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Interpretation of dissolved gas analysis (DGA) in natural and synthetic esters

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Interpretation of dissolved gas analysis (DGA) in natural and synthetic esters

FOREWORD

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

Draft	Report on voting
10/1302/FDIS	10/1305/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– withdrawn, or
– revised.

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, independently of 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 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.

Similar guidance for DGA evaluation (interpretation) exists already for mineral oil anchored in numerous national and international standards, for example IEC 60599 or IEEE Std C57™.104-2019 [35][1]. IEEE Std C57™.155-2014 [36] describes the evaluation of the dissolved gas analysis of esters (mainly natural esters) based on absolute values.

Synthetic ester insulating liquids have been used in electrical equipment since the late 70s, natural esters since the late 90s. The electrical energy demand is growing and with it the demand for synthetic and natural esters. Synthetic and natural esters are often used in susceptible environmental areas, due to their high flash and fire points (when stringent fire requirements are demanded) and extended to numerous applications, even independently of their limited flammability. There are some standards for the maintenance of the liquid itself but few for the interpretation of the dissolved gas analysis. This document gives guidance for the interpretation of dissolved gas analysis in ester-filled equipment.

[1] Numbers in square brackets refer to the Bibliography.

1 Scope

This document gives guidelines to the transformer operator in evaluating dissolved gas analysis (DGA) data obtained from natural ester according to IEC 62770 [31] and synthetic ester according to IEC 61099 [29] in liquid filled transformers and similar equipment. Due to limited information on equipment filled with mono- and blended esters (IEC 63012 [33]) at present they are included in Annex D.

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 tables related to the data gathered in this document. Nowadays their use has been extended to power transformers. Ester liquids are also increasingly used in combination with tap-changers. Due to insufficient DGA data available, switching equipment is excluded from this document.

This document includes the following:

– gas generation in a natural or synthetic ester-filled transformer;
– gas concentration guide values valid for the use of DGA interpretation tools;
– methods for the interpretation of the dissolved gas results;
– recommended actions based on the interpretation of dissolved gas analysis results;
– examples of faulty equipment.

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 60475, *Method of sampling insulating liquids*

IEC 60567:2023, *Oil-filled electrical equipment - Sampling of free gases and analysis of free and dissolved gases in mineral oils and other insulating liquids - Guidance*

IEC 60599:2022, *Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis*

3 Terms, definitions, abbreviated terms, chemical names and formulae

3.1 Terms and definitions

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

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

– IEC Electropedia: available at https://www.electropedia.org/
– ISO Online browsing platform: available at https://www.iso.org/obp

NOTE Terms more specific to the interpretation of DGA and validated by TC10 experts are also used.

3.1.1
insulating liquids

3.1.1.1
natural ester
vegetable oils obtained from seeds and oils obtained from other suitable biological materials and comprised of triglycerides

[SOURCE: IEC 62770:2024 [31], 3.1.2]

3.1.1.2
synthetic ester
synthetic organic esters for electrical purposes fulfilling the requirements of Specification Sheet 1 (Transformer ester – Type T1) in IEC 61099

Note 1 to entry: See IEC 61099:2010, Clause 9.

3.1.2
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, 3.1.1]

3.1.3
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: IEC 60599:2022, 3.1.5]

3.1.4
electrical fault
partial or disruptive discharge through the insulation

[SOURCE: IEC 60599:2022, 3.1.6]

3.1.5
partial discharge
electric discharge that only partially bridges gaseous, liquid or solid insulation

Note 1 to entry: Corona partial discharges can form in gaseous voids in solid insulation poorly impregnated with oil, or in bubbles of trapped air. Corona partial discharges produce very specific gases - mostly hydrogen - and are abbreviated by convention in IEC 60599 as "PD" or "corona PD". As a result of very large numbers of corona PDs, X-wax (polymerized solid from the insulating liquid) can sometimes be formed. It is often difficult to find by visual inspection.

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

[SOURCE: IEC 60599:2022, 3.1.7, modified – modified to include detailed description.]

3.1.6
disruptive discharge
passage of an electric arc following electric breakdown

Note 1 to entry: Depending on the amount of energy contained in the discharge, it will be described as a discharge of low or high energy based on the maximum current, and the amount of damage to the insulating material.

[SOURCE: IEC 60050-212:2010 [23], 212-11-46]

3.1.7
thermal fault
excessive temperature rise in the insulation

Note 1 to entry: Typical causes are

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

[SOURCE: IEC 60599:2022, 3.1.9]

3.1.8
90 or 95 percentiles of gas concentrations and rates of gas increase
upper gas concentrations found in an arbitrary percentage of equipment in service (e.g. 90 % or 95 % of the population) ranked in gas concentration increasing order

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

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

Note 3 to entry: 90 or 95 percentiles are not intended to be used as thresholds, alerts or alarm limits, but are intended to trigger deeper investigation diagnoses.

3.2 Abbreviated terms and chemical names and formulae

3.2.1 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_2H_6
Ethylene	C_2H_4
Acetylene	C_2H_2
NOTE Acetylene and ethyne are both used for C_2H_2; ethylene and ethene are both used for C_2H_4. In this document, the chemical names ethylene and acetylene are used.	

3.2.2 Abbreviated terms

D	disruptive discharge – see 3.1.6
DGA	dissolved gas analysis (see IEC 60567)
FAT	factory acceptance tests
OLTC	on load tap changer
PD	partial discharges – see 3.1.5
PFAE	palm fatty acid ester
SFRA	sweep frequency response analysis
T	thermal fault – see 3.1.7
µl/l	V_{gas}/V_{oil} in µl/l, which corresponds to parts per million (1 ppm) by volume of gas in oil. See IEC 60567:2023, 9.7, note 1.

4 Examples for gas generation in a natural and synthetic ester-filled transformer

4.1 General

4.1.1 General

Esters are used in susceptible environmental areas and inland and offshore wind applications. The disposal of esters, chemicals and sample containers mentioned in this document, however, can be subject to regulatory requirements and every precaution should be taken to prevent their release into the environment.

The different properties result in different values in the maintenance procedures, for example acidity, as described in IEC 61203 [30] and IEC 62975 [32], 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 relatively low number of esters-filled transformers of this type. 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 can be different. This can be due to the differences in their molecular structure in comparison to mineral oils. There is ambiguity, e.g. concerning absolute values to be used as a trigger or gas ratios.

The solubility and volatility behaviour of gases with temperature in esters follows similar rules as in mineral oil.

As mentioned in the Introduction, interpretation schemes for mineral oil and esters are to be regarded as a guideline and not as exact rules.

4.1.2 Physical and chemical properties

Natural and synthetic esters exhibit different chemical and physical properties than mineral oils (see IEC 62770 [31] and IEC 61099 [29]). The higher viscosity in comparison to mineral insulating oils can result in longer arcing times with arc-breaking type on load tap changers (OLTCs) [1]. For this reason, vacuum-type OLTCs are preferred.