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Introduction

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For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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IEC TC 10 : FLUIDS FOR ELECTROTECHNICAL APPLICATIONS		
SECRETARIAT: Italy	SECRETARY: Mr Riccardo Maina	
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 14, SC 36A, TC 38, TC 112		HORIZONTAL FUNCTION(S):
ASPECTS CONCERNED: Electricity transmission and distribution		

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TITLE:

Interpretation of Dissolved Gas Analysis in natural and synthetic esters

NOTE FROM TC/SC OFFICERS:

A period of 8 weeks for comments can be considered as reasonable, because the document was intensively commented as NWIP.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

Interpretation of Dissolved Gas Analysis in natural and synthetic esters

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

Draft	Report on voting
10/XXXX/FDIS	10/XXXX/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

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

INTRODUCTION

Dissolved gas analysis (DGA) is one of the most widely used diagnostic tools for detecting and evaluating faults in electrical equipment filled with insulating liquid, independent whether this is mineral oil, ester or silicone insulating liquid. However, interpretation of DGA results is often complex and should always be done with care, involving experienced personnel. The standards for gas-in-oil interpretation are to be understood as a guideline tool. For although there is a scientific basis for explaining the formation of gases, the interpretation of the data in terms of cause of failure(s) is not an exact science but derived from empirical evidence from which rules of interpretation have been deduced.

There are several evaluation schemes for mineral oils in transformers and similar equipment, such as key gases, quotient formation, Duval's triangle/pentagons which are anchored in numerous national and international standards, e.g. IEC 60599 or IEEE C57.104. The IEEE standard C57.155 describes the evaluation of the dissolved gas analysis of esters (mainly natural esters) based on absolute values.

Ester insulating liquids have been used in electrical equipment since the 70ies. The regenerative energy demand is growing and with it the demand for synthetic and natural esters. Synthetic and natural esters are used in susceptible environmental areas, they have high flash and fire points and therefore are preferred insulating liquids at stringent fire requirements. There are a some standards for the maintenance of the liquid itself but few for the interpretation of the dissolved gas analysis. This document gives a guidance for the interpretation of dissolved gas analysis in ester filled equipment.

Interpretation of Dissolved Gas Analysis in natural and synthetic esters

1 Scope

The purpose of this guide is to assist the transformer operator in evaluating dissolved gas analysis (DGA) data obtained from natural ester acc. IEC 62770 and synthetic ester acc. to IEC 61099-filled transformers and similar equipment. Due to limited information on equipment filled with mono- and blended esters (IEC 63012) at present they are included in the informative Annex H. Ester liquids are present in the whole range of applications including transport and distribution networks, industrial, traction, wind and solar transformers as reflected in the database. Nowadays their use has been extended to power transformers.

This guide includes the following:

- Gas generation in a natural and synthetic ester-filled transformer
- DGA Interpretation methods (fault type identification and gas levels and comparison with those for mineral oils)
- Gas concentration guide values valid for the use of DGA interpretation tools
- Interpretation of the dissolved gas analysis results.
- Recommended actions based on the interpretation of dissolved gas analysis results.
- Examples of faulty equipment

The indications obtained should be viewed only as a guidance and any resulting action should be taken with a proper engineering judgement.

2 Normative references

IEC 60072, Power transformers – Part 2: Temperature rise for liquid-immersed transformers

IEC 60072, Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air

IEC 60296, Fluids for electrotechnical application – Mineral insulating oils for electrical equipment

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 60599, Mineral oil-filled electrical equipment in service – Guidance on the interpretation of dissolved and free gases analysis

IEC 61039, Classification of insulating liquids

IEC 61099, Insulating liquids – Specifications for unused synthetic organic esters for electrical purposes

IEC 61203, Synthetic organic esters for electrical purposes – Guide for maintenance of transformer esters in equipment

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

IEC 62975, Natural esters – Guidelines for maintenance and use in electrical equipment

IEC 63012, Insulating liquids – Unused modified or blended esters for electrotechnical applications

IEEE Std C57.104-2008, IEEE Guide for the Interpretation of Gases Generated in Mineral Oil - Immersed Transformers

IEEE Std C57.104-2019, IEEE Guide for the Interpretation of Gases Generated in Mineral Oil - Immersed Transformers

IEEE C57.155, IEEE Guide for Interpretation of Gases Generated in Natural Ester and Synthetic Ester-Immersed Transformers

1 Terms, definitions and abbreviations

1.1 Terms and definitions

For the purposes of this document, the following terms and definitions, some of which are based on:

- Electropedia (www.electropedia.org - also available in the standard series IEC 60050), apply when appropriate.
- Terms more specific to the interpretation of DGA and validated by TC10 experts are also used.

