IEC 60376

Edition 3.0 2018-05

INTERNATIONAL STANDARD

Specification of technical grade sulphur hexafluoride (SF_6) and complementary gases to be used in its mixtures for use in electrical equipment

IEC 60376:2018-05(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.040.20

ISBN 978-2-8322-5744-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SPECIFICATION OF TECHNICAL GRADE SULPHUR HEXAFLUORIDE (SF_6) AND COMPLEMENTARY GASES TO BE USED IN ITS MIXTURES FOR USE IN ELECTRICAL EQUIPMENT

FOREWORD

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 SF_6 in electrical equipment have been confirmed;

b) a specification for complementary gases to be used in SF_6 mixtures with N_2 and CF_4 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

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- withdrawn,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

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

SPECIFICATION OF TECHNICAL GRADE SULPHUR HEXAFLUORIDE (SF_6) 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 (SF_6) and complementary gases such as nitrogen (N_2) and carbon tetra-fluoride (CF_4), for use in electrical equipment. Detection techniques, covering both laboratory and in-situ portable instrumentation, applicable to the analysis of SF_6, N_2 and CF_4 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 SF_6 in Annex B.

Information about SF_6 by-products and the procedure for evaluating the potential effects of SF_6 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 SF_6 and its mixtures is covered by IEC 62271-4.

Procedures to determine SF_6 leakages are described in IEC 60068-2-17.

For the purposes of this document, the complementary gases used in SF_6 mixtures will be limited to N_2 or CF_4.

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 (SF_6) 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 (SF_6) 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 SF_6
SF_6 gas having a very low level of contaminants in accordance with IEC 60376:2018, Table 1

3.1.3
SF_6 mixture
gas mixture formed by SF_6 and a complementary gas, typically N_2 or CF_4

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 SF_6

SF_6 for use in electrical equipment as pure gas or in an SF_6 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 SF_6

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_2O	< 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 SF_6 gas mixture mainly depends on handling and purity of SF_6 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).

– SF_6 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 SF_6 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 SF_6 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 SF_6 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 SF_6 measurement by speed of sound technique, available instruments are typically calibrated for SF_6/N_2 or SF_6/CF_4 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 SO_2 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 SF_6, any indication is triggered by some substance other than SF_6.

6 Requirements for complementary gases to be used in SF_6 mixtures

SF_6 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). SF_6 is mixed with a complementary gas, typically N_2 or CF_4, in the percentage as specified by the original equipment manufacturer in the operating instruction manual, typically from 10 % to 75 % SF_6 volume. The maximum permitted concentrations of other substances present in N_2 are given in Table 2 and in Table 3 for CF_4.

Table 2 – Requirements for N_2 to be used in SF_6 mixtures

Substance	Concentration
N_2	> 99,7 % volume
H_2O	< 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 CF_4 to be used in SF_6 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_2O	< 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 SF_6 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 N_2 in Table 2 and the concentration of CF_4 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 CF_4 can be different between the liquid and gas phase. Humidity, O_2 and N_2 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

SF_6, CF_4 and SF_6 mixtures with N_2 and/or CF_4 have a certain environmental impact. Due to this impact, SF_6, CF_4 and their gas mixtures shall be handled carefully to prevent deliberate release of SF_6 and CF_4 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 SF_6 and SF_6 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 SF_6 into the environment wherever possible. Further information concerning handling procedures for SF_6 and SF_6 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 (SF_6) 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.

SF_6 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 SF_6 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 N_2, up to temperatures of about 180 °C. Operation at higher temperatures up to 500 °C is possible, but SF_6 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 SF_6 [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

SF_6 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 SF_6 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 SF_6 is between 0,1 MPa and 1,0 MPa absolute. The pressure/temperature/density characteristics of the gas are shown in Figure A.1.

