IEC 60422

Edition 4.0 2013-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX X

ICS 29.040.10

ISBN 978-2-83220-560-0

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MINERAL INSULATING OILS IN ELECTRICAL EQUIPMENT – SUPERVISION AND MAINTENANCE GUIDANCE

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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,
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- replaced by a revised edition, or
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The contents of the corrigendum of December 2013 have been included in this copy.

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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).

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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.

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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.

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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

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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*

IEC 62697-1:2012, *Test methods for quantitative determination of corrosive sulfur compounds in unused and used insulating liquids - Part 1: Test method for quantitative determination of dibenzyldisulfide (DBDS)*

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*

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

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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

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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.

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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.

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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.

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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 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:

$$W_s = W_{oil} e^{(-B/T)} \tag{1}$$

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.

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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.

1 Figures in square brackets refer to the bibliography.