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BSI Standards Publication

Electrical insulation systems (EIS) — Thermal evaluation of combined liquid and solid components

Part 2: Simplified test

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National foreword

This Published Document is the UK implementation of IEC TS 62332-2:2014.

The UK participation in its preparation was entrusted to Technical Committee GEL/112, Evaluation and qualification of electrical insulating materials and systems.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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TECHNICAL SPECIFICATION

SPECIFICATION TECHNIQUE

colour inside

Electrical insulation systems (EIS) –Thermal evaluation of combined liquid and solid components –
Part 2: Simplified test

Systèmes d'isolation électrique (SIE) – Évaluation thermique de composants liquides et solides combines –
Partie 2: Essai simplifié

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62332-2, which is a technical specification, has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
112/256/DTS	112/268/RVC

Full information on the voting for the approval of this technical specification 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.

A list of all the parts in the IEC 62332 series, published under the general title *Electrical insulation systems (EIS) – Thermal evaluation of combined liquid and solid components*, can be found on the IEC website.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This technical specification describes a method for the thermal evaluation of electrical insulation systems (EIS) for electrotechnical products with combined liquid and solid components. More specifically, this part addresses liquid immersed power transformers. Part 1 covers general test requirements. This Part 2 covers a simplified test method which can be used as a screening test prior to conducting Part 1 testing or it can be used to determine a thermal classification of an EIS. This method can also be used as a quality control test to evaluate minor product changes.

This specification provides a standardized test method for sealed tube testing. The sealed tube should contain all the primary EIS elements, and in relative component ratios which compare with actual liquid immersed power transformers.

This technical specification has been prepared in conjunction with IEC TC 14, *Power transformers* and IEC TC 10, *Fluids for electrotechnical applications*. Any comments or suggestions from other technical committees to make this technical specification more general are welcome.

ELECTRICAL INSULATION SYSTEMS (EIS) – THERMAL EVALUATION OF COMBINED LIQUID AND SOLID COMPONENTS –

Part 2: Simplified test

1 Scope

This part of IEC 62332, which is a technical specification, is applicable to EIS containing solid and liquid components where the thermal stress is the dominant ageing factor, without restriction to voltage class.

This part specifies a sealed tube test procedure for the thermal evaluation and qualification of electrical insulation systems (EIS). One aspect of this procedure is to also provide a method to assign thermal classifications to materials used in EIS where solid and liquid components are both used. This procedure describes a comparative ageing method whereby a reference system composed of kraft paper and mineral oil is compared to a candidate system of any combination of solid and insulating liquid. The test procedures in this part are specifically applicable to liquid immersed transformer insulation systems.

Similar procedures should also work for other electrotechnical devices with a combination of liquid and solid components, such as bushings, cables or capacitors, but this will be added as additional parts once experience is gained using this technical specification.

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 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 60156, *Insulating liquids – Determination of the breakdown voltage at power frequency – Test method*

IEC 60216-2:2005, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1: Ageing ovens – Single-chamber ovens*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

IEC 60243-1, *Electrical strength of insulating materials – Test methods – Part 1: Tests at power frequencies*

IEC 60247, *Insulating liquids – Measurement of relative permittivity, dielectric dissipation factor (tan δ) and d.c. resistivity*

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

IEC 60317 (all parts), *Specifications for particular types of winding wires*

IEC 60450, *Measurement of the average viscometric degree of polymerization of new and aged cellulosic electrically insulating materials*

IEC 60505:2011, *Evaluation and qualification of electrical insulation systems*

IEC 60554-2, *Cellulosic papers for electrical purposes – Part 2: Methods of test*

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

IEC 60599, *Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis*

IEC 60763-2, *Specification for laminated pressboard – Part 2: Methods of test*

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

IEC 60851-5, *Winding wires – Test methods – Part 5: Electrical properties*

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

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

IEC 62021-1, *Insulating liquids – Determination of acidity – Part 1: Automatic potentiometric titration*

IEC 62021-2, *Insulating liquids – Determination of acidity – Part 2: Colourimetric titration*

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

IEC TS 62332-1:2011, *Electrical insulation systems (EIS) – Thermal evaluation of combined liquid and solid components – Part 1: General requirements*

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

ISO 2211, *Liquid chemical products – Measurement of colour in Hazen units (platinum-cobalt scale)*

ASTM D971, *Standard Test Method for Interfacial Tension Of Oil Against Water By The Ring Method*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply, some of which are taken from IEC 60505.

3.1
electrical insulation system
EIS
insulating structure containing one or more electrical insulating materials (EIM) together with associated conducting parts employed in an electrotechnical device

Note 1 to entry: EIMs with different temperature indices (ATE RTE according to IEC 60216-5) may be combined to form an EIS, which has a thermal class that may be higher or lower than that of any of the individual components according to IEC 60505.

