the clean oil tanks to the electrical apparatus should be kept clean and free from water. Dehydrating breathers should be regularly inspected and maintained. Where portable oil-handling equipment is used, flexible pipe-work and hand pumps should be carefully inspected to ensure that they are free from dirt and water, and should be flushed with clean oil before use. If the clean oil is from drums, it should have been recently tested, and the filling orifices of the drums should be clean.

Hoses used for clean oil and hoses used for dirty oil should be clearly marked and provided with plugs for sealing the ends when not in use. Hoses shall be resistant to oil, as ordinary rubber contains free sulphur, which is corrosive. If wire braided hoses are used the hoses shall be cross-bonded and properly grounded to prevent the build-up of any static charge. For specific problems, reference should be made to the equipment manufacturer's instructions.

11 Treatment

11.1 WARNING

The treatment of used oil has to be carried out with proper care. All countermeasures should be taken to minimize any unreasonable risk to workers, public health and the environment. Experienced and qualified personnel well aware of the associated health and environmental risks associated should always perform oil treatment, strictly in accordance with local regulations. A full risk assessment should always be undertaken before commencing any treatment.

Strict control shall be undertaken in order to avoid cross contamination by PCB.

Strict control shall be undertaken to avoid accidental spills to the environment. Pipes, pumps and hoses shall be carefully inspected for tightness.

As oil treatments are usually carried out under vacuum, special attention shall be paid to avoid emissions to the atmosphere.

Oil treatments produce waste, such as spent filters, oil-contaminated absorbents etc. It is therefore necessary to choose the best available technology to minimize production of waste or spent materials and to dispose of waste strictly according to local regulations.

If the treatment is performed on on-load equipment, strict safety measures shall be taken to avoid risks to the workers. Also, safety measures shall be taken to avoid any damage to the equipment itself.

Due care should be taken when working with hot oil. Workers should use appropriate personal protective equipment according to local regulations and the Risk Assessment.

The properties of the oil after any treatment should be agreed between service provider and customer.

11.2 Reconditioning

11.2.1 General

Two documents exist that give information on reconditioning CIGRÉ Technical Brochure 227, 2003 "Life management techniques for power transformer" [2] and CIGRÉ Technical Brochure 413, 2010 "Insulating Oil Reclamation and Dechlorination" [6].

Reconditioning is a process that eliminates or reduces physical contamination by means of physical processes (filtration, drying, degassing etc.).

Reconditioning is carried out at the user's site, employing physical means only, to remove contaminants from the oil. However, this process does not always result in oil that conforms to Table 3 of this standard.

Reconditioning reduces the particle and water content of the oil. The process may also remove some dissolved gases and other components such as furanic compounds. New datum levels should be established after such a process.

The physical means that are used for removing water and solids from oil include several types of filtration, centrifuging and vacuum dehydration techniques.

If vacuum treatment is not employed it is advisable to limit the temperature to 30 °C. If vacuum treatment is employed, a higher temperature may be advantageous. However, if the vacuum treatment is used, the initial boiling point of the oil being treated should not be exceeded, to avoid undue loss of lighter fractions. If this information is not available, it is recommended that the oil should not be vacuum treated at temperatures over 85 °C.

NOTE Processing inhibited mineral oil under vacuum and at elevated temperatures may cause partial loss of oxidation inhibitors. The common inhibitors, 2,6-di-tert-butyl-paracresol and 2,6-di-tert-butyl-phenol, are more volatile than mineral insulating oil. The selectivity for removal of water and air in preference to loss of inhibitor and oil is improved by use of a low processing temperature.

If it is desirable to reduce particles or free water, cold treatment at atmospheric pressure may be appropriate.

Filters efficiently remove solid impurities, but are generally capable of removing only small quantities of free water. Where relatively large quantities of free water are present, most of it can, and should, be removed before filtration of the oil.

Equipment used for filtering oils subject to the risk of contamination by carbon (e.g. from tapchangers) should not be used for other oils because of the risk of cross-contamination.