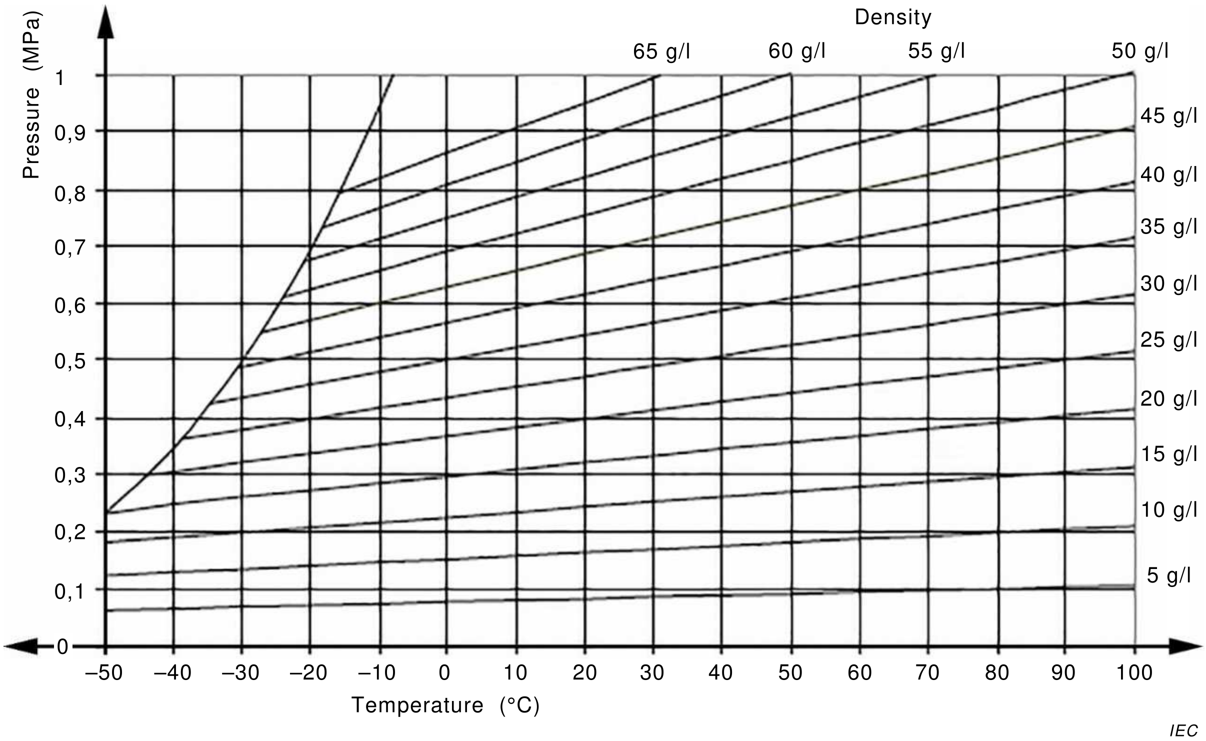

Figure A.1 – Pressure/temperature/density characteristics for SF_6 [3]

Table A.2 lists the main physical characteristics.

Table A.2 – Main physical characteristics of SF_6 [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_2O
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 SF_6 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 SF_6 is about three times higher than that of air under the same conditions.

Because of its low dissociation temperature and high dissociation energy, SF_6 is an excellent arc quenching medium.

Table A.3 lists the main electrical characteristics of SF_6.

Table A.3 – Main electrical characteristics of SF_6 [3]

Critical breakdown field relative to pressure (B)	89 $V \cdot m^{-1} \cdot Pa^{-1}$
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	$< 2,0 \times 10^{-7}$
Effective ionisation coefficient $\left(\frac{\alpha}{p}\right)$.	$\frac{\alpha}{p} = A\frac{E}{p} - B$ α: m^{-1} E: $V \cdot m^{-1}$ p: Pa A: $2,8 \times 10^{-2}$ V^{-1} B: 2,4 $m^{-1} \cdot Pa^{-1}$

Annex B
(informative)

Environmental effects of SF_6 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

SF_6, N_2 and CF_4 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, SF_6, N_2 and CF_4 do not harm the ecosystem. SF_6, N_2 and CF_4 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

SF_6, N_2 and CF_4 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 (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6). 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 SF_6 and CF_4 which are calculated over a time period of 100 years warming potential of 1 kg of a gas referred to 1 kg of CO_2. The strong infrared absorption of SF_6 and its long lifetime in the environment are the reasons for its high GWP which is 23 500 times higher than that of CO_2. CF_4 has a GWP which is 6 630 times higher than that of CO_2.