[SOURCE: IEC 60505:2011, 3.1.1 – modified, the Note 1 to entry has been added]

3.2
candidate EIS
EIS under evaluation to determine its service capability (thermal)

3.3
reference EIS
evaluated and established EIS with either a known service experience record or a known comparative functional evaluation as a basis

3.4
thermal class
designation of an EIS that is equal to the numerical value of the maximum temperature in degrees Celsius for which the EIS is appropriate according to IEC 60085

Note 1 to entry: An EIS may be subjected to operating temperatures exceeding its thermal class, which can result in shorter expected life.

3.5
EIS assessed thermal endurance index
EIS ATE
numerical value of the temperature in degrees Celsius for the reference EIS as derived from known service experience or a known comparative functional evaluation

3.6
EIS relative thermal endurance index
EIS RTE
numerical value of the temperature in degrees Celsius for the candidate EIS which is relative to the known EIS ATE of a reference EIS when both EIS are subjected to the same ageing and diagnostic procedures in a comparative test

3.7
test object
piece of original equipment, a representation (model) of equipment, a component of or part of equipment, including the EIS, intended for use in a functional test

3.8
thermal ageing factor
thermal stress that causes irreversible changes in the EIS

3.9
diagnostic test
periodic application of a specified level of a diagnostic factor to a test object to determine whether the end-point criterion has been reached

3.10
end-point criterion
selected value of either a property or a change of property that defines the end of a component's life

[SOURCE: IEC 61857-1:2008, 3.11, modified – "component's life" replaces "test object in a functional test]

3.11
end-of-life
end of a test object's life, as determined by any selected component meeting its end-point criterion

3.12
sealed tube
sealed container partially filled with the liquid EIM and in which includes the solid EIM in relative component ratios which compare with the actual electrotechnical device

3.13
halving value
HIC
numerical value of the temperature interval in Kelvins which expresses the halving of the time to end-point taken at the temperature equal to TI

[SOURCE: IEC 60050-212:2010, 212-12-13, modified – "equal to TI" replaces the original "corresponding to the temperature index or the relative temperature index"]

4 Thermal ageing test apparatus

4.1 General description

The thermal ageing test apparatus shall be designed to allow the ageing of solid and liquid components. The reference and candidate EIS shall be exposed to test periods at selected elevated temperatures. These test periods consist of a specific time exposure at the selected temperature followed by diagnostic tests. The test system consists of the following elements:

- sealed tubes
- ageing ovens
- test objects.

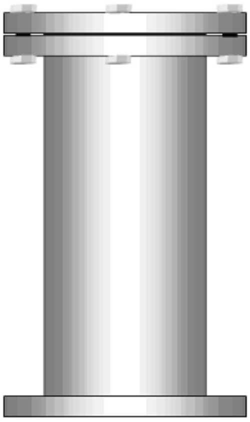
4.2 Sealed tubes

Each sealed tube is a container constructed of stainless steel or other suitable materials such as glass, the size to be determined by the size of the test objects. Additionally, the material for the tube shall either not affect the ageing (such as glass or stainless steel) or identically constructed tubes shall be used for all sets of experiments. The cell volume shall consider the space required for thermal expansion of the liquid at ageing temperatures, as well as space for the EIM to be evaluated. The EIM to be evaluated should be fully immersed in the liquid during the entire test period. Either one or both ends of the cell shall be fitted with removable, sealable bolt-on covers.

Ports shall be provided for

- sampling of the liquid,
- gas blanketing and associated pressure relief system.

For example, see Figure 1.



IEC 1019/14

Figure 1 – Sealed tube example

4.3 Gas blanketing system

A gas blanketing system shall be provided which simulates the insulation system used in the transformer being evaluated. This can be a sealed gas system, which maintains a gas blanket over the liquid in the cell for the purpose of reducing oxidation of the liquid. In each case, the gas blanket in each cell shall be regulated to maintain a positive pressure as is described in below in 4.4.

Free breathing liquid preservation systems are not included due to safety hazard of testing liquids at temperatures above their flashpoints where additional oxygen is available. In the case of a sealed test, the amount of available oxygen is limited.

NOTE Oxygen is known to increase ageing of insulation systems, so a test with air would be expected to be more severe than one sealed with nitrogen.

4.4 Pressure relief system

A pressure relief valve shall be installed on each cell to prevent the internal cell pressure from rising above the capability of the sealed tube. Additionally, the test should simulate the end application which is under evaluation. As an example, for liquid-immersed transformer applications, the transformer tanks are designed to operate at a pressure of up to 150 kPa. The technical evaluation for this design should use a method (such as a pressure relief valve) to control the pressure in the cells at a level consistent with the end use application being evaluated. If not otherwise specified, choose a level of 150 kPa for this test pressure.

