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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Natural esters – Guidelines for maintenance and use in electrical equipment

Esters naturels – Lignes directrices pour la maintenance et l'utilisation dans les matériels électriques

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Natural esters – Guidelines for maintenance and use in electrical equipment

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COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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NATURAL ESTERS – GUIDELINES FOR MAINTENANCE AND USE IN ELECTRICAL EQUIPMENT

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
10/1123/FDIS	10/1126/RVD

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

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

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

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INTRODUCTION

Natural esters are increasingly being used in transformers and electrical equipment employed in electrical power generation, transmission, distribution and industrial applications.

The use of natural esters is recommended for equipment where the liquid does not remain in continuous contact with ambient air, such as hermetically sealed units, units with closed conservators equipped with a rubber bag (bladder) or external expansion elements (external bag), units with a headspace having either a nitrogen blanket or a confined volume of air (distribution transformers).

Monitoring and maintaining liquid quality are essential to ensure the reliable operation of natural ester 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 liquid tests and to recommend uniform criteria for the evaluation of test data.

If a certain amount of liquid 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 document is to furnish users with as broad a base of understanding of liquid quality deterioration as is available, so that they can make informed decisions on inspection and maintenance practices.

Unused natural ester liquids are sustainable resources and are readily available. Natural esters are, by most regulations, deemed to be regulated and/or controlled waste. If spills occur, the user should refer to the regulations applicable to their specific location and requirements set by their local authorities.

This document, while 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 should be exerted in seeking the best compromise between technical requirements and economic factors.

Application of natural ester liquids in large power transformers at this time is still relatively limited after 20 years although a very large number of units is operating. While the collection of operating data has allowed for the development of this document, care should be used when applying the recommended values. Manufacturers of natural ester liquids should be contacted with specific questions or concerns.

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

The natural esters which are the subject of this document should be handled in compliance with local regulations and supplier’s safety datasheets.

This document is applicable to natural esters, chemicals and used sample containers. The disposal of these items should be carried out according to local regulations regarding their impact on the environment.

NATURAL ESTERS – GUIDELINES FOR MAINTENANCE AND USE IN ELECTRICAL EQUIPMENT

1 Scope

This document provides procedures and guidelines that are intended for the use and maintenance of natural ester liquid in sealed transformers and other electrical equipment.

This document is applicable to natural esters, originally supplied conforming to IEC 62770 and other applicable standards (e.g. ASTM D6871 [1][1]) in transformers, switchgear and electrical apparatus where liquid sampling is practical and where the normal operating conditions specified in the equipment specifications apply.

At present, there is a limited amount of information available for electrical equipment other than transformers.

This document is also intended to assist the power equipment operator to evaluate the condition of the natural ester 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 document includes recommendations on tests and evaluation procedures and outlines methods for reconditioning and reclaiming the liquid, when necessary.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. 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 60422:2013, *Mineral insulating oils in electrical equipment – Supervision and maintenance guidance*

IEC 60475, *Method of sampling insulating liquids*

IEC 60567, *Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases – Guidance*

IEC 60666, *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*

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1 Numbers in square brackets refer to the bibliography.

IEC 61125, *Insulating liquids – Test methods for oxidation stability – Test method for evaluating the oxidation stability of insulating liquids in the delivered state*

IEC 62021-3, *Insulating liquids – Determination of acidity – Part 3: Test methods for non-mineral insulating oils*

IEC 62770, *Fluids for electrotechnical applications – Unused natural esters for transformers and similar electrical equipment*

IEC 62961, *Insulating liquids – Test methods for the determination of interfacial tension of insulating liquids – Determination with the ring method*

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

ISO 2592, *Petroleum products – Determination of flash and fire points – Cleveland open cup method*

ISO 3016, *Petroleum and related products from natural or synthetic sources – 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 12185, *Crude Petroleum and petroleum products – Determination of density – Oscillating U-tube method*

ISO 21018-3, *Hydraulic fluid power – Monitoring the level of particulate contamination of the fluid – Part 3: Use of the filter blockage technique*

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

ASTM D1500, *Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)*

ASTM D1544, *Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)*

ASTM D3455, *Standard Test Methods for Compatibility of Construction Material with Electrical Insulating Oil of Petroleum Origin*