B.5 Reducing the environmental impact of the use of SF_6 and CF_4 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 SF_6 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 SF_6 and CF_4 alone is not enough to measure the environmental impact of electric power equipment based on SF_6 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 SF_6 and CF_4 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 SF_6 contribution to the global warming from all applications amounts to less than 0,1 % of the overall greenhouse gas effects.

Annex C
(informative)

Detection techniques

C.1 Detection techniques of SF_6

Table C.1 – Detection techniques for laboratory analysis of technical grade SF_6 (not exhaustive)

Substance	Detection technique	Typical accuracy
Air	Gas chromatography	15 µl/l to 50 µl/l (i.e. 15 ppmv to 50 ppmv)
	Density measurement	50 µl/l (i.e. 50 ppmv)
CF_4	Gas chromatography	15 µl/l (i.e. 15 ppmv)
	Infrared absorption	80 µl/l (i.e. 80 ppmv)
H_2O	Electrolytic cell	16 µl/l to 120 µl/l (i.e. 16 ppmv to 120 ppmv)
	Chilled mirror	0,5 °C
	Infrared absorption	20 µl/l (i.e. 20 ppmv)
	Capacitance	2 °C to 4 °C
Mineral oil	Photometry	2 mg/kg (i.e. 2 ppmw)
	Gravimetry	0,5 mg/kg (i.e. 0,5 ppmw)
Total acidity	Titration	1 µl/l (i.e. 1 ppmv)
	Electro-chemical sensor	3 % of full range (SO_2)

Key

ppmv = parts per million by volume

ppmw = parts per million by weight

Table C.2 – Detection techniques for on-site analysis of technical grade SF_6 (not exhaustive)

Substance	Detection technique	Typical accuracy
SF_6	Condensation	0,5 %
	Infrared absorption	0,5 %
	Speed of sound	0,5 %
H_2O	Electrolytic cell	1 %
	Chilled mirror	0,5 °C
	Infrared absorption	20 µl/l (i.e. 20 ppmv)
	Capacitance	2 °C to 4 °C
Total acidity	Electro-chemical sensor	3 % (SO_2)

Key

ppmv = parts per million by volume

C.2 Detection techniques of N_2

Table C.3 – Detection techniques for laboratory analysis of technical grade N_2 used in SF_6 mixtures (not exhaustive)

Substance	Detection technique	Typical accuracy
N_2	—	—
H_2O	Electrolytic cell	16 µl/l to 120 µl/l (i.e. 16 ppmv to 120 ppmv)
	Chilled mirror	0,5 °C
	Capacitance	2 °C to 4 °C
	Infrared absorption	20 µl/l (i.e. 20 ppmv)
O_2	Gas chromatography	15 µl/l to 50 µl/l (i.e. 15 ppmv to 50 ppmv)
Key ppmv = parts per million by volume		

C.3 Detection techniques of CF_4

Table C.4 – Detection techniques for laboratory analysis of technical grade CF_4 used in SF_6 mixtures (not exhaustive)

Substance	Detection technique	Typical accuracy
CF_4	—	—
O_2	Gas chromatography	15 µl/l to 50 µl/l (i.e. 15ppmv to 50 ppmv)
N_2	Gas chromatography	15 µl/l to 50 µl/l (i.e. 15 ppmv to 50 ppmv)
H_2O	Electrolytic cell	16 µl/l to 120 µl/l (i.e. 16 ppmv to 120 ppmv)
	Chilled mirror	0,5 °C
	Capacitance	2 °C to 4 °C
	Infrared absorption	20 µl/l (i.e. 20 ppmv)
Total acidity	Titration	1 µl/l (i.e. 1 ppmv)
Key ppmv = parts per million by volume		

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[8] IEC 60068-2-17, *Basic environmental testing procedures – Part 2-17: Tests – Test Q: Sealing*

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