BS EN 60695-1-40:2014

BSI Standards Publication

Fire hazard testing

Part 1-40: Guidance for assessing the fire hazard of electrotechnical products — Insulating liquids

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National foreword

This British Standard is the UK implementation of EN 60695-1-40:2014. It is identical to IEC 60695-1-40:2013.

The UK participation in its preparation was entrusted to Technical Committee GEL/89, Fire hazard testing.

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

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Fire hazard testing - Part 1-40: Guidance for assessing the fire hazard of electrotechnical products - Insulating liquids
(IEC 60695-1-40:2013)

Essais relatifs aux risques du feu -
Partie 1-40: Guide pour l'évaluation des risques du feu des produits électrotechniques -
Liquides isolants
(CEI 60695-1-40:2013)

Prüfungen zur Beurteilung der Brandgefahr -
Teil 1-40: Anleitung zur Beurteilung der Brandgefahr von elektrotechnischen Erzeugnissen -
Isolierflüssigkeit
(IEC 60695-1-40:2013)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 89/1191/FDIS, future edition 1 of IEC 60695-1-40, prepared by IEC/TC 89 "Fire hazard testing" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60695-1-40:2014.

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)	2014-10-25
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This European Standard is to be used in conjunction with EN 60695-1-10.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60695-1-40:2013 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:

ISO 2719:2002	NOTE	Harmonised as EN ISO 2719:2002 (not modified).
IEC 61039	NOTE	Harmonised as.EN 61039.
IEC 62271-202	NOTE	Harmonised as.EN 62271-202.
IEC 60708:2005	NOTE	Harmonised as.EN 60708:2005 (not modified).
IEC 60794-1-1:2011	NOTE	Harmonised as.EN 60794-1-1:2011 (not modified).
IEC 60836:2005	NOTE	Harmonised as.EN 60836:2005 (not modified).
IEC 61099:2010	NOTE	Harmonised as.EN 61099:2010 (not modified).
IEC 61144:1992	NOTE	Harmonised as.EN 61144:1993 (not modified).
IEC 61197:1993	NOTE	Harmonised as.EN 61197:1994 (not modified).
IEC 62271-105:2012	NOTE	Harmonised as.EN 62271-105:2012 (not modified).

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 60050		International electrotechnical vocabulary		
IEC 60296		Fluids for electrotechnical applications - Unused mineral insulating oils for transformers and switchgear	EN 60296	
IEC 60465		Specification for unused insulating mineral oils for cables with oil ducts	EN 60465	
IEC 60695-1-10		Fire hazard testing - Part 1-10: Guidance for assessing the fire hazard of electrotechnical products - General guidelines	EN 60695-1-10	
IEC 60695-1-11		Fire hazard testing - Part 1-11: Guidance for assessing the fire hazard of electrotechnical products - Fire hazard assessment	EN 60695-1-11	
IEC 60695-4	2012	Fire hazard testing - Part 4: Terminology concerning fire tests for electrotechnical products	EN 60695-4	2012
IEC/TS 60695-5-2		Fire hazard testing - Part 5-2: Corrosion damage effects of fire effluent - Summary and relevance of test methods		
IEC 60695-6-2		Fire hazard testing - Part 6-2: Smoke obscuration - Summary and relevance of test methods	EN 60695-6-2	
IEC 60695-7-2		Fire hazard testing - Part 7-2: Toxicity of fire effluent - Summary and relevance of test methods	EN 60695-7-2	
IEC 60695-8-2		Fire hazard testing - Part 8-2: Heat release - Summary and relevance of test methods	EN 60695-8-2	
IEC/TS 60695-8-3		Fire hazard testing - Part 8-3: Heat release - Heat release of insulating liquids used in electrotechnical products		
IEC 60944		Guide for maintenance of silicone transformer liquids		
IEC 61039		Classification of insulating liquids	EN 61039	
IEC 61203		Synthetic organic esters for electrical purposes - Guide for maintenance of transformer esters in equipment	EN 61203	
ISO 1716		Reaction to fire tests for building products - Determination of the heat of combustion	EN ISO 1716	
ISO 2592		Determination of flash and fire points - Cleveland open cup method	EN ISO 2592	
ISO 13943	2008	Fire safety - Vocabulary	EN ISO 13943	2010

CONTENTS

INTRODUCTION

In the design of any electrotechnical product the risk of fire and the potential hazards associated with fire need to be considered. In this respect the objective of component, circuit and product design as well as the choice of materials is to reduce to acceptable levels the potential risks of fire even in the event of foreseeable abnormal use, malfunction or failure.

For more than 100 years, insulating liquids based on mineral oil have been used for the insulating and cooling of electrical transformers and some other types of electrotechnical equipment.

During the last 70 years, synthetic insulating liquids have been developed and used in specific electrotechnical applications for which their properties are particularly suitable. However, for technical and economic reasons, highly refined mineral oil continues to be the most widely used insulating liquid for use in transformers, the major end use application. Their safe installation is covered by local, national and international regulations.

The fire safety record of electrotechnical equipment containing insulating liquids is good, for both mineral oil and synthetic liquids. In recent years improvements in design and protective measures against fire have reduced the fire hazard for electrotechnical equipment containing mineral oil. However, as for all forms of electrotechnical equipment, the objective should be to reduce the likelihood of fire even in the event of foreseeable abnormal use.

The practical aim is to prevent ignition, but if ignition occurs, to control the fire, preferably within the enclosure of the electrotechnical equipment.

FIRE HAZARD TESTING –

Part 1-40: Guidance for assessing the fire hazard of electrotechnical products – Insulating liquids

1 Scope

This international standard provides guidance on the minimization of fire hazard arising from the use of electrical insulating liquids, with respect to:

a) electrotechnical equipment and systems,

b) people, building structures and their contents.

