BS EN 62770:2014

BSI Standards Publication

Fluids for electrotechnical applications — Unused natural esters for transformers and similar electrical equipment

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The UK participation in its preparation was entrusted to Technical Committee GEL/10, Fluids for electrotechnical applications.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Fluids for electrotechnical applications - Unused natural esters for transformers and similar electrical equipment

(IEC 62770:2013)

Fluides pour applications électrotechniques - Esters naturels neufs pour transformateurs et matériels électriques analogues
(CEI 62770:2013)

Flüssigkeiten für elektrotechnische Anwendungen - Neue natürliche Ester für Transformatoren und ähnliche elektrische Betriebsmittel
(IEC 62770:2013)

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Foreword

The text of document 10/909/FDIS, future edition 1 of IEC 62770, prepared by IEC TC 10 "Fluids for electrotechnical applications" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62770:2014.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2014-10-18
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The text of the International Standard IEC 62770:2013 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60422	NOTE	Harmonised as EN 60422.
IEC 61039	NOTE	Harmonised as EN 61039.
IEC 61099	NOTE	Harmonised as EN 61099.
IEC 61868	NOTE	Harmonised as EN 61868.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60076-14	-	Power transformers - Part 14: Liquid-immersed power transformers using high-temperature insulation materials	EN 60076-14	-
IEC 60156	-	Insulating liquids - Determination of the breakdown voltage at power frequency - Test method	EN 60156	-
IEC 60247	-	Insulating liquids - Measurement of relative permittivity, dielectric dissipation factor (tan d) and d.c. resistivity	EN 60247	-
IEC 60296	-	Fluids for electrotechnical applications - Unused mineral insulating oils for transformers and switchgear	EN 60296	-
IEC 60475	-	Method of sampling insulating liquids	EN 60475	-
IEC 60666	-	Detection and determination of specified additives in mineral insulating oils	EN 60666	-
IEC 60814	-	Insulating liquids - Oil-impregnated paper and pressboard - Determination of water by automatic coulometric Karl Fischer titration	EN 60814	-
IEC 61100[1)]	-	Classification of insulating liquids according to fire point and net calorific value	EN 61100	-
IEC 61125	1992	Unused hydrocarbon based insulating liquids - Test methods for evaluating the oxidation stability	EN 61125	1993
IEC 61198	-	Mineral insulating oils - Methods for the determination of 2-furfural and related compounds	EN 61198	-
IEC 61619	-	Insulating liquids - Contamination by polychlorinated biphenyls (PCBs) - Method of determination by capillary column gas chromatography	EN 61619	-
IEC 61620	-	Insulating liquids - Determination of the dielectric dissipation factor by measurement of the conductance and capacitance - Test method	EN 61620	-

[1)] Withdrawn in 2009 and partially replaced by IEC 61039.

IEC 62021-3	-	Insulating liquids - Determination of acidity - Part 3: Test methods for non mineral insulating oils	EN 62021-3	-
IEC 62535	2008	Insulating liquids - Test method for detection of potentially corrosive sulphur in used and unused insulating oil	EN 62535	2009
IEC 62697-1	-	Test method for quantitative determination of corrosive sulfur compounds in unused and used insulating liquids - Part 1: Test method for quantitative determination of dibenzyldisulfide (DBDS)	EN 62697-1	-
ISO 2592	-	Determination of flash and fire points - Cleveland open cup method	-	-
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 - Hydrometermethod	-	-
ISO 12185	-	Crude petrolelum and petroleum products - Determination of density - Oscillating U-tube method	-	-
ASTM D 1275	-	Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils	-	-
OECD 201-203	-	Test Guidelines for ecotoxicity	-	-
OECD 301		Guideline for testing of chemicals adopted by European Council	-	-
US EPA	-	Office of Prevention, Pesticides and Toxic Substances (OPPTS)	-	-
835.311	-	Fate, Transport and Transformation Test Guidelines	-	-

CONTENTS

INTRODUCTION

Because of their higher fire points and better environmental compatibility relative to petroleum derived insulating mineral oil, the use of vegetable oils and other natural esters is on the rise as insulating and heat transfer fluids in electrical devices such as transformers.

