

INTERNATIONAL STANDARD

Specification of technical grade sulphur hexafluoride (SF₆) and complementary gases to be used in its mixtures for use in electrical equipment

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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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Specification of technical grade sulphur hexafluoride (SF₆) and complementary gases to be used in its mixtures for use in electrical equipment

INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SPECIFICATION OF TECHNICAL GRADE SULPHUR
HEXAFLUORIDE (SF₆) AND COMPLEMENTARY GASES
TO BE USED IN ITS MIXTURES FOR USE IN ELECTRICAL EQUIPMENT****FOREWORD**

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International Standard IEC 60376 has been prepared by IEC technical committee 10: Fluids for electrotechnical applications.

This third edition cancels and replaces the second edition published in 2005. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) the requirements for the use of SF₆ in electrical equipment have been confirmed;
- b) a specification for complementary gases to be used in SF₆ mixtures with N₂ and CF₄ has been included;
- c) the introduction and scope have been merged;
- d) a new repartition of the annexes of IEC 60376, IEC 60480 and IEC 62271-4 has been included.

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

FDIS	Report on voting
10/1056/FDIS	10/1060/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

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- replaced by a revised edition, or
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SPECIFICATION OF TECHNICAL GRADE SULPHUR HEXAFLUORIDE (SF₆) AND COMPLEMENTARY GASES TO BE USED IN ITS MIXTURES FOR USE IN ELECTRICAL EQUIPMENT

1 Scope

This document defines the quality for technical grade sulphur hexafluoride (SF₆) and complementary gases such as nitrogen (N₂) and carbon tetra-fluoride (CF₄), for use in electrical equipment. Detection techniques, covering both laboratory and in-situ portable instrumentation, applicable to the analysis of SF₆, N₂ and CF₄ gases prior to the introduction of these gases into the electrical equipment are also described in this document.

This document provides some information on sulphur hexafluoride in Annex A and on the environmental effects of SF₆ in Annex B.

Information about SF₆ by-products and the procedure for evaluating the potential effects of SF₆ by-products on human health are covered by IEC 60480, their handling and disposal being carried out according to international and local regulations with regard to the impact on the environment. Handling of SF₆ and its mixtures is covered by IEC 62271-4.

Procedures to determine SF₆ leakages are described in IEC 60068-2-17.

For the purposes of this document, the complementary gases used in SF₆ mixtures will be limited to N₂ or CF₄.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-212, *International Electrotechnical Vocabulary – Part 212: Electrical insulating solids, liquids and gases* (available at <http://www.electropedia.org>)

IEC 60050-441, *International Electrotechnical Vocabulary – Part 441: Switchgear, controlgear and fuses* (available at <http://www.electropedia.org>)

IEC 60050-826, *International Electrotechnical Vocabulary – Part 826: Electrical installations* (available at <http://www.electropedia.org>)

IEC 60480, *Guidelines for the checking and treatment of sulphur hexafluoride (SF₆) taken from electrical equipment and specification for its re-use*

IEC 62271-4, *High-voltage switchgear and controlgear – Part 4: Handling procedures for sulphur hexafluoride (SF₆) and its mixtures*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-212, IEC 60050-441 and IEC 60050-826 and the following apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

NOTE Some of the more important terms are listed here for easy reference.

3.1.1

electrical equipment

item used for such purposes as generation, conversion, transmission, distribution or utilization of electrical energy, such as electric machines, transformers, switchgear and controlgear, measuring instruments, protective devices, wiring systems, current-using equipment, insulated bushings, surge arresters

[SOURCE: IEC 60050-826:2004, 826-16-01, modified – "insulated bushings, surge arresters" has been added.]

3.1.2

technical grade SF₆

SF₆ gas having a very low level of contaminants in accordance with IEC 60376:2018, Table 1

3.1.3

SF₆ mixture

gas mixture formed by SF₆ and a complementary gas, typically N₂ or CF₄

3.1.4

container

vessel (cylinder) suitable for the containment of pressurized gases either in gaseous or liquid phase, according to local and/or international safety and transportation regulations

3.1.5

contaminant

foreign substance or material in an insulating liquid or gas which usually has a deleterious effect on one or more properties

[SOURCE: IEC 60050-212:2010, 212-17-27, modified – "solid" has been removed.]

3.2 Abbreviated terms

GCB	gas circuit breaker
GIL	gas insulated line
GIS	gas insulated switchgear
GIT	gas insulated transformer
GVT	gas insulated voltage transformer
LCA	life cycle assessment
OEM	original equipment manufacturer
GWP	global warming potential

4 General requirements

It is the responsibility of the supplier to guarantee that the delivered gas or gas mixture is non-toxic, in accordance with international and local regulations.