To prevent loss of additives, the conditions that have been found satisfactory for most inhibited mineral oil processing are shown in Table 7.

**Table 7 – Conditions for processing inhibited and/or
passivator containing mineral insulating oils**

Temperature °C	Minimum pressure Pa
40	8
50	15
60	30
70	80
80	200
85	280

Centrifugal separators are, in general, satisfactory for removing free water from oil and can deal also with any finely divided solid impurities.

If oil is purified whilst hot, its viscosity is reduced and the throughput with certain types of purifier is greater. On the other hand, sludge and free water are more soluble in hot oil than in cold. Particles and free water are, therefore, more effectively removed by cold treatment. Dissolved and free water and dissolved gases are effectively removed by hot vacuum treatment.

If the oil contains solid matter, it is advisable to pass it through some type of filter before processing it under vacuum.

11.2.2   Reconditioning equipment

11.2.2.1   Filters

Filtering equipment usually forces oil under pressure through absorbing material such as paper or other filter media. Filters of this type are normally used to remove contaminants in suspension. It should be noted that the nominal micron ratings, commonly used to characterise these filters, are based on gravimetric tests and applying efficiency, based on weight, which takes no regard of particle size. (The filter medium should be capable of removing particles larger than 10 μm although local regulations may prescribe a lower value e.g. 5 μm). Such equipment does not de-gas the oil.

The ability of a filter to remove water is dependent upon the dryness and quantity of the filter medium. When filtering oil that contains water, the water content of the filter medium rapidly comes into equilibrium with the water content of the oil. A continuous indication of the water content of the outgoing oil is useful to monitor the efficiency of the process.

Care should be taken to ensure that paper filters are of the correct grade so that they do not shed fibres.

During service, filters become contaminated with used oil and solid contaminants, therefore the disposal of filters should be carried out strictly in accordance with local regulations. Special consideration will have to be given to filters likely to be contaminated with PCB.

11.2.2.2   Centrifuges

In general, a centrifuge can handle a much greater concentration of contaminants than can a conventional filter but cannot remove some of the solid contaminants as completely as a filter.

Consequently, the centrifuge is generally found in use for rough bulk cleaning where large amounts of contaminated oil have to be handled.

Often the output of the centrifuge is put through a filter for the final clean-up.

11.2.2.3   Vacuum dehydrators

The vacuum dehydrator is an efficient means of reducing the gas and water content of a mineral insulating oil to very low values. (The use of a vacuum dehydrator to remove excessive water from paper insulation systems using oil circulation is not an efficient process. Special techniques may need to be considered.)

There are two types of vacuum dehydrator; both function at elevated temperature. In one method, the treatment is accomplished by spraying the oil into a vacuum chamber; in the other, the oil flows in thin layers over a series of baffles inside a vacuum chamber. In both types, the objective is to expose a maximum surface and minimum thickness of oil to the vacuum.

In addition to removing water, vacuum dehydration will de-gas the oil and may remove some of the more volatile acids and some of the 2-furfural.

11.2.3   Application to electrical equipment

11.2.3.1   Direct reconditioning

The oil is passed through a purifier and then stored in suitable clean containers. When the electrical equipment is to be refilled the oil is passed through the purifier again, and then directly into the equipment. This method can be used for switchgear. It is also suitable, too, for the smaller transformers, but care is needed to ensure that the core, the windings, the interior of the tank and other oil-containing compartments are thoroughly cleaned. The oil-containing compartments of all equipment should also be well cleaned, by means of oil from the purifier.

11.2.3.2   Reconditioning by circulation

The oil is circulated through the purifier, being taken from the bottom of the tank of the electrical equipment and re-delivered to the top. The return delivery should be made smoothly and horizontally at or near the top oil level to avoid, as far as possible, mixing cleaned oil with oil that has not yet passed through the purifier. The circulation method is particularly useful for removing suspended contaminants, but not all adhering contaminants will necessarily be removed.