ASTM D6922, *Standard Test Method for Determination of Homogeneity and Miscibility in Automotive Engine Oils*

ASTM D7042, *Standard Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)*

ASTM D7155, *Standard Practice for Evaluating Compatibility of Mixtures of Turbine Lubricating Oils*

ASTM D7647, *Standard Test Method for Automatic Particle Counting of Lubricating and Hydraulic Fluids Using Dilution Techniques to Eliminate the Contribution of Water and Interfering Soft Particles by Light Extinction*

ASTM D7752, *Standard Practice for Evaluating Compatibility of Mixtures of Hydraulic Fluids*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

– IEC Electropedia: available at http://www.electropedia.org/

– ISO Online browsing platform: available at http://www.iso.org.obp

NOTE ASTM and IEEE terminology are given in:

– ASTM D2864, Standard Terminology Relating to Electrical Insulating Liquids and Gases [2],

– IEEE C57.12.80, Standard Terminology for Power and Distribution Transformers [3].

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

Note 1 to entry: These regulations may be defined by local, regional or national legislation or even by 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 document to familiarize themselves with the regulations applicable to their situation. These regulations shall 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 liquid 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 performed to obtain further specific information about the quality of the natural ester, and may be performed to assist in the evaluation of the natural ester for continued use in service

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

4 Categories of equipment

In order to consider the different user requirements, equipment has been placed in various categories as shown in Table 1.

For practical and economic reasons, some electrical utilities may decide that their small transformers up to 1 MVA and 36 kV are not included in this classification. It is possible that routine monitoring programmes are not 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.

Table 1 – 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 conditions.
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).
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 (OLTC), including combined selector/diverter tanks (see Annex C).
NOTE 1 Separated selector tanks of on-load tap-changers belong to the same category as the associated transformer. NOTE 2 Regardless of size or voltage, a risk assessment can justify condition-monitoring techniques usually appropriate to a higher classification. NOTE 3 Due to the very limited number of actual applications, recommended limits are not yet available for Categories D and E. Such categories are here reported only for consistency purposes with IEC 60422. NOTE 4 Regarding Category F, limit values are specified for breakdown voltage (BDV) and water content. For all other parameters, the values have been adopted from the category as the associated transformer.	

5 In-service natural ester diagnostic tests

Many tests may be applied to in-service natural ester liquids in electrical equipment. The tests listed in Table 2 are considered sufficient to determine whether the condition of the in-service natural ester is adequate for continued operation and to suggest the type of corrective action required, if needed.

The tests are not listed in order of priority within a grouping. When more than one test method is reported, the reference method is the first one listed and it is also reported in Clause 9. In case of dispute this method shall be used.

Table 2 – Diagnostic tests for in-service natural esters

	Property	Sub-clause	Method
Group 1 – Routine Tests	Colour and appearance	9.2	ISO 2049[a] or ASTM D1500 or ASTM D1544
	Breakdown voltage	9.3	IEC 60156
	Water content	Annex A	IEC 60814
	Viscosity	9.4	ISO 3104[a] or ASTM D7042
	Acidity (neutralization number)	9.5	IEC 62021-3
	Dielectric dissipation factor (DDF)	9.6	IEC 60247
	Dissolved gas-in-oil [b]	9.7	IEC 60567
Group 2 – Complementary Tests	Fire point	9.8	ISO 2592[a] or ASTM D92
	Interfacial tension (IFT)	9.9	IEC 62961
	Density	9.10	ISO 12185[a] or ISO 3675 or ASTM D7042
Group 3 – Special Investigative Tests (informative)	Flash point	9.8	ISO 2592[a] or ASTM D92
	Pour point	9.11	ISO 3016
	Additives (antioxidant) content	9.12	IEC 60666[a] or other suitable methods or according to manufacturer's advice
	Particles (counting and sizing)	9.13	IEC 60970[a] or ASTM D7647 or ISO 21018-3
	Liquid Compatibility and miscibility	9.14	ASTM D7752[a] or ASTM D7155 and ASTM D6922
	Materials compatibility (see retrofilling)	Annex B	ASTM D3455

[a] Reference method (in case more than one method is specified).