Pressure control has two functions. The first is for safety and the second is to control the pressure at a low consistent level to better model the actual transformer application. This pressure control can be accomplished by using a pressure relief value equal to that used on the transformer for which the evaluation is being conducted, or by the means of an expanding bellows which allows increasing gas space of the test cell without an increase of pressure.

4.5 Ageing ovens

The ageing ovens used shall meet the requirements of IEC 60216-4-1.

5 Construction of the test object

5.1 General

The test object is designed to model the EIS portion of the transformer under evaluation and usually consists of

- a conductor insulation,
- other solid insulation components,
- structural components,
- metallic materials (typically copper or aluminium and steel),
- an insulating liquid,
- other components in the candidate if they differ from the reference system and if they reasonably affect the outcome of the test.

5.2 Determination of component weights

It is important that the ratios of weights of components used to construct the test object shall be representative of the candidate transformer being modelled. Determine the percentage of each individual component as a part of the total weight. The percentages shall be used to determine the weight of those individual components to be used in the construction of the test object. In a family of products with the same specific EIS, the ratio of weight of the individual components to the total weight should be similar. Other components which affect aging based on surface area are included on this basis.

Table 1 provides the weights and dimensions of the components to be used in the reference test. This table is based on the ratio of materials assuming 100 g of solid for each type of EIS. Each of the items in this table is described in more detail in the clauses following the table. The reference should be selected that is most appropriate for the candidate under test.

Table 1 – Reference component weight ratio calculations

	Transformer type		
Test material descriptions	**Distribution**	**Power – Core type**	**Power – Shell type**
Insulating liquid	1 330 g	760 g	330 g
Conductor insulation		10 g	10 g
Layer insulation	50 g		
Low density pressboard	50 g	10 g	80 g
High density pressboard		80 g	10 g
Ratio – Liquid to solid	13,3 to 1	7,6 to 1	3,3 to 1
Surface area of core steel	9,6 cm^2	9,6 cm^2	9,6 cm^2
Enamel wire samples	5 samples	5 samples	5 samples
Surface area of copper	9,6 cm^2	9,6 cm^2	9,6 cm^2

In addition to the ratios of the solid and liquid insulation components shown in Table 1, other materials as described in 5.3.4 and 5.3.5 should be included as well, but are not included here for simplicity. Enamel wire samples are described in Annex A.

5.3 Test object

5.3.1 Conductor insulation

Depending on the type of transformer, the conductors can range from small round wires, to larger rectangular wires or metal foils. The insulation for each of these may differ. The insulation may be either enamel coating, conductors wrapped with thin insulating materials or, in the case of the metal foils, thicker papers/films, sometimes with adhesive coatings.

The conductor insulation should be tested in a way that can allow estimation of the expected thermal capability of the material when combined with a fluid. For thin wire wrap materials, the test specimens can be pre-cut tensile strips. A minimum of 20 test specimens per ageing cell should be included in each cell. For enamel coated round wires, twisted wire pairs of can be aged, again with a minimum of 20 test specimens per ageing cell. For applications such as distribution transformers, the thicker layer papers or films used with metal foils, can be evaluated similar to the thin wire wrap materials.

For papers/films with adhesive coatings, a separate test to evaluate the technical characteristic of the adhesive should be conducted. The failure mode for this test may be bond strength retention of the adhesive rather than a tensile retention test of the base paper/film insulation.

Include the same ratio of exposed surface area of the conductor metal (copper or aluminium) as in the transformer being evaluated for paper/film wrapped conductors.

5.3.2 Other solid insulation components

Other solid materials are typically used in the transformers. These components include pressboard products that are adjacent to the conductors (spacer materials), and as such experience the same temperature extremes as the conductor insulation or other materials which are used in the cooler part of the transformer (such as cylinders or oil-flow barriers). In other type of designs, the insulated conductors may be separated by insulating papers which again experience the same extreme temperatures as the conductor insulation. Each of these materials should be included in the correct ratio as described in 5.2.

5.3.3 Liquid component

The cell shall be filled with the liquid component used in the transformer being evaluated. The weight of the liquid shall be determined from requirements in 5.2 based on weight and temperature calculations. Care shall be taken to allow space for expansion of the liquid in the cell at elevated temperatures.

5.3.4 Structural components

Other materials are used in the transformer that are for “mechanical purposes” only, and have no direct impact on electrical performance of the insulation system, but if they fail in the application, could cause a degradation of the insulation system. Examples of such components include, but are not limited to, tie cords, netting tapes, adhesive tapes, etc. Many of these components are manufacturing aids, so a failure in operation is not a design problem, as long as the components degrade in a way that does not affect the other materials (chemical compatibility) or affect design parameters, e.g. block cooling.

These materials could be included in the test consistent with 5.2.

NOTE At present, no method has been developed as to how to evaluate the addition of these materials into the test object. Once experience with this test specification has been obtained, a method to evaluate these materials will be added.