This standard sets performance criteria for unused natural esters earmarked for electrical applications. However, the use of natural esters is recommended only for equipment that is not open to the atmosphere, e.g. sealed transformers and reactors because these fluids are prone to rapid oxidation.

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

Unused natural esters which are the subject of this standard should be handled with due regard to personal hygiene. Direct contact with eyes should be avoided. In case of eye contact, irrigation with copious amounts of clean running water should be carried out and medical advice sought.

Performance of some of the tests mentioned in this standard could lead to a hazardous situation. Attention is drawn to the relevant standard test method for guidance.

The disposal of natural esters, chemicals and sample containers mentioned in this standard should be carried out in accordance with current national legislation with regard to the impact on the environment. Every precaution should be taken to prevent the release of natural esters into the environment.

FLUIDS FOR ELECTROTECHNICAL APPLICATIONS – UNUSED NATURAL ESTERS FOR TRANSFORMERS AND SIMILAR ELECTRICAL EQUIPMENT

1 Scope

This International Standard describes specifications and test methods for unused natural esters in transformers and similar oil-impregnated electrical equipment in which a liquid is required as an insulating and heat transfer medium.

Use of natural esters is not recommended for electrical equipment that is open to the atmosphere.

In this standard the term “natural esters” applies to insulating fluids for transformers and similar electrical equipment with suitable biodegradability and environmental compatibility. Such natural esters are vegetable oils obtained from seeds and oils obtained from other suitable biological materials and delivered to an agreed point, at a set time period. These oils are comprised of triglycerides.

Natural esters with additives are within the scope of this standard. Because of their different chemical composition, natural esters differ from insulating mineral oils and other insulating fluids that have high fire points, such as synthetic esters or silicone fluids.

Natural, ester-derived insulating fluids with low viscosity have been introduced but are not covered by this standard. Pertinent properties of such fluids are given in Annex B.

This standard is applicable only to unused natural esters. Reclaimed natural esters and natural esters blended with non-natural esters fluids are beyond the scope of this standard.

The chemical nomenclature and scientific notations used in the standard are in accordance with the IUPAC handbook (Quantities, Units and Symbols in Physical Chemistry).

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 60076-14, *Power transformers - Part 14: Liquid-immersed power transformers using high-temperature insulation materials*

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 and DC resistivity of insulating fluids*

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

IEC 60475, *Method of sampling liquid dielectrics*

IEC 60666, *Detection and determination of specific additives in mineral insulating oils*

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

IEC 61100, *Classification of insulating liquids according to fire-point and net calorific value*[1]

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

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

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

IEC 61620, *Insulating liquids – Determination of the dielectric dissipation factor by measurement of the conductance and capacitance – Test method*

IEC 62021-3, *Insulating liquids – Determination of acidity – Part 3: Test methods for non mineral insulating oils*[2]

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

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

ISO 2592, *Determination of flash and fire point – Cleveland open cup method*

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 fluids – 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*

ASTM D 1275, *Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils*

OECD 201-203, *Test Guidelines for ecotoxicity*

OECD 301, *Guideline for testing of chemicals adopted by European Council on July 17th 1992*

US EPA, *Office of Prevention, Pesticides and Toxic Substances (OPPTS)*

835.311, *Fate, Transport and Transformation Test Guidelines*

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1 Withdrawn in 2009 and partially replaced by IEC 61039.

2 To be published.

3 Terms and definitions

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

3.1
additives
suitable chemical substances which are deliberately added to natural ester insulating fluids in order to improve certain characteristics, e.g. pour point, viscosity, foaming, and oxidation stability

Note 1 to entry: Examples include antioxidants, pour-point depressants, electrostatic charging tendency depressant, metal passivator or deactivators, antifoam agent, refining process improver, etc.