This basic safety publication is intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 104 [1] [1] and ISO/IEC Guide 51 [2]. It is not intended for use by manufacturers or certification bodies.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications.

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 60050, *International electrotechnical vocabulary*

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

IEC 60465, *Specification for unused insulating mineral oils for cables with oil ducts*

IEC 60695-1-10, *Fire hazard testing – Part 1-10: Guidance for assessing the fire hazard of electrotechnical products – General guidelines*

IEC 60695-1-11, *Fire hazard testing – Part 1-11: Guidance for assessing the fire hazard of electrotechnical products – Fire hazard assessment*

IEC 60695-4:2012, *Fire hazard testing – Part 4: Terminology concerning fire tests for electrotechnical products*

IEC 60695-6-2, *Fire hazard testing – Part 6-2: Smoke obscuration – Summary and relevance of test methods*

IEC 60695-7-2, *Fire hazard testing – Part 7-2: Toxicity of fire effluent – Summary and relevance of test methods*

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1 Numbers in square brackets refer to the Bibliography.

IEC 60695-8-2, *Fire hazard testing – Part 8-2: Heat release – Summary and relevance of test methods*

IEC 60944, *Guide for the maintenance of silicone transformer liquids*

IEC 61039, *Classification of insulating liquids*

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

IEC/TS 60695-5-2, *Fire hazard testing – Part 5-2: Corrosion damage effects of fire effluent – Summary and relevance of test methods*

IEC/TS 60695-8-3, *Fire hazard testing – Part 8-3: Heat release – Heat release of insulating liquids used in electrotechnical products*

ISO 1716*, Reaction to fire tests for products – Determination of the gross heat of combustion (calorific value)*

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

ISO 13943:2008, *Fire safety – Vocabulary*

3 Terms and definitions

For the purposes of this document, terms and definitions given in ISO 13943:2008 and IEC 60695-4:2012, some of which are reproduced below for the user's convenience, as well as the following additional definitions, apply.

3.1
arc
electrical breakdown of a gas which produces a sustained plasma discharge, resulting from an electric current flowing through a normally nonconductive medium such as air

3.2
bund
outer wall or tank designed to retain the contents of an inner container in the event of leakage or spillage

Note 1 to entry: A bund should be designed to capture well in excess of the volume of liquids held within the bund area.

3.3
bushing
insulating liner in an opening through which a conductor passes

3.4
combustion
exothermic reaction of a substance with an oxidizing agent

Note 1 to entry: Combustion generally emits fire effluent accompanied by flames and/or glowing.

[SOURCE: ISO 13943:2008, 4.46]

3.5
corrosion damage
physical and/or chemical damage or impaired function caused by chemical action

[SOURCE: ISO 13943:2008, 4.56]

3.6
enclosure
⟨electrotechnical⟩ external casing protecting the electrical and mechanical parts of apparatus

Note 1 to entry: The term excludes cables.

[SOURCE: IEC 60695-4:2012, 3.2.6]

3.7
fire
⟨general⟩ process of combustion characterized by the emission of heat and fire effluent and usually accompanied by smoke, flame, glowing or a combination thereof

Note 1 to entry: In the English language the term “fire” is used to designate three concepts, two of which, fire and fire, relate to specific types of self-supporting combustion with different meanings and two of them are designated using two different terms in both French and German.

[SOURCE: ISO 13943:2008, 4.96]

3.8
fire effluent
totality of gases and aerosols, including suspended particles, created by combustion or pyrolysis in a fire

[SOURCE: ISO 13943:2008, 4.105]

3.9
fire growth
stage of fire development during which the heat release rate and the temperature of the fire are increasing

[SOURCE: ISO 13943:2008, 4.111]

3.10
fire hazard
physical object or condition with a potential for an undesirable consequence from fire

[SOURCE: ISO 13943:2008, definition 4.112]

3.11
fire load
quantity of heat which can be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces

Note 1 to entry: Fire load may be based on effective heat of combustion, gross heat of combustion, or net heat of combustion as required by the specifier.

Note 2 to entry: The word “load” can be used to denote force or power or energy. In this context, it is being used to denote energy.

Note 3 to entry: The typical units are kilojoules (kJ) or megajoules (MJ).

[SOURCE: ISO 13943:2008, 4.114]

3.12
fire point
minimum temperature at which a material ignites and continues to burn for a specified time after a standardized small flame has been applied to its surface under specified conditions

Note 1 to entry: In some countries, the term "fire point" has an additional meaning: a location where fire-fighting equipment is sited, which may also comprise a fire-alarm call point and fire instruction notices.

Note 2 to entry: The typical units are degrees Celsius (°C).

[SOURCE: ISO 13943:2008, 4.119]

3.13
fire risk
probability of a fire combined with a quantified measure of its consequence

Note 1 to entry: It is often calculated as the product of probability and consequence.

[SOURCE: ISO 13943:2008, 4.124]

3.14
fire scenario
qualitative description of the course of a fire with respect to time, identifying key events that characterise the studied fire and differentiate it from other possible fires

Note 1 to entry: It typically defines the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that impact on the course of the fire.

[SOURCE: ISO 13943:2008, 4.129]

3.15
flame, noun
zone in which there is rapid, self-sustaining, sub-sonic propagation of combustion in a gaseous medium, usually with emission of light

[SOURCE: ISO 13943:2008, 4.133 – modified by addition of "zone in which there is"]

3.16
flammability
ability of a material or product to burn with a flame under specified conditions

[SOURCE: ISO 13943:2008, 4.151]

3.17
flash point
minimum temperature to which it is necessary to heat a material or a product for the vapours emitted to ignite momentarily in the presence of flame under specified conditions

Note 1 to entry: The typical units are degrees Celsius (°C).

[SOURCE: ISO 13943:2008, 4.154]

3.18
gross heat of combustion
heat of combustion of a substance when the combustion is complete and any produced water is entirely condensed under specified conditions

Note 1 to entry: The typical units are kilojoules per gram ($kJ \cdot g^{-1}$).