5.3.5 Other components

For products being simulated, representative components that are not included in the EIS but are expected to affect it, shall be included. Examples include pieces of core steel, material supporting the leads, coatings, solder and enclosure materials. The relative weights of these components should match those of the evaluated product, with the exception of magnetic core steel and tank material. The relative quantity of magnetic core steel and tank shall be determined, based on the surface area exposed to the liquid component. An example is given in Annex A. Core steel is considered a surface area rather than a weight ratio since only the surface is available to affect the aging of the insulation system.

In addition to the core steel, these materials could be included in the test consistent with 5.2.

NOTE At present no method has been developed as to how to evaluate the addition of these materials into the test object. Once experience with this test specification has been obtained, a method to evaluate these materials will be added.

6 Test procedures

6.1 General

A three-temperature ageing test shall be completed to establish the thermal rating of the new system. A reference EIS shall be used to validate the testing of the candidate EIS. Unless otherwise stipulated by the equipment technical committee, the reference system shall be cellulose solid insulation and mineral oil.

NOTE For transformers which include enamel coated wires, the enamel coated wires to be evaluated as part of the reference EIS are specified in IEC 60317 – PVF (polyvinyl formal).

6.2 Preparation of the test objects

6.2.1 General

The quantity of samples of solid and liquid insulation should be sufficient to supply all reference and candidate test objects and requirements for diagnostic testing.

All solid samples shall be pre-conditioned by drying. Lower temperature drying will take longer than high temperatures, but will prevent damage of the insulation prior to the ageing experiment. For optimum drying conditions, refer to the relevant material testing standards. The moisture content of the solid insulation materials shall be between 0,25 % and 0,50 % at the start of the ageing.

Immediately after drying, the conductor materials, other solid materials and all additional materials shall be vacuum-impregnated with the liquid under evaluation. The impregnation process is conducted for 6 h to 24 h, at 70 °C to 90 °C.

Prior to inserting the test objects into the ageing cell, remove the pre-conditioned solid and liquid diagnostic test samples. Verify the initial moisture content after the impregnation process to determine whether or not the materials are adequately dried prior to start-up.

A clean, dry ageing cell is then filled with the previously determined weight of liquid and the impregnated solid components are inserted. The cell is quickly sealed then purged with dry sealing gas.

Following its assembly, the ageing cell is placed into an ageing oven. The temperature of the oven is then increased to the ageing temperature.

6.2.2 Reference test object

The reference EIS shall be composed of solid materials and liquid that have an established performance in combination. At the time of issue of this technical specification, the only established reference EIS is composed of cellulose solid materials and mineral oil. The EIS ATE of this reference system is recognized to be 105 °C. However, if the equipment technical committee has established another EIS with known performance, this may be used as the reference EIS. The equipment technical committee should provide specific details:

- conductor with Kraft cellulose insulation (samples described in 5.3.1);

- non-inhibited mineral oil according to IEC 60296.

For verification of reference EIS ageing, a single set of three test objects composed of the reference EIS shall be evaluated along with the candidate test objects. For the reference EIS cellulose and mineral oil system, the ageing temperatures shall be as shown below.

Testing shall be carried out with three temperatures for the referenced EIS as shown in Table 2 below. Evaluate the per cent tensile strength of the three sets and average them for the end of life criteria for the candidate system. Ageing times for the reference EIS is based on a 20,000 h life at the ATE (of 105 °C) with a HIC of 6 K.

Table 2 – Reference EIS ageing conditions and candidate EIS ageing temperatures

Insulation system	**Expected increase in thermal rating** °C	**Ageing time 3 536 h** °C	**Ageing time number 2: 625 h** °C	**Ageing time number 3: 110 h** °C
Reference EIS		130	145	160
Candidate EIS	10	140	155	170
	20	150	165	180
	30	160	175	190
	40	170	185	200
	50	180	195	210
	60	190	205	220

The expected value for the reference EIS at the above times and temperatures is in the range of 25 % tensile strength. For dielectric strength of enamel coated wire, the expected value is in the range of 80 % retained dielectric strength. In either case, the property retention of the reference EIS will determine the end of life criteria for the candidate EIS. Unless there is a good reason for an alternative end of life test (other than tensile strength for solid insulation and dielectric strength for enamel/wire coatings) these should be chosen.

6.2.3 Candidate test object

At least four ageing cells shall be used for the candidate system for each test temperature. At least one cell shall have ageing results that extend past the end of life criteria determined from the reference EIS testing for each test temperature.

Select the ageing temperatures for the candidate EIS, based on the expected thermal class from IEC 60085, listed below in Table 3. The four ageing period durations are defined for each ageing temperature.