1.1.1 Insulating liquids considered in this document

The term **Natural Ester** is used for insulating liquids fulfilling definition and requirements of standard IEC 62770.

The term **Synthetic Ester** is used for insulating liquids fulfilling definition and requirements of standard IEC 61099 (Transformer ester – Type T1).

1.1.2 Fault

Unplanned occurrence or defect in an item which may result in one or more failures of the item itself or of other associated equipment.

[SOURCE: IEC 60599:2022]

1.1.3 Failure

Loss of ability to perform as required.

Note 1 to entry: In electrical equipment, failure will result from a damage fault or incident necessitating outage, repair or replacement of the equipment, such as internal breakdown, rupture of tank, fire or explosion.

[SOURCE: Electropedia, 192-03-01 modified and IEC 60599:2022]

1.1.4 Electrical fault

Partial or disruptive discharge through the insulation

1.1.5 Partial discharge

Electric discharge that only partially bridges gaseous, liquid or solid insulation

Note 1 to entry: Corona partial discharges may form in gaseous voids in solid insulation badly impregnated with oil, or in bubbles of air trapped. Corona partial discharges produce very specific gases - mostly hydrogen - and are abbreviated by convention in IEC 60599 as "PD" or "corona PD".

105 As a result of very large numbers of corona PDs, X-wax (polymerized solid from the insulating liquid) may sometimes
106 be formed. It is often difficult to find by visual inspection.

107 Note 2 to entry: **Scintillations** of low energy and “tracking” on the surface of insulating materials, detected during
108 electrical tests, are often described as partial discharges but should rather be considered as disruptive discharges
109 of low energy, since they are the result of local dielectric breakdowns of high ionization density, or small arcs
110 according to the conventions of physics. They are characterized by the formation of acetylene.

111 [SOURCE: IEC 60599 2022, modified]

112 **1.1.6 Disruptive discharge**

113 **Passage of an electric arc following electric breakdown**

114 Note – Depending on the amount of energy contained in the discharge, it will be described as a discharge of low or
115 high energy based on the maximum current, and the amount of damage to the insulating material.

116 [SOURCE: Electropedia, 212-11-46]

117 **1.1.7 Thermal fault**

118 **Excessive temperature rise in the insulation**

119 Note 1 to entry: typical causes are

- 120 – insufficient cooling or lack of circulation of the insulating fluid;
- 121 – excessive **heat** circulating in adjacent metal parts (e. g. as a result of bad contacts),
- 122 losses due to eddy currents, stray losses or leakage flux;
- 123 – excessive currents circulating through the insulation (as a result of high dielectric losses), leading to a thermal
- 124 runaway;
- 125 – overheating of internal winding, selector or bushing connection lead;
- 126 – overloading.

127 [SOURCE: IEC 60599:2022]

128

129 **1.1.8 90 or 95 percentiles of gas concentrations and gassing rates**

130 **Upper** gas concentrations found in an arbitrary percentage of equipment in service (e.g.: 90%
131 or 95% of the population) **ranked in gas concentration increasing order**

132 Note 1 to entry: Alternatively other values based on justified utility/user experience can be applied.

133 Note 2 to entry: Those values will differ in different types of equipment and in different networks, depending on age
134 of transformer, type and location of the fault, operating practices (load levels, climate, etc.) and will be also dependent
135 on the available number of equipment and analyses included in the evaluated databases.

136 Note 3 to entry: 90 or 95 percentiles are not to be intended as thresholds, alert or alarm limit, **but are intended to**
137 **trigger deeper investigation diagnoses (see also Chapter 5).**

1.2 Abbreviations

1.2.1 Chemical names and formulae

Name	Formula
Nitrogen	N ₂
Oxygen	O ₂
Hydrogen	H ₂
Carbon monoxide	CO
Carbon dioxide	CO ₂
Methane	CH ₄
Ethane	C ₂ H ₆
Ethylene	C ₂ H ₄
Acetylene	C ₂ H ₂

NOTE Acetylene and ethyne are both used for C₂H₂; ethylene and ethene are both used for C₂H₄

1.2.2 General abbreviations

DGA dissolved gas analysis (ref. IEC 60567)

ppm parts per million by volume of gas in oil, equivalent to µl(of gas)/l(of oil). See IEC 60567:2023, 9.7, note 1.