3.2
corrosive sulfur
free sulfur and corrosive sulfur compounds detected by subjecting metals such as copper to contact with an insulating liquid under standardized conditions

[SOURCE: IEC 60050-212:2010, definition 212-18-20, modified – inclusion of "metals such as"]

3.3
natural esters
vegetable oils obtained from seeds and oils obtained from other suitable biological materials and comprised of triglycerides

3.4
potentially corrosive sulfur
organo-sulfur compounds present in transformer oils that may cause copper sulfide formation

[SOURCE: IEC 62535:2008, definition 3.1 – modified, the NOTE to entry has been omitted]

3.5
unused natural esters
unused natural esters as delivered by the supplier

Note 1 to entry: Such a liquid has not been used in, nor been in contact with electrical equipment or other equipment not required for its manufacture, storage or transport.

Note 2 to entry: The manufacturer and supplier of unused natural esters will have taken all reasonable precautions to ensure that the natural esters are not contaminated with polychlorinated biphenyls, polychlorinated terphenyls or polycyclic aromatics (PCB,PCT, PCAs,) or corrosive sulfur compounds; used, reclaimed, or dechlorinated oils, or other contaminants.

4 Properties, their significance and test methods

4.1 General

Salient characteristics of unused natural esters are listed in Table 1.

NOTE Additional information on natural esters for transformers and similar electrical equipment is available in CIGRE brochure 436 and IEEE report C57.147.

4.2 Physical properties

4.2.1 Appearance

A visual inspection of unused natural esters (with light transmitted through approximately 10 cm thickness of natural esters at ambient temperature) indicates the presence of visible contaminants, free water and suspended matter.

4.2.2 Viscosity

Viscosity influences heat transfer and therefore affects the increase of temperature in the transformer and other equipment. The lower the viscosity, the easier the oil circulates leading to better heat transfer. Viscosities at lower temperatures is a critical factor for cold start of transformers with ON cooling (absence of circulation can lead to possible overheating at hot spots). It can have negative impact on the speed of moving parts such as on-load tap changer mechanism, pumps and regulators. Due consideration should be given to viscosity at the lowest cold start energizing temperature (LCSET). Viscosity at 40 °C and 100 °C shall be measured according to ISO 3104.

4.2.3 Pour point

Pour point of unused natural esters is the lowest temperature at which the natural esters will just flow. Pour point shall be measured in accordance with ISO 3016.

Crystallization behaviour of natural esters depends on time and temperature. Crystals should not be present in liquid at application temperature; precautions shall be taken if oil temperature inside the electrical device is lower than 0 °C. Below this temperature thermal and dielectric behavior of the device with natural esters can be adversely affected. A well-defined method to measure crystallization behavior is not available at present.

4.2.4 Water content

Water content of natural esters affects their dielectric properties. Water content shall be measured in accordance with IEC 60814.

NOTE Due to the moderately polar nature of natural esters, water content at which free water will appear and cause deterioration of electric strength is significantly higher in natural esters than that in mineral insulating oils.

4.2.5 Density

Density of natural esters shall be measured in accordance with ISO 3675 (reference method), but ISO 12185 is also acceptable.

4.3 Electrical properties

4.3.1 Breakdown voltage

Breakdown voltage of unused natural esters shall be measured in accordance with IEC 60156.

Because of the difference in properties of natural esters, an initial set-up time is required; it may range between 15 min and 30 min, when there are no visible bubbles in the liquid before measurements are made.

4.3.2 Dielectric dissipation factor (DDF)

DDF is a measure for dielectric losses caused by the liquid. High DDF can indicate contamination of the liquid with moisture, particles or soluble polar contaminants or poor refining quality. DDF shall be measured in accordance with IEC 60247 or IEC 61620 at 90 °C. In case of dispute, IEC 60247 at 90 °C should be used.

By agreement between parties, DDF may be measured at temperatures other than 90 °C. In such cases the measurement temperature should be stated in the report.

4.3.3 Relative permittivity (dielectric constant)

It is the ratio of the amount of electrical energy stored in the liquid at an applied voltage, relative to that stored in a vacuum. It shall be measured in accordance with IEC 60247 or IEC 61620 at 90 °C. In case of dispute, IEC 60247 at 90 °C should be used.