5 Requirements for technical grade SF₆

SF₆ for use in electrical equipment as pure gas or in an SF₆ mixture shall fulfil requirements given in Table 1. The accuracy of the measuring devices shall be taken into account when checking the quality of the gas.

Further handling and storage of the gas and operation of equipment may introduce additional quantities of contaminants. This situation is covered in IEC 60480.

Table 1 – Requirements for technical grade SF₆

Substance	Concentration
SF ₆	> 98,5 % volume in the gas phase For use in mixtures: > 99,7 % volume in the gas phase
Air	< 10 000 µl/l (i.e. 1 % volume) for pure SF ₆ For use in mixtures: < 2 000 µl/l (i.e. 0,2 % volume)
CF ₄	< 4 000 µl/l (i.e. 0,4 % volume) for pure SF ₆ For use in mixtures: < 800 µl/l (i.e. 0,08 % volume)
H ₂ O	< 200 µl/l (i.e. 200 ppmv)
Mineral oil	< 10 mg/kg (i.e. 10 ppmw)
Total acidity	< 7 µl/l (i.e. 7 ppmv)
Key	
ppmv = parts per million by volume	
ppmw = parts per million by weight	

Regarding the values in Table 1 and depending on the situation, the following considerations shall be taken into account:

- The error in the final mixing percentage of the SF₆ gas mixture mainly depends on handling and purity of SF₆ and the complementary gas. The error due to handling can be reduced by using gas mixing devices, or high accuracy manometers and thermometers (e.g. class 0.1 or better). The error due to purity can be reduced by using high purity gases (e.g. 99,9 % volume or higher).
- SF₆ for use in filling electrical equipment shall fulfil specifications given in Table 1. This is with the exception of gas mixtures with a rated tolerance specified by the original equipment manufacturer (OEM) to be less than ± 5 % by volume of the SF₆ percentage. In that case, to limit the total uncertainty after a typical gas handling operation such as re-filling in order to comply with OEM specifications on the mixture composition ratio, higher SF₆ purity grade > 99,7 % volume shall be used.
- For the determination of total acidity, the sum of all acidic compounds is reported as one value and expressed as HF equivalent. For further information, refer to [1]¹ and [2].
- For humidity measurement, the limit expressed in Table 1 is equivalent to –36 °C frost point at 100 kPa.

¹ Numbers in square brackets refer to the Bibliography.

NOTE 1 The concentration of the contaminants in SF₆ can be different between the liquid and gas phase. Humidity and air are most likely present in the gas phase while oil is most likely present in liquid phase.

NOTE 2 Detection techniques applicable for laboratory and field verification of these limits are given in Annex C.

NOTE 3 For SF₆ measurement by speed of sound technique, available instruments are typically calibrated for SF₆/N₂ or SF₆/CF₄ mixtures. The presence of significant quantities of a third gas as contaminant in excess of 1 % would affect the accuracy of the measurement.

NOTE 4 Electrochemical sensors have certain cross sensitivities to other substances. The value of 2 µl/l, measured by an electrochemical SO₂ sensor, can be interpreted as an approximation of the total acidity of 7 µl/l. Different sensors can react differently to the presence of further substances or flow/pressure variations. Since the electrochemical cells are not sensitive to SF₆, any indication is triggered by some substance other than SF₆.

6 Requirements for complementary gases to be used in SF₆ mixtures

SF₆ mixtures are used in electrical equipment mainly for cold ambient temperature applications, typically under -40 °C. Other applications at normal ambient temperature include gas insulated transmission lines (GIL) and gas insulated transformers (GIT). SF₆ is mixed with a complementary gas, typically N₂ or CF₄, in the percentage as specified by the original equipment manufacturer in the operating instruction manual, typically from 10 % to 75 % SF₆ volume. The maximum permitted concentrations of other substances present in N₂ are given in Table 2 and in Table 3 for CF₄.