Table 3 – Recommended ageing temperatures and periods for expected thermal class

Duration of ageing period h		**Expected thermal class**							
	90 °C	**105** °C	**120** °C	**130** °C	**140** °C	**155** °C	**180** °C	**200** °C	**220** °C
2 000/4 000/6 000/8 000	110	125	140	150	160	175	200	220	240
500/1 000/1 500/2 000	125	140	155	165	175	190	215	235	255
100/200/300/400	140	155	170	180	190	205	230	250	270

The physical shape, size and construction of the reference and candidate test objects shall be similar, with one or more of the solid materials and/or liquid replaced with the candidate materials to be evaluated.

6.3 Diagnostic tests

6.3.1 General

Samples of the solid insulation shall be tested prior to start-up and after shutdown of each cell. Electrical or physical properties of the solid insulation shall be measured according to the end of life criteria selected. Changes between the initial and final states shall be used to determine the amount of degradation occurring during the testing cycle.

6.3.2 Solid insulation

At start-up, the solid insulation samples pre-conditioned according to 6.2 shall be tested using one or more diagnostic tests to determine end of life. Additional tests may be used for monitoring purposes. In some cases multiple methods are available for diagnostic testing. It is important to use the same test method for both the reference and candidate EIS. Examples of typical diagnostic tests for solid materials are as follows:

Characteristics	Test specification
Dielectric strength in oil:	IEC 60243-1
Dielectric strength of winding wire:	IEC 60851-5
Tensile strength:	IEC 60554-2
Compression strength:	IEC 60763-2
Degree of polymerization (cellulose):	IEC 60450

Solid insulation includes enamel coated wires. Most of the above test methods are not appropriate for enamel coated wires. In such cases, the key characteristic to monitor for the enamel coated wires is the dielectric strength retention. There has only been limited experience using such coated wires with this test method.

6.3.3 Liquid insulation

At start-up, the liquid insulation pre-conditioned according to 6.2 shall be tested using one or more diagnostic tests to use for characterization.It is important to use the same test method for both the reference and candidate EIS. Examples of typical diagnostic tests for liquids are as follows:

Characteristic	Test specification
Colour and appearance:	ISO 2049 or ISO 2211
Breakdown voltage:	IEC 60156
Interfacial tension:	ASTM D971
Acidity:	IEC 62021-1, IEC 62021-2, or IEC 62021-3
Dielectric dissipation factor (DDF)	IEC 60247 or IEC 61620
Water content:	IEC 60814
Dissolved gas:	IEC 60567 and IEC 60599
Furanic compound concentrations in oil:	IEC 61198

NOTE Concentrations of furanic compounds such as 2-furfural are useful as a measurement of the degradation of cellulose tested in the oil.

6.4 End-point testing

The diagnostic test of the solid samples shall be selected according to 6.3, for example, from among the following:

- tensile strength;
- compression strength;
- degree of polymerization;
- solid dielectric strength;
- dielectric strength of enamel coated wires.

The end-point criteria may be established for each diagnostic test with suitable justification as reported in Clause 7.

6.5 Simplified one-point test

A simplified single point ageing can also be conducted for the purpose of quality control, minor product changes or for screening prior to a full three-point evaluation. The procedure would be similar to that described for the three-point ageing, however in this case the comparison to the reference EIS is conducted at the midpoint temperature of the reference EIS test.

While a complete thermal index may not be determined based on such a single point test, this test could be used to understand the expected capability of a proposed candidate EIS without the time and effort of completing a full evaluation.

7 Analysis of data

7.1 End-point criteria

7.1.1 General

The criteria by which a test object is considered to have failed shall be fully defined prior to the start of the test. An adequate test shall be included in the test period to detect when a failure occurs, denoting end-of life for each test object. The use of more than one end-point criterion will tend to make interpretation of the test results more difficult. It is recommended that only one end-point criterion be used for each component in the test object (solid/liquid).

7.1.2 End-of-life of the solid component

The preferred end-point criterion for the solid insulation shall be degradation of the original value of the selected mechanical property from 6.4 or the corresponding DP value in case of paper. Other choices for end-point criterion are described in Table 1 of IEC 60216-2:2005. The end of life value for the candidate EIS shall be determined based on the test of the same component in the reference EIS.

NOTE 1 This may not be valid for other materials, e.g enamel coated wires, where the end of life criteria of 80 % retention of dielectric strength is expected. As there is limited experience with this method and enamel coated wires, this number may be conservative, and with experience may be changed to a different number.

The total number of hours to end-of-life shall be recorded for the solid component in the test object at each ageing temperature. The life (in hours) at each ageing temperature shall be calculated according to IEC 60216-3.

7.1.3 Extrapolation of data

Linear regression analysis on the solid component data shall be carried out in accordance with IEC 60216-5. Interpretation of the analysis will be included according to IEC 60505.

7.2 Report

The report shall include all records, relevant details of the test, and analysis, including

- reference to this technical specification,
- description of the EIS tested (reference and candidate EIS),
- ageing temperatures and ageing periods of each EIS,
- sealing gas and pressure used for evaluation,
- diagnostic tests and end-point criterion used for each EIS,
- detailed description of the test objects (including weight ratios),
- number of test objects at each temperature for each EIS,
- individual times to end-of-life for each component,
- mean log times to end-of-life for each ageing temperature, for each EIS.