NOTE Typical value 2,8 – 3,3.

4.4 Chemical properties

4.4.1 Acidity

Unused natural esters should be near neutral; acidity shall be measured in accordance with IEC 62021-3.

NOTE Natural esters may contain very low concentrations of free fatty acids; presence of free fatty acids can affect acidity of natural esters.

4.4.2 Corrosive sulfur

Free corrosive sulfur and potentially corrosive compounds are detected by contacting copper with insulating liquid under standardized conditions (IEC 62535 or ASTM D1275B). Known corrosive sulfur compounds such as dibenzyl disulphide (DBDS) shall not be present above detection limit (IEC 62697-1).

NOTE Corrosive sulfur compounds are not naturally present in vegetable oils or other natural esters. The tests can verify that additives are non-corrosive and cross-contamination with potentially corrosive oils has not occurred.

4.4.3 Additive content

Additives include antioxidants, metal deactivators, pour point depressants, etc. Antioxidant additive slows down the oxidation of esters and, in turn, the formation of gels and acidity. One such antioxidant is 2, 6-di-tert-butyl-p-cresol (DBPC), also known as BHT, but others are also used. Detection and measurement of defined anti-oxidant additives shall be in accordance with IEC 60666 or other suitable methods.Total concentration of additives shall be less than a weight fraction of 5 %.

The supplier with mutual consent should declare the generic types of all additives, and their concentrations in the case of antioxidants and passivators. Information on initial type and concentration of additives is useful for supervision and maintenance guidance during the life of natural esters in transformers and similar electrical equipment.

4.4.4 Furfural content

Furanic compounds, including 2-Furfural, are degradation products of Kraft insulating paper; such compounds are not typically present in unused natural esters. 2-Furfural and related compounds shall be determined in accordance with IEC 61198.

NOTE Certain furanic compounds may be present at trace levels in unused natural esters.

4.5 Performance

NOTE This concerns the properties that are related to the long-term behaviour of natural ester insulating fluids in service and/or their reaction to high electric stress and temperature. Acceptable operating temperatures for esters are provided in IEC 60076-14.

4.5.1 Oxidation stability

Unused natural esters are recommended for application only in equipment that is not open to atmosphere because these fluids are prone to rapid oxidation. Oxidation stability of these fluids can be assessed with modifications to the procedure as described in Method C of IEC 61125:1992.

NOTE The modifications in IEC 61125 for natural esters are given in Annex A.

4.5.2 Total acidity

Acidity of natural esters subjected to oxidation stability test. Acidity should be measured in accordance with 1.9.4 of IEC 61125:1992.

4.5.3 Viscosity

Viscosity of natural esters subjected to oxidation stability test shall be measured at 40 °C according to ISO 3104.

4.5.4 Dielectric dissipation factor (DDF)

DDF measurements after oxidation stability test provides a measure for dielectric losses resulting from the water and soluble polar compounds formed in a dielectric liquid as a result of oxidation. DDF shall be measured in accordance with IEC 60247 or IEC 61620.

4.6 Health, safety and environmental (HSE) properties

NOTE These are the properties that are related to safe handling of natural esters and minimization of their adverse impact. Examples can include flash and fire points, polycyclic aromatics (PCAs), and polychlorinated biphenyls/polychlorinated terphenyls (PCBs/PCTs).

4.6.1 Fire point and flash point

The safe operation of electrical equipment requires an adequately high fire point that is measured in accordance with ISO 2592. Flash point is measured according to ISO 2719.

4.6.2 Polychlorinated biphenyls (PCBs)

Unused natural esters shall be free from PCBs.

Concentrations of these chemicals can be measured according to IEC 61619; total concentration shall be less than 2 mg kg^{-1}.

NOTE PCBs and related compounds can be present in unused natural esters only because of cross-contamination.

4.6.3 Biodegradation

Natural esters exhibit better environmental compatibility relative to petroleum-derived insulating mineral oils. Specific tests need to be undertaken to demonstrate ready biodegradability of these fluids. Tests include OECD 301B, C or F; or US EPA – OPPTS 835.311.