Table 2 – Requirements for N₂ to be used in SF₆ mixtures

Substance	Concentration
N ₂	> 99,7 % volume
H ₂ O	< 200 µl/l (i.e. 200 ppmv)
O ₂	< 3 000 µl/l (i.e. 3 000 ppmv)
Mineral oil	< 10 mg/kg (i.e. 10 ppmw)
Total acidity	< 7 µl/l (i.e. 7 ppmv)
Key	
ppmv = parts per million by volume	
ppmw = parts per million by weight	

Table 3 – Requirements for CF₄ to be used in SF₆ mixtures

Substance	Concentration
CF ₄	> 99,7 % volume
O ₂	< 500 µl/l (i.e. 500 ppmv)
N ₂	< 1 500 µl/l (i.e. 1 500 ppmv)
H ₂ O	< 200 µl/l (i.e. 200 ppmv)
Mineral oil	< 10 mg/kg (i.e. 10 ppmw)
Total acidity	< 7 µl/l (i.e. 7 ppmv)
Key	
ppmv = parts per million by volume	
ppmw = parts per million by weight	

The error in the final mixing percentage of the SF₆ gas mixture mainly depends on the handling and purity of the gas. The error due to handling can be reduced by using gas mixing devices, or high accuracy manometers and thermometers (e.g. class 0.1 or better). The error due to purity can be reduced by using high purity gases (e.g. 99,9 % volume or higher).

The concentration of N₂ in Table 2 and the concentration of CF₄ in Table 3 are calculated by subtracting from 100 % volume the sum of all contaminants. For the determination of total acidity, the sum of all acidic compounds is reported as one value and expressed as HF equivalent, for further information refer to [1] and [2].

NOTE 1 The concentration of the contaminants in CF₄ can be different between the liquid and gas phase. Humidity, O₂ and N₂ are most likely present in the gas phase while oil is most likely present in liquid phase.

NOTE 2 Detection techniques applicable for laboratory and field verification of these limits are given in Annex C.

7 Environmental impact

SF₆, CF₄ and SF₆ mixtures with N₂ and/or CF₄ have a certain environmental impact. Due to this impact, SF₆, CF₄ and their gas mixtures shall be handled carefully to prevent deliberate release of SF₆ and CF₄ gas into the atmosphere.

More detailed information concerning environmental impact is reported in Annex B.

8 Handling, storage and transportation

8.1 Gas handling procedures

The need to handle SF₆ and SF₆ mixtures in accordance with the present document, arises when:

- the gas is introduced into electrical equipment,
- the gas pressure is topped up in closed pressure systems,
- the gas is drawn from a container for analysis.

For other handling procedures, for example when the gas has to be recovered from an enclosure, a proper handling procedure shall be defined and implemented to limit any release of SF₆ into the environment wherever possible. Further information concerning handling procedures for SF₆ and SF₆ mixtures is provided in IEC 62271-4.

8.2 Storage and transportation

Information concerning gas storage and transportation is provided in IEC 62271-4.

Specific labelling of containers shall be implemented in accordance with the mode of transport and the local and international regulations.

Annex A (informative)

Sulphur hexafluoride

A.1 General

Sulphur hexafluoride (SF₆) is a synthetic gas formed by 6 atoms of fluorine gathered around a centrally situated atom of sulphur. The chemical bond between fluorine and sulphur is known as one of the most stable existing atomic bonds. Six of them grant the molecule very high chemical and thermal stability.

SF₆ has a unique combination of properties: high dielectric strength, high thermal interruption capabilities (about 10 times that of air) and high heat transfer performance.

A.2 Chemical properties

Pure SF₆ is odourless, tasteless, colourless, non-toxic, non-flammable, very stable and inert.

Its compatibility with materials used in electric constructions is similar to that of N₂, up to temperatures of about 180 °C. Operation at higher temperatures up to 500 °C is possible, but SF₆ may decompose (producing by-products) in the presence of some catalytic materials.

Table A.1 lists the main chemical characteristics.

Table A.1 – Main chemical characteristics of SF₆ [3]

Formula	SF ₆
CAS number ^a	2551-62-4
Molecular weight	146,05 g/mol
Sulphur content	21,95 %
Fluorine content	78,05 %
Molecular structure	Octahedral with fluorine atoms at the six corners
Bonds	Covalent
Collision cross-section	0,477 nm ²
Decomposition temperature in quartz container	500 °C
^a The CAS number is assigned by the Chemical Abstracts Service who maintain a registry of chemical substance information. It has no chemical significance. More information is available on ECHA website. Refer to [7].	

A.3 Physical properties

SF₆ is one of the heaviest known gases: in normal ambient conditions it is approximately five times heavier than air. So there is a risk of asphyxiation under conditions of insufficient ventilated areas with a low oxygen concentration (see IEC 62271-4).

The mixing with air by convection and diffusion is slow, but once it has mixed it does not separate again.

Its solubility in water is four times lower than that of air. The thermal conductivity of SF₆ is lower than that of air, the overall heat transfer properties are two to five times better due to its lower viscosity and higher density.