Multiple point ageing tests shall also include

- regression line with log mean points, for the solid component,
- regression equation and coefficient of correlation for the solid component,
- EIS ATE and/or thermal class of the reference EIS solid component,
- EIS RTE and assigned thermal class of the candidate EIS solid component.

Annex A
(informative)

Consideration of weight ratios

A.1 Examples of transformers leading to actual weight ratios in Table A.1

Table A.1 – Examples obtained from industry sources

Distribution transformers		**Power transformers – Core form**		**Power transformers – Shell form**	
Example	Oil/solid ratio	Example	Oil/solid ratio	Example	Oil/solid ratio
Distribution	10,0	Large power	6,1	**Large power**	**3,3**
2 500 kVA	10,5	50 MVA	6,2		
100 kVA	12,2	508 MVA	7,0		
1 600 kVA	12,6	20 MVA	7,5		
NEMA MW 1000 Std.	**13,3**	**IEC 62332-1**	**7,6**		
25 kVA	13,6	450 MVA	8,0		
630 kVA	14,2	40 MVA	8,0		
1 000 kVA	15,0	290 MVA	9,0		

The above list of transformers contains examples obtained from industry sources. The values in boldface are what were used to make up Table 1 in 5.2. The values in boldface are close to the average of the values from which they are listed and are also close to the median value. Additionally, these values are also used already in other similar industry test methods.

A.2 Calculation of core steel surface ratios

Subclause 5.3.5 describes the need to specify the surface area of the core steel to be included in the sealed tube testing. The core steel surface area may impact the aging process of the insulation system. A wide range of transformers were surveyed (100 kVA to 400 MVA), and this resulted in a broad range of ratios of core steel to insulating liquid. Using Table A.2 below (taken from Table A.1 of IEC TS 62332-1:2011), a calculated surface area of 9,6 cm^2 was obtained for power transformers. The calculated ratio of 12,6 is lower than the data submitted (ranging from 15 cm to 60 cm^2/kg of fluid), but is used to be consistent with IEC TS 62332-1.

Table A.2 – Examples of component volume ratio calculations

Component (ratio)	**Materials (units)**	**Reference transformer**	**Reference model (cellulose)**	**Candidate model (hybrid)**
A	Hot insulation volume (cm^3)	269 000	155	165
B	Low temperature insulation volume (cm^3)	683 000	373	373
C	Mineral oil volume (cm^3)	8 325 000	3 270	3 270
D	Core surface area (cm^2)	128 000	69,7	69,7
(B/A)	Low temperature insulation/hot insulation	2,54	2,41	2,26
(B/C)	Low temperature insulation/liquid	0,082	0,114	0,114
(A/C)	Hot insulation/liquid	0,032	0,048	0,050
(B/D)	Low temperature insulation/core area	5,34	5,36	5,36

A.3 Calculation of copper components of test

A.3.1 Wire enamel samples

Prepare 5 wire samples as described in IEC 60851-5 of heavy film-coated wire sized from 1,00 mm to 1,12 mm. This will be the volume of wire samples for all tests. For equipment where a high volume of wire enamel is used, more than 5 samples can be included in the test, but only 5 samples need to be tested electrically.

NOTE It is impractical to include sufficient wire samples to represent the weight of copper present in the transformer, as the ratio of copper weight to insulating fluid weight ranged from 0,40 to 0,70 in the example transformers, which would have required 100 wire samples for the power transformer example. With a lower ratio of enamel coated wire than is actually used in the transformer, the evaluation will look at negative effects of degradation products from the solid insulation materials on the enamel and not vice versa.

A.3.2 Bare copper samples

Exposed bare copper is present in most liquid immersed transformer insulation systems, either as foil in low voltage windings of distribution transformers or as leads in all types of transformers. Paper wrapped copper windings are also present in many transformers. For this reason, samples of bare copper should be present in this test set-up to address the potential of copper to act as a catalyst in some degradation reactions. Surveyed values for copper area to liquid weight showed a very large range of values, however most of the copper is covered. To simplify the values in Table 1, the same volume of bare copper (9,6 cm^2) was selected for each of the types of transformers as that selected for core surface area.

Annex B
(informative)

Consideration of ageing time and temperature

As described in 6.2.2, 20,000 h as the ATE with a HIC of 6 K was chosen as a basis for aging. This is very close to life assumption in the loading guide IEC 60076-7. For non-upgraded Kraft papers, the HIC is assigned as 6 K and normal life depends on the conditions (moisture, access to oxygen, etc.). In the graph below, 150,000 h was used for this normal life at 98 °C.