NOTE Natural esters can be classified in accordance with IEC 61039, based on biodegradability observed with OECD 301:1992.

4.6.4 Toxicity

Unused natural esters are considered non-toxic and suppliers shall supply assays that define the product as non-toxic.

NOTE Toxicity of natural esters can be assessed with test methods such as a modified Ames test or other suitable internationally recognized assays such as OECD 201-203; US EPA 600/4.82.068:1983.

5 Classification, identification, general delivery requirements and sampling

5.1 Classification

For the purpose of this standard, natural esters are classified in a single class.

– less flammable natural esters.

NOTE There are other natural ester derived liquids, which may have a different classification. However, these liquids are not covered by this standard, an example of such liquids is described in Annex B.

5.2 Identification and general delivery requirements

a) Natural esters are normally delivered in bulk, rail tank cars, tank containers, or packed in drums or (intermediate bulk containers). These shall be clean and suitable for this purpose in order to avoid any contamination.

b) Liquid drums and sample containers shall carry at least the following markings:
   – supplier’s designation;
   – classification;
   – liquid net weight.

c) Each natural esters delivery shall be accompanied by a document from the supplier specifying at least: supplier’s designation, liquid classification and quality certificate. At the request of the purchaser and by mutual consent, the supplier should declare all generic types of additives and their concentrations in a datasheet in accordance with the international and local regulations.

5.3 Sampling

Sampling shall be carried out in accordance with the procedure described in IEC 60475.

Table 1 – General specifications

Property	Test method	Limits
Physical		
Appearance		Clear, free from sediment and suspended matter
Viscosity at 100 °C	ISO 3104	Max. 15 $mm^2 \cdot s^{-1}$
Viscosity at 40 °C	ISO 3104	Max. 50 $mm^2 \cdot s^{-1}$
Pour point	ISO 3016	Max. –10 °C
Water content	IEC 60814	Max. 200 $mg \cdot kg^{-1}$
Density at 20 °C	ISO 3675 or ISO 12185	Max. 1 000 $kg \cdot m^{-3}$
Electrical		
Breakdown voltage	IEC 60156 (2,5 mm gap)	Min. 35 kV [a]
Dissipation factor (tan δ) 90 °C	IEC 60247	Max. 0,05
Chemical		
Soluble acidity	IEC 62021-3	Max. 0,06 mg KOH g_{oil}^{-1}
Corrosive sulfur DBDS	IEC 62535 or ASTM D1275B IEC 62697-1	Non corrosive Below detection limit
Total additives	IEC 60666 or other suitable methods	Max. weight fraction 5 %
Performance – Salient properties after oxidation stability test in accordance with Method C of IEC 61125:1992 [b]		
Total acidity	1.9.4 of IEC 61125:1992	Max. 0,6 mg KOH g_{oil}^{-1}
Viscosity at 40 °C	ISO 3104	Max. 30 % increase over the initial value
DDF (tan δ) at 90 °C	IEC 60247	Max. 0,5
Health, safety and environment (HSE)		
Fire point Flash point	ISO 2592 ISO 2719	Min. 300 °C Min. 250 °C
Biodegradation	US EPA OECD 301 B, C or F US EPA OPPTS 835.311	Readily biodegradable

[a] At delivery.

[b] See Annex A for details of oxidation stability parameters.

Annex A
(normative)

Summary of the test method for evaluating oxidation stability of unused natural esters

A.1 Introductory remark

Oxidation stability of natural esters is evaluated under accelerated aging conditions similar to those described in Method C of IEC 61125:1992.

Aliquots of the natural esters samples are maintained at 120 °C in the presence of a solid copper catalyst, while a constant volume of air is bubbled through the samples for 48 h. The resistance to oxidation is estimated by measuring volatile acidity, soluble acidity, sludge formation, viscosity and DDF. The values obtained for these parameters after accelerated oxidation are compared against the values obtained prior to accelerated oxidation.