Experience has shown that it is generally necessary to pass the total volume of oil through the purifier not less than three times, and equipment having an appropriate capacity should be chosen with this in mind. The final number of cycles will depend on the degree of contamination, and it is essential that the process be continued until a sample taken from the bottom of the electrical equipment after the oil has been allowed to settle for a few hours, passes the breakdown voltage test.

It is recommended that the circulation should be performed with the electrical equipment disconnected from the power source. In all cases the oil should be allowed to stand for some time in accordance with the manufacturer's instructions before the equipment is re-energized.

WARNING It is the practice in some countries to perform this process with the transformer energized, but this shall only be done after full risk assessment has been carried out.

Another technique is sometimes used for transformers, in which oil is continuously circulated during normal service through an adsorbent, such as molecular sieve, thus keeping both oil and windings dry and removing many oil oxidation products. This is a specialized method not further considered in this guide.

11.2.3.3 Sealed instrument transformers

In order to avoid the risk of introducing air into the transformer, which may lead to premature failure, oil reconditioning shall be done strictly in accordance with the manufacturer's instructions pertinent at the time of reconditioning.

11.3 Reclaiming

11.3.1 General

This is a process that eliminates or reduces soluble and insoluble polar contaminants from the oil by chemical and physical processing. Reclamation processes require special competence, equipment and experience. The resulting product should be evaluated on critical parameters to achieve information about process efficiency and to be able to estimate remaining lifetime.

This process may result in oil, which originally conformed to IEC 60296, being restored to an acceptable standard. Reclamation of oils of moderate to high acidity will usually result in oils with a lower oxidation resistance than the original new oil.

Before performing a reclamation process, a laboratory feasibility test is recommended.

There are two types of oil reclaiming: percolation and contact.

11.3.2 Reclaiming by percolation

The full process consists of three consecutive steps.

1) The oil, being taken from the bottom of the electrical equipment, is heated to a given temperature and circulated through a filter (to eliminate the particles and suspended solids) being re-delivered to the top.
2) It is then circulated through one or more cartridges containing fuller's earth or other suitable material, to eliminate soluble polar contaminants.
3) The oil is finally circulated through a reconditioning device (vacuum dehydrator or centrifuge) to eliminate water and gases.

Fuller's earth is an active material containing both internal and external polar active sites, which allow the non-polar components of the oil to pass through without retention but which retains the polar contaminants or degradation compounds dissolved in the oil.

Several different clays are available that have proven suitable for these purposes. The most widely used are of the sepiolite, bentonite, attapulgite or montmorillonite type of which fuller's earth is the most commonly used. They are constituted of silicate anions $[Si_2O_5]_n$ condensed with octahedral layers of the type $X(OH)_2$ where X may be magnesium, aluminium, etc.

Normally, fuller's earth is treated to increase its specific surface area and the concentration and polarity of its Lewis acids. Fuller's earth can be used alone or in combination with other chemicals like trisodium phosphate, activated charcoal and sodium silicate.

The retention of contaminants by adsorbent active sites is, generally, improved by temperature, thus the process normally takes place at 60 °C to 80 °C.

Experience has shown that it is usually necessary to pass the total volume of oil through the adsorbent not less than three times; therefore, equipment of appropriate capacity should be chosen for this purpose. The final number of cycles will depend on the degree of initial contamination and the desired final level for properties.

In the case of highly contaminated equipment, it is usual to transfer all the oil to a suitable clean container, reclaim a small portion of the oil and use it to thoroughly wash the electrical

equipment, especially the windings. This portion of the oil is disposed of according to local regulations, and the remaining oil is then reclaimed as described above.

It is important to bear in mind that a small portion of the oil, less than 5 %, remains absorbed by the adsorbent, thus some unused oil shall be used for topping-up the equipment at the end of the process.

During service the adsorbent becomes contaminated with used oil and solid contaminants, therefore the disposal, or re-activation, of the substance should be carried out strictly in accordance with local regulations. Special consideration will have to be given to adsorbent likely to be contaminated with PCB.