In electric power equipment the normal pressure range of SF₆ is between 0,1 MPa and 1,0 MPa absolute. The pressure/temperature/density characteristics of the gas are shown in Figure A.1.

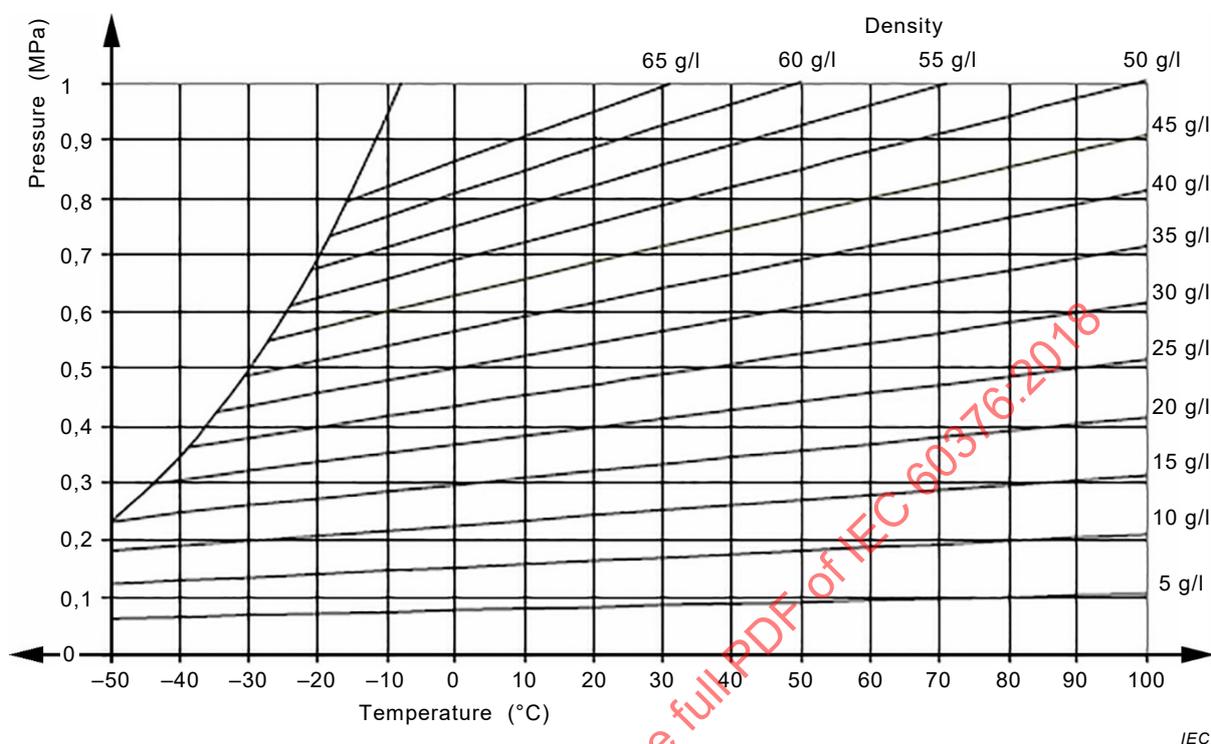


Figure A.1 – Pressure/temperature/density characteristics for SF₆ [3]

Table A.2 lists the main physical characteristics.

Table A.2 – Main physical characteristics of SF₆ [3]

Density at 20 °C and 100 kPa	6,07 kg/m ³
Thermal conductivity at 25 °C and 100 kPa	0,013 W/(m·K)
Critical temperature	45,58 °C
Critical pressure	3,759 MPa
Critical density	740 kg/m ³
Solubility in water at 20 °C	6,31 cm ³ SF ₆ /kg H ₂ O
Sound velocity at 0 °C and 100 kPa	129,06 m/s
Refractive index	1,000 783
Heat of formation	(-1 221,58 ± 1,0) kJ/mol
Entropy of reaction	-349,01 J/(mol·K)
Specific heat at constant pressure at 20 °C and 100 kPa	96,60 J/(mol·K)
Sublimation point	-63,8 °C at 0,1 MPa

A.4 Electrical properties

The excellent dielectric properties of SF₆ are due to the strong electronegative character of its molecule. It has a pronounced tendency to bind free electrons forming heavy ions with low mobility making the development of electron avalanches very difficult.

The electric strength of SF₆ is about three times higher than that of air under the same conditions.

Because of its low dissociation temperature and high dissociation energy, SF₆ is an excellent arc quenching medium.

Table A.3 lists the main electrical characteristics of SF₆.