A.2 Test conditions

All test conditions i.e. the amount of natural esters, length and diameter of copper catalyst, oxidation temperature and oxidant (air) flow rate are the same as described in Method C of IEC 61125:1992. The only modification is in the duration for accelerated aging, which is set at 48 h.

A.3 Precision

Precision values obtained during the Round Robin test on commercially available natural esters after 48 h oxidation are given in Table A.1. Relative reproducibility for each parameter is based on results obtained from 11 participating laboratories. The values reported in Table A.1 are in general agreement with values reported for mineral insulating oils in IEC 61125.

A.4 Relative repeatability (*r*)

Duplicate determinations carried out by one laboratory at the 95 % confidence level.

A.5 Relative reproducibility (*R*)

Duplicate determinations carried out by different laboratories at the 95 % confidence level.

Table A.1 – Relative repeatability and relative reproducibility obtained for different parameters during RRT

Parameter	*r* %	*R* %
Viscosity at 40 °C	5	7,5
Total acidity	13	38
Sludge	22	57
DDF (tan δ) at 90 °C	–	47

Annex B
(informative)

Specifications of low-viscosity insulating fluids derived from natural esters

From a chemical and biochemical point of view, the natural esters (i.e. esters that can be found in biological materials) comprise many other molecules besides the triglycerides to which the definition of natural esters in this standard refers.

The triglycerides are the main constituents of vegetable oils (and animal fats) and these fluids are usually characterized by high fire point and flash point, which categorize them in class K according to IEC 61100. Compared to mineral oils, they are less flammable but they have also a higher viscosity and a higher pour point.

NOTE According to IEC 61100, class K fluids have a fire point > 300 °C (according to ISO 2592 – open cup) and a flash point > 250 °C (according to ISO 2719 – closed cup)

Other insulating fluids, derived from various natural esters, have been developed for use in some electrotechnical applications (e.g. low/medium voltage power transformers with ONAN cooling). Such fluids mainly consist of fatty acid mono-esters that allow lowering the viscosity or mixtures of triglycerides and fatty acid mono-esters.

The properties of the low-viscosity insulating fluids derived from natural esters are close to those of mineral oils, as shown in Table B.1.

Table B.1 – Specifications for low-viscosity of monoesters derived from natural esters

Property	Test method	Limits
Physical		
Viscosity at 100 °C	ISO 3104	Max. 6 $mm^2 \cdot s^{-1}$
Viscosity at 40 °C	ISO 3104	Max. 18 $mm^2 \cdot s^{-1}$
Viscosity at 0 °C	ISO 3104	Max. 90 $mm^2 \cdot s^{-1}$
Pour point	ISO 3016	Max. –25 °C [a]
Electrical		
Breakdown voltage	IEC 60156 (2,5 mm gap)	Min. 35 kV [b]
Dissipation factor (tan δ) at 90 °C	IEC 60247	Max. 0,05
Health, safety and environment (HSE)		
Fire point	ISO 2592 (open cup)	Min. 175 °C
Flash point	ISO 2719 (closed cup)	Min. 135 °C
Biodegradation	US EPA OECD 301 B,C,F US EPA OPPTS 835.311	Readily biodegradable

[a] LCSET Lowest cold start energizing temperature –10 K.

[b] At delivery and ≥70 kV after treatment (see IEC 60296 for a description of the laboratory treatment).

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IEC 60050-421, *International Electrotechnical Vocabulary – Chapter 421: Power transformers and reactors*

IEC 60422, *Mineral insulating oils in electrical equipment – Supervision and maintenance guidance*

IEC 61039, *Classification of insulating fluids*

IEC 61099, *Specification for unused synthetic organic esters for electrical purposes*

IEC 61868, *Mineral insulating oils – Determination of kinematic viscosity at very low temperatures*

ASTM D6871: Standard specification for natural (vegetable oil) ester fluids used in electrical apparatus

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US EPA 600/4.82.068:1983, *Interim Procedure for Conducting the Salmonella/Microsomal Mutagenicity Assay (Ames Test)*

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