[SOURCE: ISO 13943:2008, 4.170]

3.19
heat of combustion
thermal energy produced by combustion of unit mass of a given substance

Note 1 to entry: The typical units are kilojoules per gram ($kJ \cdot g^{-1}$).

[SOURCE: ISO 13943:2008, 4.174]

3.20
heat of gasification
thermal energy required to change a unit mass of material from the condensed phase to the vapour phase at a given temperature

Note 1 to entry: The typical units are kilojoules per gram ($kJ \cdot g^{-1}$).

[SOURCE: ISO 13943:2008, 4.175]

3.21
heat release
thermal energy produced by combustion

Note 1 to entry: The typical units are joules (J).

[SOURCE: ISO 13943:2008, 4.176]

3.22
heat release rate
burning rate (deprecated)
rate of burning (deprecated)
rate of thermal energy production generated by combustion

Note 1 to entry: The typical units are watts (W).

[SOURCE: ISO 13943:2008, 4.177]

3.23
high voltage
HV
voltage greater than 1 kV (a.c.) or greater than 1,5 kV (d.c.)

3.24
ignitability
ease of ignition
measure of the ease with which a test specimen can be ignited, under specified conditions

[SOURCE: ISO 13943:2008, 4.182]

3.25
ignition
sustained ignition (deprecated)
⟨general⟩ initiation of combustion

[SOURCE: ISO 13943:2008, 4.187]

3.26
mineral oil
liquid conforming to IEC 60296 or IEC 60465

3.27
net heat of combustion
heat of combustion when any water produced is considered to be in the gaseous state

Note 1 to entry: The net heat of combustion is always smaller than the gross heat of combustion because the heat released by the condensation of water vapour is not included.

Note 2 to entry: The typical units are kilojoules per gram ($kJ \cdot g^{-1}$).

[SOURCE: ISO 13943:2008, 4.237]

3.28
opacity of smoke
ratio of incident light intensity to transmitted light intensity through smoke, under specified conditions

Note 1 to entry: Opacity of smoke is the reciprocal of transmittance.

Note 2 to entry: The opacity of smoke is dimensionless.

[SOURCE: ISO 13943:2008, 4.243]

3.29
origin fire scenario
fire scenario involving electrotechnical equipment where the electrotechnical equipment is the source of ignition

3.30
PCB
polychlorinated biphenyl

Note 1 to entry: PCB mixtures were developed as insulating liquids in the 1930s. They are known by various trade names, e.g. Aroclor™, Askarel™, Clophen™, Inerteen™ and Pyranol™ [2].

3.31
pool fire
fire characterized by diffusion flames formed above a horizontal body of liquid fuel where buoyancy is the controlling mechanism for transport of fire effluent from the fire and transport of air to the fire

3.32
routine test
test on a number of items taken at random from a batch

3.33
sampling test
conformity test made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17, modified – original term was "routine test"]

3.34
tapchanger
device fitted to power transformers for regulation of the output voltage to required levels

3.35
toxic hazard
potential for harm resulting from exposure to toxic combustion products

[SOURCE: ISO 13943:2008, 4.337]

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2 Aroclor™, Askarel™, Clophen™, Inerteen™ and Pyranol™ are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

3.36
type test
conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-581:2008, 581-21-08]

3.37
victim fire scenario
fire scenario involving electrotechnical equipment where the electrotechnical equipment is the victim of a fire of external origin

4 Classification of insulating liquids

Insulating liquids have been classified in IEC 61039 according to fire point and net heat of combustion, as shown in Table 1.

Table 1 – Classification of insulating liquids

Fire point		**Net heat of combustion**	
Class O	≤300 °C	Class 1	≥42 MJ/kg
Class K	>300 °C	Class 2	<42 MJ/kg ≥32 MJ/kg
Class L	No measurable fire point	Class 3	<32 MJ/kg
EXAMPLE Mineral transformer oil (IEC 60296) has a classification of O1.			

NOTE 1 Fire point is measured using the Cleveland open cup method, ISO 2592, and is used as the primary method of classification.

NOTE 2 The determination of the flash point is sometimes used as a secondary method of classification. IEC TC10 usually adopts ISO 2719:2002 [3] in order to measure the flash point using the Pensky-Martens methodology (closed cup). If the value of the flash point determined by this method is < 250 °C, then the product is classified with the letter "O"; if the flash point is ≥ 250 °C, then the product is classified with the letter "K", and, if there is no detectable flash point, the product is classified with the letter "L".

5 Types of electrotechnical equipment containing insulating liquids

Insulating liquids are used in some designs of:

– transformers and reactors,
– capacitors,
– cables,
– bushings,
– switchgear, and
– miscellaneous power electronics (and in some other electrotechnical applications in which the liquid serves partly as an insulant, but primarily as a coolant)

In many cases, alternative designs use solid or gaseous insulation materials as an alternative to liquids. This international standard does not discuss the relative advantages and disadvantages of these alternatives.

NOTE As insulating liquids are always part of an insulating system, the fire hazard assessment of the complete system could also be of interest.

6 Fire parameters

6.1 General

The main parameters which relate to the ignition and combustion of insulating liquids are described in 6.2.

6.2 Ignition

6.2.1 General

Ignitability can be measured by fire point as described in ISO 2592.

6.2.2 Combustion

Combustion characteristics are be considered in terms of the contribution to the fire load, the potential fire growth, and the fire hazards caused by fire effluent.

NOTE A fire may not cause the insulating liquid to burn but may cause leakage of the insulating liquid. In this case, the hazards caused by leakage should also be considered.

6.2.3 Potential fire growth

Important parameters relating to the potential fire growth are net heat of combustion, heat release rate and heat of gasification.