NOTE   Some on-line reclaiming and procedures using sorbents or combinations of sorbents and pre-treatment steps have been shown to efficiently remove also corrosive sulphur compounds from oil.

11.3.3   Reclaiming by contact

This process consists of stirring the contaminated oil, in the presence of fuller's earth, in a suitable container. It is not an appropriate system for industrial applications as it needs very long outage periods for the electrical equipment, but may be useful for the recycling of large amounts of waste oils.

Normally this process is used in the laboratory to investigate the feasibility of a reclamation process in a given oil and to estimate the final levels of the properties that can be reached by reclamation in the field.

11.3.4   Renewal of additives

As oil reclamation is performed after the oil its ageing, it is inevitable that the inhibitors (natural or added ones) in the oil are at least partly spent. It is therefore recommended that the additives be replaced in the reclaimed oil after the reclaiming process and before the equipment is re-energized. The most widely used additives are 2,6-di-tert-butyl-paracresol (DBPC) and 2,6-di-tert-butyl-phenol (DBP). Metal passivators will also be reduced or removed due to their polar nature.

11.4   Decontamination of oils containing PCBs

11.4.1   General

As keeping in service transformers containing PCB-contaminated oil may be permitted by some local regulations, these devices shall not always be considered waste. Should the oil became accidentally contaminated, there are several processes and techniques available for either on-site and off-site decontamination of PCB contaminated oils. These processes are based on chemical reactions between PCBs and the reagent to remove the chlorine present. All PCB decontamination methods, either off-site or on-site, have to be applied by skilled companies complying fully with local regulations.

Off-site decontamination techniques are limited by considerations for the safe transportation of contaminated equipment and liquid to an authorized oil processing facility and are the subject of local regulations.

11.4.2   Dehalogenation processes using sodium and lithium derivatives

These processes are typically applied in batch and use reagents based on metallic sodium, sodium hydride, lithium hydride and additives, for the dehalogenation of PCB in the oil. This type of process is typically run under pressure and medium to high temperature (150 °C to 300 °C). This temperature is higher than the flash point of the oil (140 °C to 150 °C) and therefore introduces subsequent safety risks.

WARNING Proper measures shall be taken to minimize the risk of fire or explosion, especially in the presence of wet oil.

11.4.3 Dehalogenation processes using polyethylene glycol and potassium hydroxide (KPEG)

This process, developed to overcome the problems associated with the use of metallic sodium, uses a liquid reagent based on polyethylene glycol (PEG) and an alkaline metal hydroxide such as potassium hydroxide (KOH). This type of process, which is run at temperatures of 130 °C to 150 °C, has a limited efficiency on some types of contaminants (e.g. Aroclor 1242).

11.4.4 Dehalogenation in continuous mode by closed circuit process

This process uses a solid reagent consisting of a high molecular weight glycol mixture, a mixture of bases and a radical promoter or other catalyst for chemical conversion of organic chlorine to inert salts, on a high surface area particulate support.

This process normally runs at 80 °C to 100 °C and has the capability to decontaminate equipment on-site, through continuous circulation of the oil in a closed system (without draining the oil or using auxiliary tanks), using the solvent capability of the oil for continuous extraction of PCB from solid materials inside the equipment.

NOTE Some dehalogenation processes have been shown to efficiently remove some corrosive sulphur compounds from oil.

12 Replacement of oil in electrical equipment

12.1 Replacement of oil in transformers rated below 72,5 kV and in switchgear and associated equipment

A small extra quantity of oil is needed to rinse the interior of the tank and the immersed parts. It is essential that the tank and the surfaces of conductors and insulators be cleaned effectively and subsequently be kept free from fibres. Such fibres are readily introduced by the use of unsatisfactory cleaning materials during plant maintenance; in practice the only efficient and permissible materials are synthetic. It is also essential that the tank and other surfaces be kept free from water.

A final pressure flush with clean oil of known quality has proved beneficial in the removal of fibres and other extraneous material.