[b] DGA test is intended for hermeticity check only, based on air (N_2 + O_2) content.

6 Evaluation of natural esters in new equipment

A substantial proportion of electrical equipment is supplied to the final user, already filled with natural ester liquids. In these cases, as the natural ester has already come into contact with insulating and other materials, it can no longer be considered as "unused natural ester" as defined in IEC 62770. Therefore, its properties shall be regarded as those applicable to a natural ester in new electrical equipment prior to energization.

Natural ester properties for new equipment shall be appropriate to the category and functions of the transformers and reactors (see Table 3).

NOTE As the characteristics of the natural ester in new equipment prior to energization are an integral part of that equipment design, the user can 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 natural esters properties after filling in new electrical transformers and reactors prior to energization

Property	Highest voltage for equipment (kV)		
	≤ 72,5 kV	72,5 kV to 170 kV	> 170 kV
Appearance	Clear, free from sediment matter		
Colour (on scale given in ISO 2049)	< 2,0		
Breakdown voltage (kV)	> 55	> 60	> 60
Water content (mg/kg) [a]	< 200 [b]	< 150	< 100
Acidity (mg KOH/g)	< 0,08	< 0,08	< 0,08
Dielectric dissipation factor at 90 °C	< 0,07	< 0,07	< 0,07
Density at 20 °C (g/ml)	< 1		
Viscosity at 40 °C (mm^2/s)	< 50		
Fire point (°C)	> 300		
Flash point (°C)	> 250		
Total gas content (dissolved gas analysis) (% or 10^4 µl/l)	< 1,5 [c]		
Total PCB [d] content (mg/kg)	Not detectable		

[a] The values are not corrected for temperature since not enough time may have elapsed to reach an equilibrium between the natural ester 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] This limit (O_2 + N_2 total, only; see Table 2) is applicable only to transformers equipped with a hermetic preservation system and without nitrogen blanked. Differences can be negotiated between customer and manufacturer.

[d] According to IEC 61619 [4] modified for esters.

7 Evaluation of natural ester in equipment in service

7.1 General

A natural ester in service is subjected to heat, oxygen, water and other catalysts, all of which are detrimental to the properties of all insulation. In order to maintain the quality of the natural ester in service, regular sampling and analysis shall be performed.

From an environmental point of view, visual inspection can also be used to monitor leakage and spills of natural esters.

In case of leakage, natural esters are very prone to be oxidized, much faster than mineral oil, forming thin films that are difficult to clean if not done in a short time.

Often the first sign of natural ester deterioration may be obtained by direct observation of the natural ester clarity and colour through the sight glass of the conservator or sight glass of the Buchholz relay.

The interpretation of results, in terms of the functional deterioration of the natural ester, shall 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 natural ester and equipment, developed by statistical methods;

- evaluation of trends and the rate of variation of the values for a given natural ester property;
- typical values, for "good", "fair" and "poor" for the appropriate type and family of equipment as are given in Table 5.

Application of natural ester liquids in power transformers is recommended for sealed equipment only and at this time is still relatively limited compared to mineral oil. The collection of operating data (approximately 35 000 records) from a very large, but young, population of transformers contributed to the development of this document. The recommended values proposed in this document shall be used carefully. Manufacturers of natural ester liquids should be contacted in case of specific questions or concerns.

7.2 Frequency of examination

It is impossible to lay down a general rule for the frequency of examination of natural esters 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 natural esters 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 natural ester deterioration levels which are acceptable for all applications of insulating liquids 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 liquids dielectric 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 but, 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 shall be carried out on the basis of the following criteria, which apply to natural esters as other transformer dielectric liquids.

a) Characteristics may be tested 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 liquid is in fair or poor condition, or when trend analysis indicates significant changes.

c) The degradation of the natural ester will accelerate with increased temperature and in the presence of oxygen (oxidation) and water (hydrolysis). Therefore, heavily loaded transformers may need more frequent liquid-sampling and complementary testing. As a consequence, the use of natural esters is recommended only for equipment that are not open to the atmosphere.

d) The testing frequency shall 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 this type of equipment and small industries may prefer to include this type of equipment even in a higher category.