6.2.4 Fire effluent

The important hazardous effects of fire effluent are opacity of smoke, corrosion damage and toxic hazard.

7 Fire scenarios

7.1 General

Fire scenarios for electrotechnical equipment containing insulating liquids are described below. These fire scenarios are particularly relevant for transformers, the major end use application for insulating liquids, and in some cases for other types of electrotechnical equipment.

The fire hazard shall be assessed with reference to IEC 60695-1-10 and IEC 60695-1-11.

For electrotechnical equipment containing insulating liquids, the two types of scenario that are considered are:

a) when the electrotechnical equipment is the source of ignition, known as an “origin fire scenario”, and
b) when the electrotechnical equipment is the victim of a fire of external origin, known as a “victim fire scenario”.

In the origin fire scenario, fire is initiated by failure within the electrotechnical equipment. In the victim fire scenario, the insulating liquid contributes to the fire load for a fire of external origin.

7.2 Origin fire scenarios

7.2.1 General

Consideration shall be given to

a) whether the insulating liquid can be heated to its fire point under equipment overload conditions. This could result in fire initiation if exposed to an external source of ignition;
b) whether fire can be initiated by an uncontrolled high-energy internal arc.

Either of these situations may create internal pressure sufficient to rupture the insulating liquid container in the electrotechnical equipment. The liquid is then ejected, normally as a spray, which may be ignited. The spray burns intensely for a short period but then forms a pool, which may or may not be burning at the base of the electrotechnical equipment. Experience with Class O1 insulating liquids has shown that burning of a resultant pool fire causes most damage but no pool fires have been reported for Class K liquids.

Tests on Class K insulating liquids (known as less-flammable insulating liquids) have shown that even if spray ignites, the resulting pool of liquid rapidly ceases to burn. This is largely due to its high fire point. However, mineral oils (Class O1) are much more likely to continue to burn as a pool fire. Therefore, much of the information relating to fire damage applies to Class O1 liquids.

PCB mixtures (see 3.30 and Annex A) exhibit similar behaviour to Class K insulating liquids. The spray and dissolved gases can ignite, even though PCB mixtures are rated as Class L. The resulting pool will not continue to burn.

For many types of electrotechnical equipment, Class O1 insulating liquids are almost always used for technical and/or economic reasons. Protection against fire can then be provided by appropriate design and safe location of the electrotechnical equipment, including physical and electrical control devices (see Annex B).

Class K insulating liquids require less stringent protective measures than Class O insulating liquids (see Annexes A and C).

The major use of insulating liquids is in transformers. The following lists of major and minor fire scenarios apply to transformers and in some cases to other types of electrotechnical equipment containing insulating liquids.

Provisions shall be made for protection of people against fire effluent or other effluent from equipment containing PCB mixtures or mineral oil contaminated by PCBs. Such equipment shall be identified and dealt with in accordance with local regulations which may result in decommissioning. This is important because PCBs present a toxic hazard if decomposed thermally with or without combustion of the carrier liquid [4].

Although failures leading to a fire in electrotechnical equipment containing insulating liquids are rare, it is evident that any equipment transmitting a high level of electrical energy and containing significant quantities of flammable solid and/or liquid insulating materials presents a potential fire hazard. With good protective measures, damage caused is usually small and confined to within the container, with possible ejection of a small quantity of insulating liquid.

7.2.2 Major causes of fire

The major causes of fire in origin fire scenarios are as follows:

a) Container damage leading to a leakage of insulating liquid, possibly in the form of a liquid spray.
b) An increase in internal container pressure due to thermal expansion under overload or to the production of gases from the decomposition of the insulating liquid. This can result in the release of liquid and vapours from a pressure relief valve.
c) Undetected leakage leading to a lack of circulation, resulting in overheating and a change in liquid characteristics, eventually leading to breakdown due to arcing from exposed conductors.

d) A high energy arc, or arcs, between incoming HV terminations caused by high voltage transients, lightning or a switching surge.

e) Low magnitude faults in the centre of HV windings, causing breakdown and decomposition of the insulating liquid into flammable gaseous components.

f) Failure of protection to clear a fault, resulting in severe overheating and winding failure.

g) Tapchanger faults – failure may spread to the transformer.

h) Bushing faults in an overheated connection resulting in a cracked insulator. This can result in the slow release of insulating liquid on to the overheated connection, which may cause a fire if not detected.

i) Cable box faults – cable boxes may be either compound-filled or oil-filled. Failure of the insulation may cause a phase-to-phase arc and the resulting high pressure could cause the cable box to burst.

j) Oil-filled cable faults.

7.2.3 Minor causes of fire

The minor causes of fire in origin fire scenarios are as follows:

a) An overheated connection resulting in a cracked insulator.

b) A slow release of insulating liquid on to an overheated connection. Depending on the combustion characteristics of the liquid, this may cause a fire if not detected.

7.2.4 Pool fires

Experience with mineral oil-filled transformers has shown that, if the transformer tank is ruptured by a catastrophic failure caused by a high energy internal arc, the insulating liquid can be ejected as a spray. This spray burns intensely for a short time and can itself cause damage, but, in most recorded accidents, a considerable contribution to total fire damage was caused by the high heat release rate from the resulting burning pool of oil. For this reason, the possibility of a pool fire must be a matter for particular consideration.

7.2.5 Burning spray

Spray may burn intensely for only a short period of time. Pressure is limited by comparison with e.g. hydraulic applications, because the container in most electrotechnical equipment has only a limited pressure withstand capability.

7.2.6 Ignition on hot surface

A fault in a high current connection, external to the electrotechnical equipment, can result in a high local temperature, possibly exceeding 500 °C. If insulating liquid leaks from the electrotechnical equipment and runs over such an overheated surface, it may ignite. This will be dependent on the temperature of the surface, the ignition temperature of the liquid, and the rate of flow.