It should be noted that possibly up to 10% of the original oil might remain adsorbed in the solid insulation and its contaminants may take some time to migrate into the new oil.

Application of a vacuum extraction procedure has proved valuable in removing other contaminants, provided the equipment can withstand the vacuum.

There should be as little aeration as possible during the filling of tanks and, as far as possible, the end of the delivery pipe should be held below the surface of the oil in order to avoid splashing; alternatively, the tanks should be filled from the bottom.

There should be a standing period of not less than 12 h to allow de-aeration before commissioning transformers (1 h may be adequate for switchgear and 1 h to 2 h for power transformers both with a nominal system voltage of less than 16 kV).

12.2 Replacement of oil in transformers rated 72,5 kV and above

Reference should be made to the equipment manufacturer.

12.3 Replacement of oil in electrical equipment contaminated with PCB

Reference should be made to the equipment manufacturer and local regulations. A full Risk Assessment should be carried out.

13 Passivation

Metal passivator is added as a stock solution, dissolved in insulating oil. Such stock solution is commercially available, but some service providers prepare the stock solution on-site, with oil from the actual unit. The stock solution can be added via an oil processing unit or other suitable equipment.

This treatment is recommended for unused and in-service insulating oil. For in-service oils that fall in fair or poor condition for acidity (Table 5), a case-by-case study is recommended.

Annex A
(informative)

Evaluating water in oil and insulation

A.1   General

The tools presented in this annex for interpreting the results are applicable only if the following conditions are fulfilled:

- equilibrium exists between oil and paper;
- no abnormal ingress of water (leaks);
- presence of paper in the equipment;
- absence of free water.

A.2   Sampling temperature at or above 20 °C

For the proper interpretation of moisture content and for trending purposes, the analytical result of water content of the oil at a given sampling temperature needs to be corrected to that at a defined temperature. For practical reasons, the defined temperature is set at 20 °C, since below 20 °C the rate of diffusion of water is too slow to achieve equilibrium in operational equipment

The correction formula, as demonstrated by several independent studies (Figure A.1), is:

where f is the correction factor and t_s is the oil sampling temperature in Celsius.

The oil sampling temperature t_s should be determined by measuring the temperature directly in the oil stream. In the case that top oil indicator readings or corrections for ONAN or OFAF cooling mode are used, this should be explicitly noted.

NOTE 1   Corrected values are valid only for comparing results obtained at different oil temperatures. Actual values of water in oil at sampling points are the measured values, not the corrected ones.

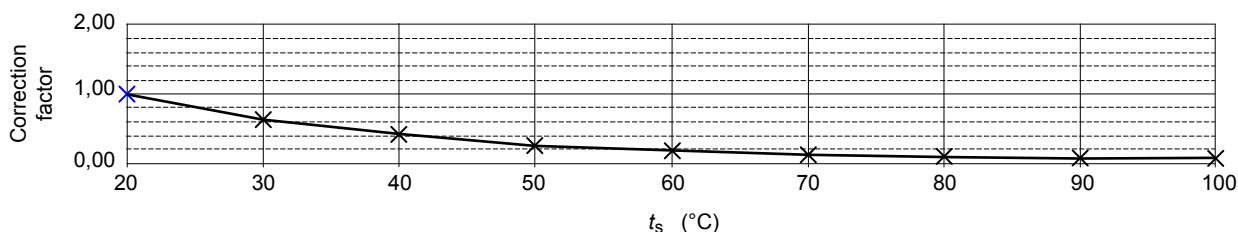NOTE 2   This formula is not applicable to temperatures below 20 °C.

Figure A.1 – Typical correction factors

EXAMPLE

Measured water content	10 mg/kg
Sampling temperature	40 °C
Correction factor (from the formula given in Clause A.2)	0,45
Corrected dissolved water content (10 × 0,45)	4,5 mg/kg

Water saturation of insulating oil is also very useful for trending. Saturation is the ratio of the water content present in a mineral oil at a certain temperature to the solubility of water in mineral oil at the same temperature, expressed in percent. It can be calculated from known values, obtained by Karl Fischer titration or by on-line moisture sensors.

