



TECHNICAL REPORT

Guidance on the interpretation of carbon dioxide and 2-furfuraldehyde as markers of paper thermal degradation in insulating mineral oil

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.040.10

ISBN 978-2-8322-2661-2

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references	7
3 Significance.....	8
3.1 General.....	8
3.2 Thermal and mechanical degradation of paper	8
3.2.1 General	8
3.2.2 Impact of temperature.....	8
3.2.3 Impact of humidity and oxygen	9
3.3 Symptoms of paper ageing in insulating oil	10
3.3.1 General	10
3.3.2 Volatile by-products	11
3.3.3 Soluble by-products	11
3.3.4 Insoluble by-products	11
3.4 Operational parameters influencing paper thermal ageing	11
3.5 Role of oil type and condition	12
3.6 Fault conditions that may affect thermal ageing	12
3.7 Maintenance operations that may affect thermal ageing indicators	13
3.7.1 General	13
3.7.2 Effects of oil reconditioning.....	13
3.7.3 Effects of oil reclamation	13
3.7.4 Effects of oil change	13
4 Monitoring protocol	14
4.1 General.....	14
4.2 Parameters	14
4.2.1 Basic monitoring	14
4.2.2 Complementary monitoring	14
4.3 Recommended testing frequencies	14
5 Typical values of paper ageing symptoms.....	15
5.1 General.....	15
5.2 Families of equipment.....	15
6 Estimation of paper thermal degradation and ageing rate	16
6.1 General approach	16
6.2 Practice	16
7 Actions	17
Annex A (informative) Typical values tables	19
A.1 General warning	19
A.2 2-FAL typical values	19
A.2.1 General	19
A.2.2 Family: GSU (generation step-up units)	19
A.2.3 Family: network transmission units	20
A.2.4 Family: large distribution units	20
A.2.5 Family: industrial distribution units.....	20
A.2.6 Family: LVDC units	21

A.3	Carbon dioxide typical values.....	21
A.3.1	General	21
A.3.2	Family: GSU (generation step-up units)	21
A.3.3	Family: network transmission units	21
A.3.4	Family: large distribution units	22
A.3.5	Family: industrial distribution units.....	22
A.3.6	Family: LVDC units	22
	Bibliography.....	23

Figure 1 – Schematic diagram showing rate of ageing k , depending on different ageing mechanisms.....	9
---	---

Figure 2 – Relationship between mechanical properties of insulating paper and paper degree of polymerization (DP) [5].....	10
--	----

Figure 3 – Example of flow-chart for the estimation of paper degradation conditions.....	17
--	----

Table A.1 – 2-FAL typical values for GSU transformers, filled with uninhibited mineral oil (based on a population of 1 860 units).....	19
--	----

Table A.2 – 2-FAL typical values for GSU transformers, filled with inhibited mineral oil (based on a population of 176 units)	19
---	----

Table A.3 – 2-FAL typical values for network transmission transformers, filled with uninhibited mineral oil (based on a population of 2 845 units)	20
--	----

Table A.4 – 2-FAL typical values for large distribution transformers, with open breathing conservator, filled with uninhibited mineral oil (based on a population of 7 107 units).....	20
--	----

Table A.5 – 2-FAL typical values for large distribution transformers, with sealed conservator, filled with uninhibited mineral oil (based on a population of 288 units)	20
---	----

Table A.6 – 2-FAL typical values for industrial distribution transformers, filled with uninhibited mineral oil (based on a population of 3 885 units)	20
---	----

Table A.7 – 2-FAL typical values for LVDC transformers, filled with uninhibited mineral oil (based on a population of 360 units)	21
--	----

Table A.8 – CO ₂ typical values for GSU and excitation transformers, filled with uninhibited mineral oil (based on a population of 1 098 units)	21
--	----

Table A.9 – CO ₂ typical values for network transmission transformers, filled with uninhibited mineral oil (based on a population of 435 units)	21
--	----

Table A.10 – CO ₂ typical values for large distribution transformers, filled with uninhibited mineral oil (based on a population of 7 291 units)	22
---	----

Table A.11 – CO ₂ typical values for industrial distribution transformers, filled with uninhibited mineral oil (based on a population of 4 556 units)	22
--	----

Table A.12 – CO ₂ typical values for LVDC transformers, filled with uninhibited mineral oil (based on a population of 273 units)	22
---	----

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**GUIDANCE ON THE INTERPRETATION OF CARBON DIOXIDE
AND 2-FURFURALDEHYDE AS MARKERS OF PAPER THERMAL
DEGRADATION IN INSULATING MINERAL OIL**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 62874, which is a Technical Report, has been prepared by IEC technical committee 10: Fluids for electrotechnical applications.