7.3 Victim fire scenarios

The electrotechnical equipment under consideration can be involved when a fire begins externally. This could include collapse of a building causing damage to the container and release of the insulating liquid into a pool which can ignite.

Another type of victim fire scenario is an interactive fire, which begins in adjacent associated electrotechnical equipment, such as connecting cables, capacitors or switchgear. For example, fire damage to connecting cables can result in a short-circuit.

Consideration shall be given to the probability that the insulating liquid can be exposed to an external fire, whether the liquid is fully contained within the electrotechnical equipment or is released after physical damage to the equipment. Important parameters are the ignitability of the insulating liquid and, if ignition occurs, the contribution to the fire hazard of heat release and fire effluent. In a victim fire scenario, Class K (less-flammable) insulating liquids can be heated to a higher temperature than Class O insulating liquids before they will ignite in contact with an external flame and continue to burn.

8 Protective measures against fire

Protective measures against fire are as follows:

a) the retention of the insulating liquid within the electrotechnical equipment, allowing for thermal expansion in service;
b) provision to retain any liquid released, by means of a sump or bund;
c) ensuring that there is a sufficient distance to the nearest building (for outdoor installations);
d) the use of fire barriers or fire compartments;
e) provision of a fire extinguisher or extinguishers actuated by excess temperature rise;
f) provision of a circuit breaker or breakers actuated by pressure relief valves;
g) provision of over-current protection; and
h) provision of fast-acting short-circuit protection.

Annex B describes these in more detail. Some are specified by regulatory or advisory bodies with responsibility for particular geographical regions, e.g., USA, Europe and Japan.

For electrotechnical equipment installed in areas of particular fire hazard (e.g., in buildings), less stringent measures are required in the case of less flammable liquids.

Electrotechnical equipment containing quantities of insulating liquids below a specified minimum (usually about 4 litres) is exempted from many of the restrictions in such regulations, even when the liquid is Class O. In a victim fire scenario, the small quantity of insulating liquid will provide only a small addition to the fire load.

However, the electrotechnical equipment containing Class O insulating liquid could still be a cause of fire if the tank is ruptured by an internal high energy arc and flaming liquid is ejected. This could apply particularly to capacitors, smaller transformers and switchgear. It should be noted that, unlike transformers, which normally have pressure relief devices built in to avoid tank rupture, electrotechnical equipment which has no such facility will rupture if an internal arc is not extinguished by a fuse or other protective measure.

Further information is given in Annexes B and C.

9 Considerations for the selection of test methods

9.1 General

The test methods and limits selected shall be relevant to the fire scenario (see IEC 60695-1-10).

Test methods may be used for the selection of the most appropriate insulating liquid, and they may be used for type tests, sampling tests, or routine tests. Sampling and routine tests are normally used for quality control purposes.

The ignition source used in the test method has to be relevant to the actual fire scenarios. When considering origin fire scenarios the ignition source should simulate localized, internal sources of excessive heat, and ignition within electrotechnical equipment. When considering victim fire scenarios the ignition source should simulate the anticipated external source of flame or excessive heat.

9.2 Type tests

Ignitability (ease of ignition) is measured in terms of fire point (see ISO 2592).

The heat of combustion can be measured using ISO 1716. This test method measures the gross heat of combustion, but the net heat of combustion can be calculated if the hydrogen content of insulating liquid is known (see IEC 60695-8-2).

The heat release rate can be measured using a cone calorimeter according to IEC/TS 60695-8-3.

The corrosion damage, smoke opacity and toxic hazard characteristics of fire effluent can be measured in a variety of ways. IEC/TS 60695-5-2 provides a summary and relevance of test methods for corrosion damage. IEC 60695-6-2 provides a summary and relevance of test methods for smoke opacity. IEC 60695-7-2 provides a summary and relevance of test methods for toxic hazard.

9.3 Sampling tests

The open cup fire point is the most appropriate test for quality control. Open cup flash point can be measured at the same time (see ISO 2592). IEC 60944 and IEC 61203 have been written for the maintenance and testing of samples of insulating liquid taken after time in service.

The facility to take samples and measure them for quality, including flash and fire point, after time in service, is a particular advantage for the insulating liquids used in many forms of electrotechnical equipment. This is not possible with solid insulation materials.

9.4 Arc resistance tests

For transformers, methods have been developed to assess the resistance to continued low-energy arcing, and also to assess the ability to withstand specified high energy arcing without rupture of the transformer tank. These test methods are used by a US approval body [5], but have not been developed into national or international standards.

9.5 Relevance of test results to fire scenario

The hazard to life and property from fire is due to the release of heat and fire effluent.

By measuring the fire point and heat release rate of insulating liquids, and the corrosion damage, smoke opacity and toxic hazard effects of fire effluent from burning insulation liquids, the hazards associated with insulating liquids used in electrotechnical equipment can be assessed, based on the principles that:

- the higher the fire point, the more difficult is ignition, and
- if ignition occurs, the lower the heat release rate and production of fire effluent, the lower is the expected hazard and difficulty of fire fighting.

The fire behaviour of an insulating liquid depends on its properties as well as the size and geometry of its container, the presence of other combustible material and heat sources.

Annex A
(informative)

History of insulating liquids

Mineral oil, the most commonly used insulating liquid, has been used for more than 100 years. Its first electrical industry application began in the 1890s, when higher-voltage transformers and cables were developed. The use of Impregnated porous paper and the use of other, solid, insulating materials, was necessary in order to raise working voltages by eliminating air and moisture, while also providing convective cooling where needed.

Today, mineral insulating oils used for electrical insulation are highly refined products with stabilising additives and are covered by IEC 60296 for transformers and switchgear and IEC 60465 for cables with oil ducts. Vegetable oils (particularly castor oil) have also been used and are still used today in some types of capacitors.