By way of a guide, the condition of cellulosic insulation referred to oil percent saturation is given in Table A.1 below.

Table A.1 – Guidelines for interpreting data expressed in per cent saturation

Percent saturation water in oil %	Condition of cellulosic insulation
< 5	Dry insulation
> 5, <20	Moderately wet, low numbers indicate fairly dry to moderate levels of water in the insulation. Values toward the upper limit indicate moderately wet insulation
20 to 30	Wet insulation
> 30	Extremely wet insulation
Source: IEEE C57.106:2006 [7]	

Annex B
(informative)

Particles

Table B.1 – Typical contamination levels (particles) encountered on power transformer insulating oil as measured using IEC 60970 [a]

Adaption of ISO 4406 (Edition 1999) class	ISO 4406 [8] (Edition 1987) class	Maximum count per 100 ml		Contamination designation	Notes
		5 μm (equal to 6 μm(c))	15 μm (equal to 14 μm(c))		
Up to10/8/5	Up to 8/5	250	32	Background contamination	Cleanliness requirement for sample bottles filled with clean solvent
11/9/6 to 13/10/7	9/6 to 10/7	1 000	130	Low	Oil cleanliness encountered during factory acceptance test and transformer commissioning (Table 3) [b]
14/11/8 to 17/15/12	11/8 to 15/12	32 000	4 000	Good	Contamination level typical for transformers in service
18/16/13 to 19/17/14	16/13 to 17/14	130 000	16 000	Fair	Contamination level found on a significant number of transformers in service
20/18/15 and above	18/15 and above			Poor	Contamination level rare and usually indicative of abnormal operating conditions

NOTE   Considering the field measurements reported by various countries, it is recommended that the contamination level encountered in service should be classified as indicated in this table. A more refined classification would not be realistic in view of the variations that can occur in this type of measurement.

[a]   SOURCE: CIGRÉ Technical Brochure 157, June 2000 [4].

[b]   Statistical survey has shown that values 15/11/9 are more realistic. The cleanliness requirements may depend on the rating and shall be clarified between customer and manufacturer.

Annex C
(informative)

Test method for determination of sediment and sludge

C.1   Sediment determination

To determine sediment:

- weigh a P 10 glass filter or a suitable 8 μm membrane filter to the nearest 0,1 mg;
- filter 100 g of an homogenized sample of the oil through the glass filter;
- flush the filter with 100 ml of n-heptane in portions until the filter is free from oil;
- dry the filter at 105 °C, weigh the filter and calculate the amount of sediment in %.

C.2   Sludge determination

To determine sludge:

- take 25 g of the filtered oil from the sediment determination;
- follow the procedure for sludge precipitation and calculation described in 1.9.1 of IEC 61125:1992.

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[4]   CIGRE Technical Brochure 157, 2000 "*Effect of particles on transformer dielectric strength*

[5]   CIGRE Technical Brochure 378, 2009 "*Copper Sulphide in Transformer Insulation*"

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[8]   ISO 4406:1987, *Hydraulic fluid power – Fluids – Method for coding level of contamination by solid particles*

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[10]   IEC 60599, *Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis*

[11]   IEC 61198, *Mineral insulating oils – Methods for the determination of 2-furfural and related compounds*

[12]   ISO 4407, *Hydraulic fluid power – Fluid contamination – Determination of particulate contamination by the counting method using an optical microscope*

[13]   ISO 4793, *Laboratory sintered (fritted) filters – Porosity grading, classification and designation*

[14]   ISO 6247, *Petroleum products – Determination of foaming characteristics of lubricating oils*

[15]   ISO 12185, *Crude petroleum and petroleum products – Determination of density – Oscillating U-tube method*

[16]   ISO Guide 73, *Risk management – Vocabulary*

[17]   ASTM D 5185: *Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)*

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