OLTC on load tap changer

PD partial discharges - see 1.1.5

D disruptive discharge – see 1.1.6

T thermal fault – see 1.1.7

Other faults - see Annex C

2 Gas generation in a natural and synthetic ester-filled transformer

2.1 General

Ester insulating liquids (synthetic and natural) exhibit lower environmental impact relative to most mineral insulating liquids (see 61039 and 62770). For this reason, esters are used in susceptible environmental areas and inland and offshore wind **applications**. The disposal of esters, chemicals and sample containers mentioned in this standard, however, can be subject of regulatory requirements and every precaution should be taken to prevent their release into the environment.

They have high flash and fire points and are preferred insulating liquids at stringent fire requirements. Nevertheless, they should not be considered as “not flammable”, but only as “less flammable”. Smoke formation in case of fire is much less than with mineral oils.

The different properties result in different values in the maintenance procedures, e.g. acidity, DDF etc as described in IEC 61203 and IEC 62975 and can influence the gassing behaviour of synthetic and natural esters.

Ester liquids have been already **used** for many years in electrical equipment. The most common use is with distribution and industrial (traction and offshore) transformers. Up to now the experience with medium and power transformers is limited, due to the relative low number esters used in those. This is reflected in the databases gathered.

Fault gases generated in ester liquids under fault conditions are the same as those generated in mineral oil, however, the ratios and rates may be different. This can be due to the differences in their physical and chemical properties in comparison to mineral oils.

2.1.1 Physical and Chemical properties

Natural and synthetic esters exhibit different chemical and physical properties than mineral oils (see IEC 62770 and IEC 61099). The higher viscosity in comparison to mineral insulating oils which may result in longer arcing times with arc-breaking type OLTCs [1].

Esters can be hydrolyzed by water, which may lead to higher acidity and eventually to higher carbon dioxide concentration. Oxidation in a free breathing equipment in case of synthetic esters can also lead to a higher carbon dioxide concentration. Natural ester molecules are composed of long chains of hydrocarbons and can have one or more double bonds called unsaturations. Multiple unsaturated double bonds will cause the development of ethane and hydrogen, especially in the presence of air. Unsaturated bonds will facilitate oxidation, therefore natural esters shall be used in equipment closed from the atmosphere.

Note: some monoesters and blends of monoesters can have lower viscosity.

2.1.2 Dielectrical properties

Esters have different properties under LI (lightning impulse) test, streaming propagation, positive and negative polarities in comparison to mineral oils. Also their electrostatic charging tendency is different [2, 3]. See also 2.1.

2.1.3 Gassing behaviour under dielectric breakdown and thermal stress

User experience shows that the main fault manifestations in gas-in-oil analyses is similar to those of mineral oil. A lot of systematic research on gassing experience and comparison has been carried out. Results of gas-in-oil behaviour under vacuum extraction of uninhibited mineral oil (acc. IEC 60296), synthetic ester (acc. IEC 61099) and natural ester on soybean basis (acc. IEC 62770) under dielectric and thermal conditions are shown below.

2.1.3.1 Example for gas generation under dielectric breakdown conditions [4]

An example for the gas generation under breakdown conditions is shown on Fig. 1.