The text of this standard is based on the following documents:

Enquiry draft	Report on voting
10/903/DTR	10/917A/RVC

Full information on the voting for the approval of this Technical Report 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 website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The cellulosic solid insulation of transformers and other electrical apparatus is subject to thermal degradation during their operational lifetime. This results in a progressive loss of paper's mechanical properties, such as tensile strength, which are related to the duration of the technical life of the equipment [3,4] ¹.

During its thermal degradation process (also called "ageing" in this Technical Report), cellulose forms several by-products, some of which may be detected by means of insulating oil's chemical analysis [1,2]. The concentration and rate of increase of those by-products can be used as a tool to estimate the progress of paper thermal degradation in transformers and other electrical apparatus in service.

For this reason, IEC technical committee 10 has prepared this Technical Report for the monitoring of insulating oil parameters related to cellulose ageing and the interpretation of results, as a guidance to the thermal degradation evaluation of insulating paper.

This Technical Report is based on the evaluation of cellulose ageing by-products content in insulating oil, and their rate of formation during the life of the oil-immersed electrical equipment. Statistical reference values reported in Annex A of this Technical Report are based on data collected by TC10. The final report of CIGRE WG D1.01.TF13 [7] was taken as a source of information concerning mechanisms and parameters influencing the formation of furanic compounds.

NOTE Methods for the estimation of actual degree of polymerization (DP) values of paper, which are widely available in literature, were not applied within this Technical Report. This is due to the fact that a number of different models have been developed and reported, and they often lead to different results. Moreover, the applicability of those models has not been sufficiently proven by comparison with field experience to be included into an IEC standard.

Health and safety

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

The mineral oils which are the subject of this Technical Report should be handled with due regard to personal safety and hygiene. Direct contact with 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.

Some of the tests specified in this Technical Report involve the use of processes that could lead to a hazardous situation. Attention is drawn to the relevant standard for guidance.

Environment

This Technical Report involves mineral oils, chemicals and used sample containers. The disposal of these items 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 into the environment of mineral oil.

¹ Figures in square brackets refer to the Bibliography

GUIDANCE ON THE INTERPRETATION OF CARBON DIOXIDE AND 2-FURFURALDEHYDE AS MARKERS OF PAPER THERMAL DEGRADATION IN INSULATING MINERAL OIL

1 Scope

IEC TR 62874, which is a Technical Report provides guidance for the estimation of consumed thermal life of transformers' cellulosic insulators, through the analysis of some compound dissolved in the insulating mineral oil. A comparison between analytical results of 2-furfural (2-FAL) and carbon oxides and their correspondent typical values estimated for different families of equipment gives information on the estimated thermal degradation of papers.

The ageing rate of insulating papers can be evaluated, in short time ranges (e.g. 1 year), by regularly monitoring 2-FAL and carbon oxides content in the oil and by comparing them to typical rates of increase.

A statistical approach for the estimation of paper thermal degradation, and the evaluation of ageing rate is given.

Typical values for concentrations and rates of increase of the parameters related to paper ageing were extrapolated from a statistical database collected, and are reported in Annex A. They may be used as a rough guide, but they should not be considered as threshold values.

This Technical Report is only applicable to transformers and reactors filled with insulating mineral oils and insulated with Kraft paper. The approaches and procedures specified should be taken as a practical guidance to investigate the thermal degradation of cellulosic insulation, and not as an algorithm to calculate the actual degree of polymerization (DP) of papers.

The paper thermal life evaluation protocol described in this Technical Report applies to mineral oil impregnated transformers and reactors, insulated with Kraft paper. Any equipment filled with insulating liquids other than mineral oil (i.e. esters, silicones) or insulated with solid materials other than Kraft paper (i.e. TUP – thermally upgraded Kraft paper, synthetic polymers) is outside of the scope of this Technical Report.

This Technical Report is applicable to equipment that has been submitted to a regular monitoring practice during the service, and for which maintenance and fault history is known.

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.

None.