Table A.3 – Main electrical characteristics of SF₆ [3]

Critical breakdown field relative to pressure (B)	89 V·m ⁻¹ ·Pa ⁻¹
Relative dielectrical constant at 25 °C and 0,1 MPa absolute	1,002 04
Loss factor (tan δ) at 25 °C and 0,1 MPa absolute	< 2,0 × 10 ⁻⁷
Effective ionisation coefficient $\left(\frac{\alpha}{p}\right)$.	$\frac{\alpha}{p} = A \frac{E}{p} - B$ $\alpha: \text{ m}^{-1}$ $E: \text{ V} \cdot \text{ m}^{-1}$ $p: \text{ Pa}$ $A: 2,8 \times 10^{-2} \text{ V}^{-1}$ $B: 2,4 \text{ m}^{-1} \cdot \text{ Pa}^{-1}$

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Annex B (informative)

Environmental effects of SF₆ and its mixtures

B.1 General

Activities where gases are produced or used may cause releases to the atmosphere. Three major aspects are considered:

- ecotoxicology: toxic material and gases with effects on the environment and all forms of life;
- ozone depletion: increase in dimensions of the holes in the stratospheric ozone layer;
- global warming/climate change: increase in the greenhouse effect.

B.2 Ecotoxicology

SF₆, N₂ and CF₄ are not toxic and have no reported potential to be acutely or chronically ecotoxic. As their solubility in water is very low, they present no danger to surface and ground water or the soil. A biological accumulation in the nutrition cycle does not occur. Therefore, SF₆, N₂ and CF₄ do not harm the ecosystem. SF₆, N₂ and CF₄ are:

- not carcinogenic: not causing cancer;
- not mutagenic: not causing damage to the genetic constitution;
- not nitrifying: no enrichment in the food chain.

B.3 Ozone depletion

SF₆, N₂ and CF₄ do not contribute to the destruction of the stratospheric ozone layer [3] because they do not contain either chlorine or bromine.

B.4 Global warming/climate change (greenhouse effect)

Both manmade and natural greenhouse gases contribute to the greenhouse effect. The Kyoto Protocol [5] is an international agreement to control the emission of manmade greenhouse gases.

The greenhouse gases to be monitored according to the Kyoto Protocol are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF₃) and sulphur hexafluoride (SF₆). The latter four substances are fluorinated greenhouse gases (F-gases).

The concentrations of different gases relevant to the environment including those in the Kyoto Protocol are regularly monitored by several scientific bodies. In particular the Intergovernmental Panel on Climate Change (IPCC) periodically prepares assessment reports, updating the existing information on emissions and evaluating their potential future impact on the environment according to different hypothesis of their emission trends. The latest is the Fifth Assessment Report (AR5) published in 2013 [4].

The Fifth Assessment Report provides the global warming potential (GWP) of SF₆ and CF₄ which are calculated over a time period of 100 years warming potential of 1 kg of a gas referred to 1 kg of CO₂. The strong infrared absorption of SF₆ and its long lifetime in the environment are the reasons for its high GWP which is 23 500 times higher than that of CO₂. CF₄ has a GWP which is 6 630 times higher than that of CO₂.

B.5 Reducing the environmental impact of the use of SF₆ and CF₄ in electrical equipment

Major failures causing gas releases are extremely rare as records from 50 years of experience show. The quantities released in such extreme cases are again very limited by the fact that the standard design of products is compartmented, limiting the fault to the place where it originates. The gas quantities concerned are subsequently small fractions of the total gas banked in a substation.

The electric industry utilizes SF₆ and its mixtures in a closed cycle, banking it for example in gas insulated switchgear (GIS), medium-voltage and high-voltage gas circuit breakers (GCB), high-voltage gas insulated lines (GIL), gas insulated voltage transformers (GVT) and gas insulated power transformers (GIT). To avoid any deliberate release to the environment, gas recovery and re-use have the highest priority.

The GWP of SF₆ and CF₄ alone is not enough to measure the environmental impact of electric power equipment based on SF₆ technology. The environmental impact of any specific application should be evaluated and compared using the life cycle assessment (LCA) approach as regulated by ISO 14040 [6].

To reduce the overall environmental impact:

- design equipment with reduced quantities of SF₆ and CF₄ and lower leakage rates;
- improve handling processes and handling equipment for all life cycle stages according to the present document; refer to IEC 62271-4;
- quantify and minimize emissions during testing, manufacturing, installation, operation and maintenance of electric power equipment;
- reclaim gas at the equipment's end of life according to IEC 62271-4.

As a consequence, total SF₆ contribution to the global warming from all applications amounts to less than 0,1 % of the overall greenhouse gas effects.