PCB mixtures were introduced about 1930, to replace mineral oil in transformers installed indoors or in other fire hazard locations. Transformer PCB mixtures have no measurable fire point and for this reason were regarded as non-flammable. However, it was later found that the spray of such liquids and their decomposition gases could still ignite and burn briefly if a transformer ruptured following an uncontrolled high energy internal arc failure. More seriously, the combustion products of PCB mixtures are toxic and persist in the environment, as do the undecomposed PCBs, and they pose an environmental hazard [4]. The further use and manufacture of PCBs has been prohibited worldwide.

To replace transformer PCBs, insulating liquids (including silicones, esters and high molecular weight hydrocarbons) with fire points above 300 °C came into use in the 1970s. It was shown that their behaviour in a high energy arc transformer failure was similar to that of PCB mixtures. Though ejected spray might be decomposed and ignited by the arc, burning was only of short duration.

More than 150 000 transformers containing Class K (less flammable) insulating liquids are in service, with an excellent fire safety record. Unlike PCB mixtures, these Class K insulating liquids do not pose a similar environmental hazard.

Until 1970, PCB mixtures were also used in capacitors. After their withdrawal, changes in capacitor design led to the introduction of other synthetic liquids, particularly low-viscosity aromatic hydrocarbons. These generally comply with IEC 60867 [6]. Unlike PCB mixtures, the fire point of these low viscosity synthetic aromatic liquids is about 165 °C.

Insulating liquids for cables were originally based on mineral oils produced from the refining of crude oil, but since the 1960s synthetic aromatic hydrocarbon liquids have also been used. IEC 61100 [7] was issued in 1992, which classifies insulating liquids according to their fire-point and net heat of combustion. This has since been superseded by IEC 61039.

More than 90 % of all insulating liquids now in use are in the most flammable classification of IEC 61039, Class O1. The fire safety record of electrotechnical equipment containing all types of insulating liquids is generally good. There have been some serious fire incidents involving Class O1 liquids but it is important to note that millions of transformers containing mineral oil in this classification are in service globally and that such incidents are rare. Class L3 insulating liquids have also been involved in serious fire incidents due primarily to the ensuing environmental pollution and clean-up costs.

For these reasons, fire hazard analysis and appropriate protective measures are of great importance.

Annex B
(informative)

Preventive and protective measures against fire

B.1 General

Some of the measures listed below pertain specifically to transformers, others relate to liquid-filled devices in general. Application of these measures also depends on the particular type and insulation system of the electrotechnical equipment, the assessed fire hazard of its location and relevant local and/or national fire safety regulations.

B.2 Physical protective measures

a) The use of pressure relief devices.

   NOTE Pressure relief devices offer only limited protection with high energy faults, though they may prevent shock waves in case of explosion, but they offer good protection with low energy faults in a victim fire scenario.

b) Conformance with an appropriate burst strength requirement for the containment.
c) The use of fire barriers.
d) Provision of a bund around and under transformers.
e) Installation in a vault.
f) Provision of automatic fire extinguishers.
g) The use of corrugated containers for expansion due to temperature increase or gas production.
h) The use of a nitrogen (or other inert gas) blanket.

B.3 Chemical protective measures

a) The use of non-flammable or high fire point insulation liquids.
b) Conformance with an appropriate minimum breakdown voltage requirement for the insulating liquid.

B.4 Electrical protective measures

a) The use of internal or external power fuses.
b) The use of internal or external current limiting fuses.
c) The use of other internal or external overcurrent limiting devices.

B.5 Sensing devices

a) Coil or insulating liquid temperature alarms with trip-switches.
b) Overpressure alarms with trip-switches.
c) Gas detection (Buchholz) relays.

B.6 Maintenance and inspection

a) Visual inspection of the equipment.
b) Electrical testing of the equipment and the insulating liquid.
c) Chemical testing of the insulating liquid for signs of degradation.
d) Dissolved gas analysis (DGA).

e) Analysis for the PCB content of new or used insulating liquid.

NOTE Fire effluent from a PCB contaminated insulating liquid may contain toxic furans and dioxins. The levels of PCBs in insulating liquids above which this may occur are not known precisely. Acceptable levels are usually considered to be the same as for spills in the environment, in accordance with local and/or national regulations. When these levels are exceeded, special protection measures are required for fire-fighters and for cleaning the environment after the fire.

f) Review of equipment design with the manufacturer (for those types of electrotechnical equipment which are prone to fire or explosion in service).

Annex C
(informative)

Transformers

C.1 General

The text contained in C.2 is intended to provide general guidance on the fire protection of different types of transformer, but it is usually necessary to consider each specific application in detail to ensure the best choice is made, and different types of transformers will often be used in different applications and environments on the same project.

C.2 Transformer choice

The choice of a transformer for a particular application depends on many factors. Large power transformers operating at voltages in the range 33 kV to 400 kV and above are commonly filled with highly refined mineral oil. These transformers are usually installed outdoors and the foundations on which they stand are designed to provide pebble filled containment of any oil leakage. By using this method, the likelihood of a pool fire is minimised. Where fire safety is critical, such as within underground installations, Class K fluids may be used to fill large power transformers.

This type of transformer is fitted with overcurrent and earth fault protection, differential protection, winding temperature protection and an oil temperature alarm with a trip-switch. Such transformers are also fitted with an oil conservator and an oil level alarm with a trip-switch, and a Buchholz gas and surge operated relay that will give an alarm and trip in the event of gas production or discharge faults.

Large power transformers are fitted with on-load tapchangers, and failures within these complex switching units can cause damage to the transformer.

Outdoor transformers are sited away from buildings and protected from access by the public. In addition, water deluge fire protection systems may be fitted to transformers filled with Class O liquids.

Many large power transformers are mounted inside noise abatement enclosures, usually of substantial concrete or brick construction, which also contributes to fire protection.

Multiple transformers are frequently separated by blast walls to prevent the catastrophic failure of one unit from affecting an adjacent unit.