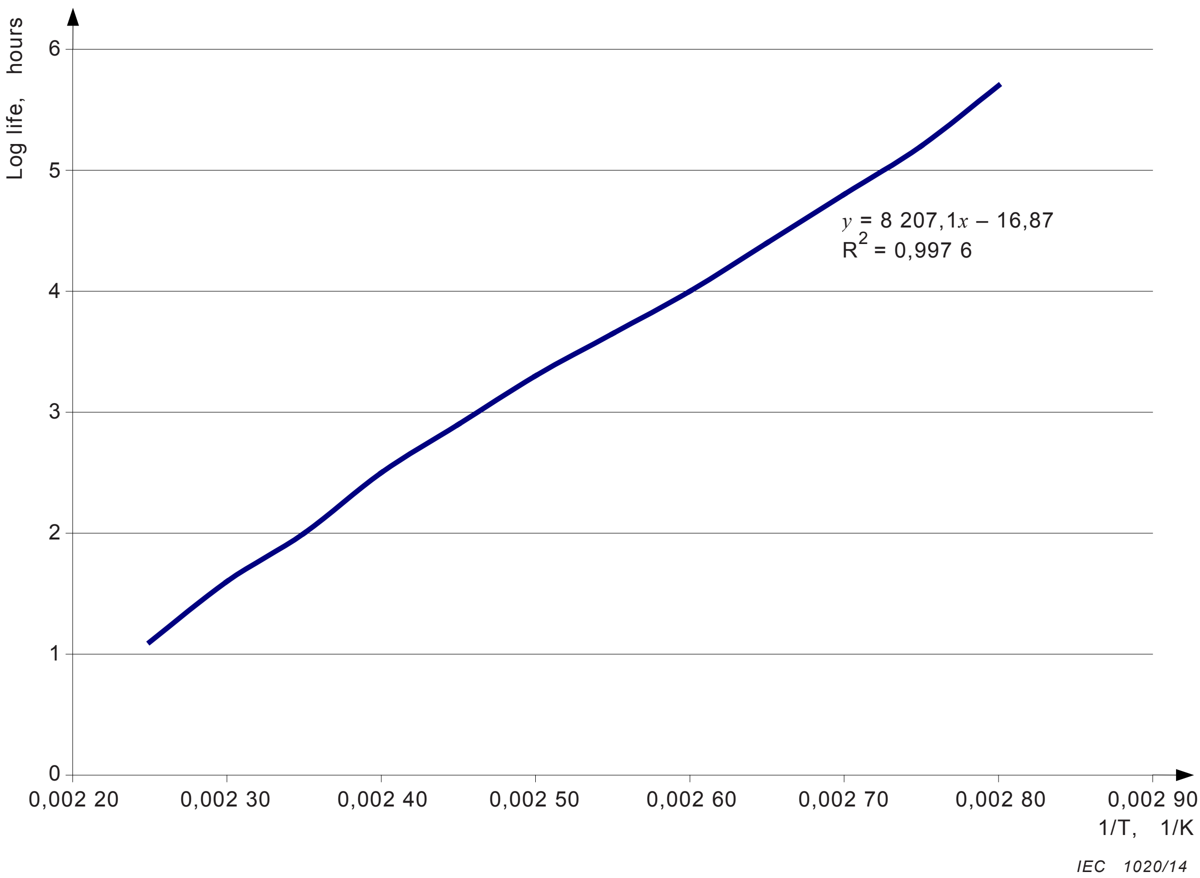


Figure B.1 – Reference EIS system

Annex C
(informative)

Aging example

C.1 Reference system test

The values in Table C.1 are a fictitious example of the results from a test for the evaluation of the reference system under the conditions described in Table 2. The listed values in this table are provided as percentages. They could be the per cent retention of any of the values of the parameters described in 6.3.2.

When conducting the aging experiments for the reference system, it would be advantageous to test multiple parameters of the components of the reference EIS. Multiple end-of-life criteria could then be available for comparison to the candidate EIS.

Table C.1 – Calculation of end-of-life criteria for comparative evaluation

		Aging time 130 °C	**Aging time 145 °C**	**Aging time 160 °C**
Insulation system		**3 536 h**	**625 h**	**110 h**
Reference EIS	Test one %	43,3	44,0	42,4
	Test two %	47,0	46,5	38,0
	Test three %	45,3	35,0	45,6
	Average result		43,01 %	

C.2 Candidate system test

Once the end-of-life criteria for the test program has been determined for the reference EIS, then the aging of the candidate system can be conducted. Of course, both sets of aging can be conducted concurrently, but the full analysis of the candidate system is not possible until the end-of-life criteria has been established. As was described in 6.2.3, the expected thermal class for the candidate system is identified, and then by using Table 3, the aging program can proceed. Table C.2 is a made up example of such an experiment, for a candidate EIS expected to qualify as a 130 °C thermal class.