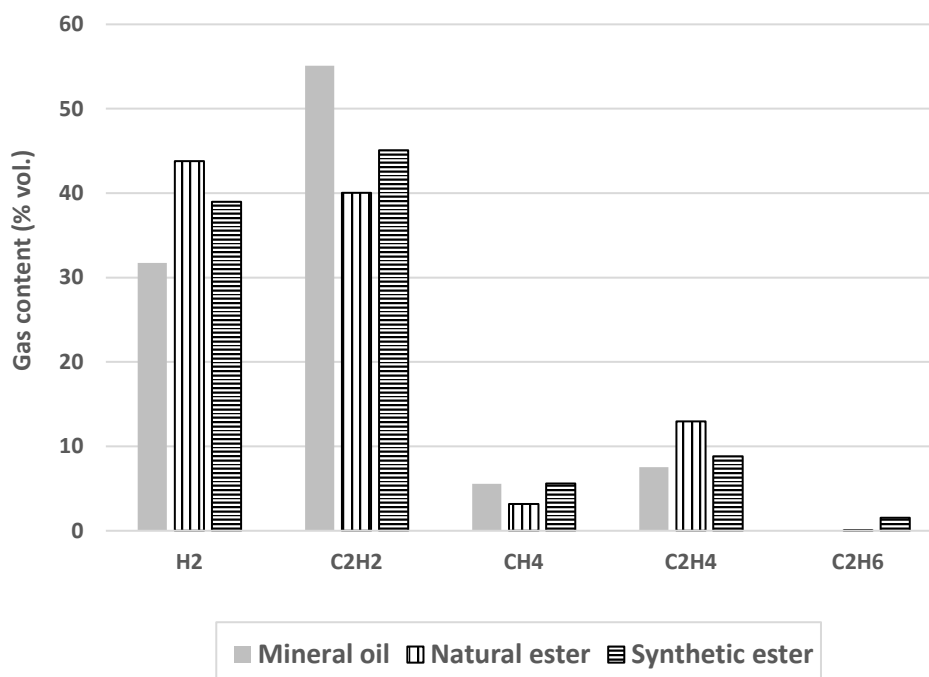


Fig. 1. Relative gas generation after 100 breakdowns in accordance with IEC 60156 (5s pause between breakdowns without stirring).

2.1.3.2 Example for gas generation under thermal conditions [4]

An example for gas generation after ageing at 120°C for 64h on air saturated insulated liquids [i.e., thermal stray gassing of oil according to the definition [5]], is shown on Fig.2.

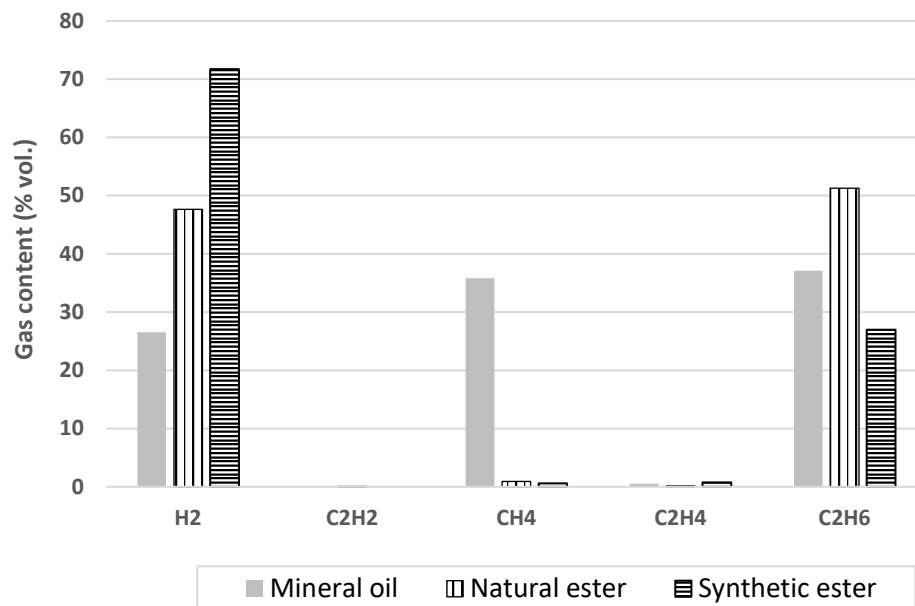


Fig. 2. Gas generation after ageing at 120°C for 64h on air saturated insulated liquids

Note: In this experiment a stray gassing uninhibited mineral oil according to IEC 60296:2020 and natural ester on soybean base have been used.

Similarity in the gas pattern between ester liquids and mineral oil under corona partial discharge conditions have been found in other publications [6, 7]. Although the gas patterns of synthetic and natural esters for partial discharge, discharge and thermal faults are similar for those for mineral oils, the individual gas concentrations may be different.

Since many ester filled transformers can have paper or aramid insulation (or both), at this stage it is difficult to evaluate the source of high carbon dioxide concentration.

2.1.4 Stray Gassing under thermo-oxidative stress

Stray gassing investigations on the presence and absence of air, as well as in presence and absence of copper have been carried out by Cigre WG D1.70 at 105°C for 48h [8]. The results for synthetic ester (IEC 61099) and for natural ester on soybean base (IEC 62770) compared to uninhibited mineral oil (IEC 60296) are presented on Fig 3a – 3c (hydrogen), Fig. 4a – 4c (methane), Fig. 5a – 5c (ethane) and Fig. 6a – 6c (carbon monoxide) respectively. No acetylene has been generated under these test conditions. The amount of ethylene generated under these conditions using those insulating liquids was negligible, therefore not presented in the graphic. Behaviour of other types of natural esters can be different.

Note: A stray gassing test according to [8] in unused state can give a useful indication on the stray gassing performance of the corresponding liquid filling