Public distribution transformers in the range 100 kVA to 1 000 kVA are mineral oil or Class K fluid filled and can be housed outdoors, in enclosures of steel, concrete or GRP, or in designated secure substations within buildings.

Secondary distribution systems with fuses or circuit breakers limit the duration of short circuits, and circuit breakers or fused HV protection will disconnect the supply rapidly, should an internal fault occur.

For indoor installations, provision is required for liquid retention and, as a minimum, portable fire extinguishers suitable for electrical fires should be available. The use of mineral oil filled transformers inside buildings tends to be restricted to specially designated areas, e.g. in basements or car parks, where it is unlikely that they will ever be involved in a building fire.

Transformers for industrial applications where there is a significant fire hazard may be specified to be filled with a Class K fire resistant liquid with a fire point greater than 300 °C. These transformers may be installed outside buildings or inside in designated substations.

This type of transformer is usually hermetically sealed and the tank may be of the corrugated expanding type or have a nitrogen-filled expansion headspace.

In addition to the standard electrical protection, a pressure relief valve may be fitted to the tank to release gases generated by a fault and also to trip the incoming supply.

Inside public buildings, especially high rise or where large crowds of people are expected to gather, the fire performance becomes of paramount importance. Depending on local regulations and practice, dry-type transformers, which do not require provision for insulating liquid retention, are sometimes preferred, especially in Europe. International practice varies and each specific insulation must be considered in detail.

Several standards and technical papers refer to transformer fire performance. Examples include: IEC 60076-8 [8], IEC 61330 [9] and ISO 14000 [10].

Annex D
(informative)

Power capacitors

There are few reported fires originated by insulating liquid-filled HV capacitor packs, partly because they are now well protected by external or internal fuses, fast acting protection relays or surge arresters.

Because of the possibility that a capacitor unit might rupture, capacitor packs in sub-stations are surrounded by a protective barrier. Most failures are not followed by fires.

However, special attention should be given to installations where PCB mixture-filled capacitors are near to other equipment that may either cause or contribute to a fire, because highly toxic fire effluent results from the thermal decomposition of the PCB mixtures.

Capacitor units each contain only a small volume of insulating liquid of which only a smaller amount (typically 10 % to 20 %) is free liquid that can spill and contribute to a pool fire. In many low voltage applications, banks of insulating liquid-filled capacitors are installed inside industrial or commercial buildings. For such installations, the capacitor bank is normally located so as to restrict access and to minimise the contribution of the capacitors to the hazards of a building fire.

Annex E
(informative)

Cables

E.1 Power cables

Insulating liquids are necessary to impregnate all power cables in which the principal insulation is paper. The main functions of the liquid are:

- to form part of the liquid/paper dielectric insulation. A metallic sheath is necessary to prevent water absorption;
- to suppress electrical discharges which could cause failure, by pressurisation of the liquid to exclude gas-filled voids under all operating conditions in cables designed to operate at high electric stress, and
- to increase the thermal conductivity of the insulation in order to maximise the cable current rating.

Power cables with solid insulation are increasingly being specified for new installations, but large quantities of impregnated power cables are installed worldwide and remain in service with an expected life of many years. For some applications such as submarine power distribution, and systems with rated voltages above 275 kV, impregnated paper remains the insulation medium of choice.

NOTE Communication cables may also contain impregnants, such as petroleum jelly, which are used to block longitudinal water penetration.

Power cable impregnants can be divided into the following types:

a) oil mixtures with viscosities ranging from > 10 000 centistokes (cSt) at 20 °C to less than 10 cSt at high temperature. Currently used oils are typically characterised by the viscosity curve shown in Figure E.1. These liquids typically have open cup flash points above 220 °C. In a fire situation, the liquid will drain under gravity or because of thermal expansion, but will not provide a continuing source of combustible liquid.

   NOTE 1 Medium voltage impregnated-paper a.c. cables are no longer produced in Europe, but many hundreds of km of such cables remain in service.

   NOTE 2 High voltage d.c. cables for long runs use this type of oil.

   NOTE 3 The quoted viscosities are kinematic viscosities (1 cSt = 1 $mm^2 \cdot s^{-1}$).

b) low viscosity liquids (e.g. <15 cSt at ambient and service temperatures) with typical open cup flash points above 120 °C. These liquids are used in a.c. cables as described in IEC 60141-1 **Error! Reference source not found.**. In an external fire, the insulating liquid will be expelled under pressure from its reservoir tank until the reservoir is exhausted which could involve hundreds of litres of liquid;

c) very low viscosity liquids (e.g. <5 cSt at ambient temperature) with typical open cup flash points of approximately 115 °C. These liquids are used in long length a.c. and d.c. submarine cables. Reservoirs contain several tens of cubic metres under vacuum. Hydraulic pressures may be in the order of 20 bar to 25 bar.

Most of these impregnants are based on hydrocarbons, and are therefore flammable. In the case of buried cables, fire hazard is limited except in locations where the cable is exposed to free air as in joint bays or chambers, tunnels, shafts or risers, unfilled ducts or inside buildings such as switching stations. However, it is in such locations where the cable is most likely to be involved in a fire and the consequences most serious.