Table C.2 – Example of aging experiment

	Aging tests	
Temperature °C	**Time** h	**Tensile strength** %
180	100	80
180	200	65
180	300	45
180	400	30
165	500	85
165	1 000	70
165	1 500	53
165	2 000	40
150	2 000	90
150	4 000	72
150	6 000	55
150	8 000	42

With this aging data, the time temperature plots for the candidate can then be obtained. Figure C.1 shows the plot for the above example for 165 °C.

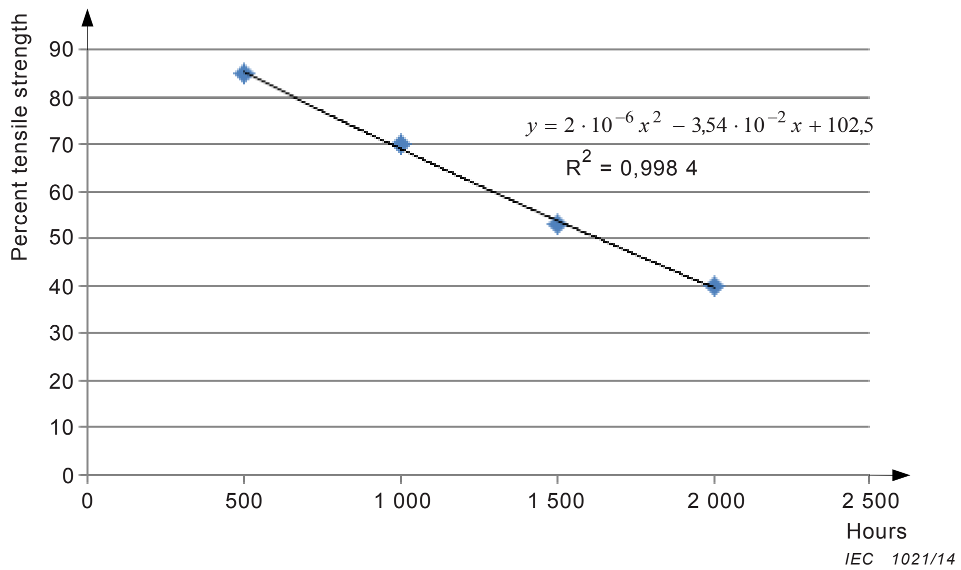


Figure C.1 – Example of aging result at a temperature of 165 °C

Finally, using the equation generated from the aging experiment for each temperature, the hours to reach the targeted end-of-life criteria determined from the Reference EIS test (43,01 % from the example in Table C.1). The value calculated for the 165 °C example from Figure C.1 is 1 880,2 h, With the complete set of test data, three times are calculated from the aging daa in Table C.2. These can then be plotted as shown in Figure C.2.

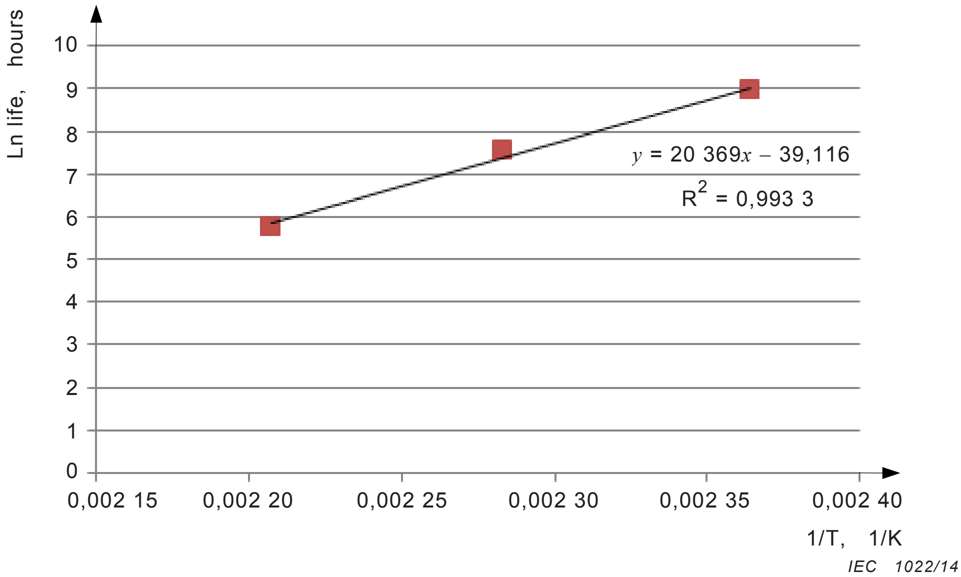


Figure C.2 – Aging life curve

The life equation can then be used to calculate the EIS RTE. For this example, the candidate insulation system is rated for 142,5 °C for 20 000 h. This would then exceed the thermal class of 140 °C, but not meet the thermal class of 155 °C, so this candidate EIS would be assigned a thermal class of 140 °C.

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