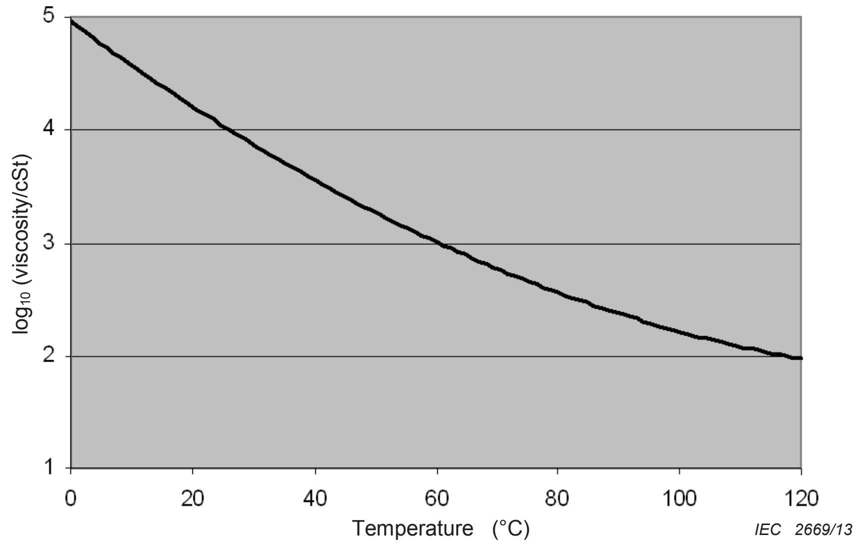

Figure E.1 – Oil viscosity

In situations where the fire hazard is relatively high, some cables have been impregnated with liquids based on silicones with high flash and fire points, to reduce the fire hazard associated with hydrocarbon cable insulating liquids [12]. Such cables are not in general use because of the relatively high cost of the insulating liquid and the requirement for special cable production and processing facilities. Gels in communication cables are based on either hydrocarbons or silicones.

E.2 Communication cables

Impregnants used in communication cables, with either metallic conductors or optical fibres are viscous gels at ambient temperature (which is usually also the service temperature) but may be liquid at higher temperatures. Their open cup flash point is typically greater than 200 °C. In an external fire, if the impregnant liquefies and if the cable sheath is ruptured, it will drain under gravity or because of thermal expansion, but will not provide a continuing source of combustible liquid.

E.3 Cables with water blocking compounds

Communication and power cables with solid insulation, but in which gels or greases are used for water blocking, may be tested as complete cables for fire safety. Water blocking compounds should not liquefy at maximum service temperatures (typically 80 °C).

E.4 Cable terminations

Cable terminations for higher voltages may contain up to 100 litres of low or very low viscosity liquid in a ceramic or composite enclosure.

Annex F
(informative)

Bushings

Bushings, shields and HV (high voltage) leads on transformers should be given particular attention to minimise fire hazard. Although these components are often considered only as accessories, they are the major origin of fires (about 80 %) involving transformers filled with Class O1 (IEC 61039) insulating liquid (mineral oil).

Failures of bushings often result in porcelain sheds being cracked or fragments being projected over a wide area. Oil sprayed into the surrounding atmosphere through the cracked or fractured bushings may be ignited by the arc associated with the fault.

If the fault is in the upper part of the bushing, usually only relatively small fires are caused, which do not spread further than the HV bushing. Breakdown of the HV bushing shield or HV lead, however, may cause rupture of: a) the connection between the bushing and the container, b) the turret, or c) even the container itself, with more severe spray burning and pool fire involving large amounts of oil from the container.

In the most extreme cases, fire balls some five times higher than the transformer have been observed following explosion of a bushing.

However, to put this into perspective, fire occurs in only a minority of transformer failures (typically less than 13 % according to one report [13]).

Physical protection measures against fires and explosions of HV bushings in service are in general difficult or impossible to put in place, owing to the size and location of the equipment. When a particular type of bushing is prone to such failures, access to the site is usually first limited, then changes to the design of the equipment are discussed with the manufacturer to improve safety and reliability.

Mineral oil in the transformer bushing and the transformer tank are usually in the same IEC 61039 class (e.g. Class O1). However, brands may differ, especially in replacement bushings already filled with oil by the manufacturer.

Class K liquids (IEC 61039) minimise fire hazard when used in bushings as in other equipment (see Annex A) but are only used in a minor proportion of equipment (less than 10 %).

Annex G
(informative)

Switchgear

This annex covers oil-filled circuit breakers, oil-filled switches and on-load transformer tapchangers, all of which are normally filled with Class O (IEC 61039) insulating liquid (mineral oil to IEC 60296). In practice, the safety record of all three types is good and the failure rate is very low. In some areas, especially circuit breaking, new technologies allow the replacement of oil, but many oil-filled units will remain in service for some time.

Each of these types of switchgear contains only a small volume of insulating liquid and, in the event of a fire, would make a small contribution to the fire load in a victim fire scenario. Tapchangers however are attached to transformers and malfunction could cause ignition of the larger volume of oil in the transformer.

The main hazard posed by circuit breakers and switches is in the origin of a fire, and such a fire is most likely to be initiated by an uncontrolled high energy internal arc due to insulation failure within the equipment. To minimise this hazard, it is important to maintain the electrical insulation properties of both the insulating liquid and the solid insulation materials used in their construction.

Mineral oil for this application should conform to IEC 60296 and in particular should be clear and free from sediment and suspended matter, especially fibrous materials. The oil should also be dried to remove moisture before use to ensure high volume resistivity.

Under ideal conditions, oil-filled equipment would be hermetically sealed from its surroundings. However, most oil-filled switchgear is free breathing and the moisture content of the oil inside the container will attain equilibrium with the environment. Great care is necessary on the part of designers and manufacturers to ensure operational compatibility between any solid insulation and oil.

Contamination of equipment can occur in service and, to maintain a low failure rate, operators should establish inspection and maintenance programmes. These practices should also be designed to minimise contamination of the equipment and any replacement oil used.

If the oil inside the switchgear becomes seriously contaminated, electrical failure can occur in the form of an electrical short circuit in the oil or, more commonly, across an interface between oil and solid insulation. These short circuit fault currents are large, and back-up electrical protection will limit their duration. However, oil may vaporise in the vicinity of the short circuit arc and this can generate sufficient ignitable gas to cause catastrophic failure. To minimise any risk to personnel and surrounding buildings, attention to safety should be given at the substation design stage.

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