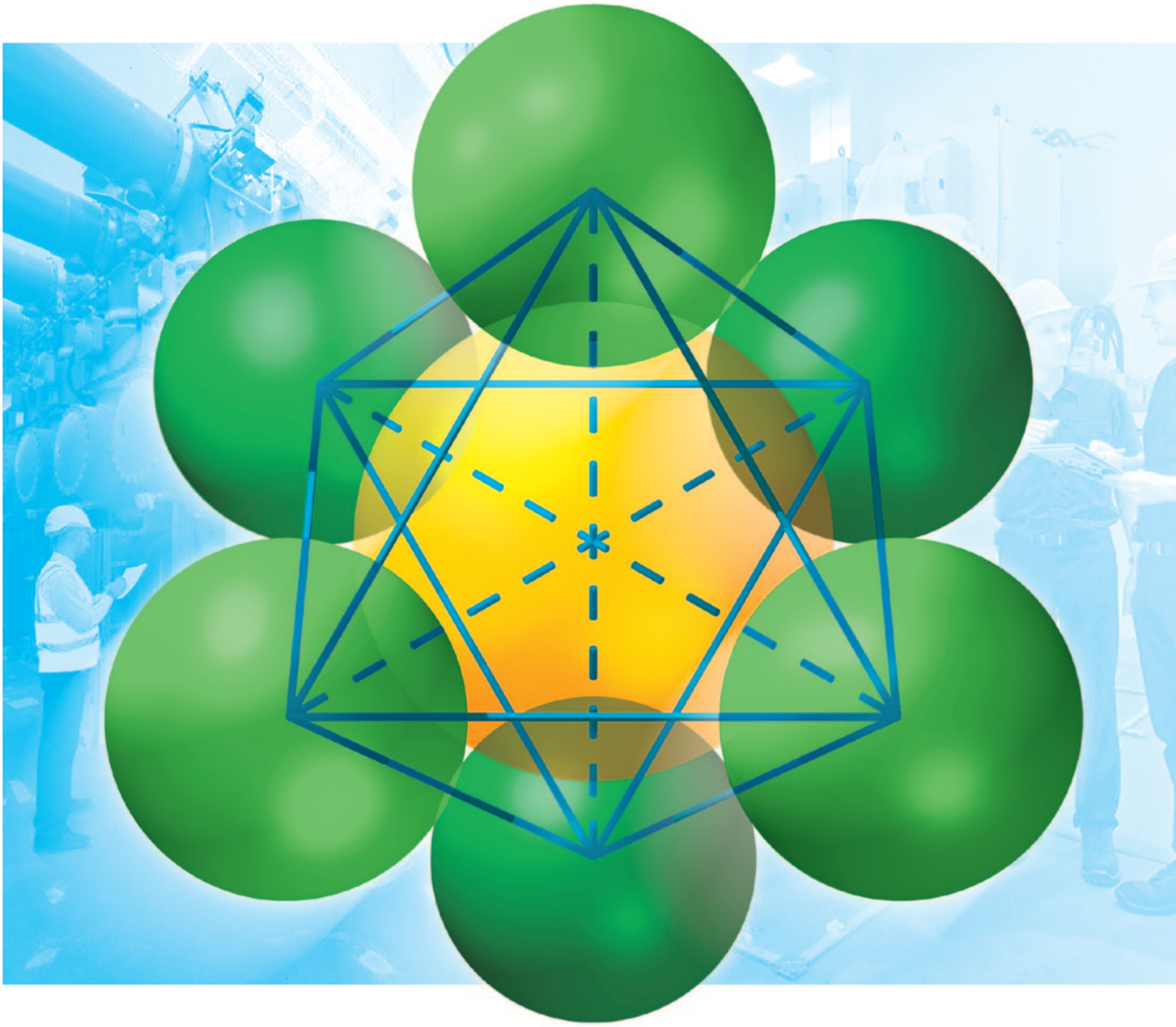
Sulphur Hexafluoride



Solvay
Special Chemicals

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Contents

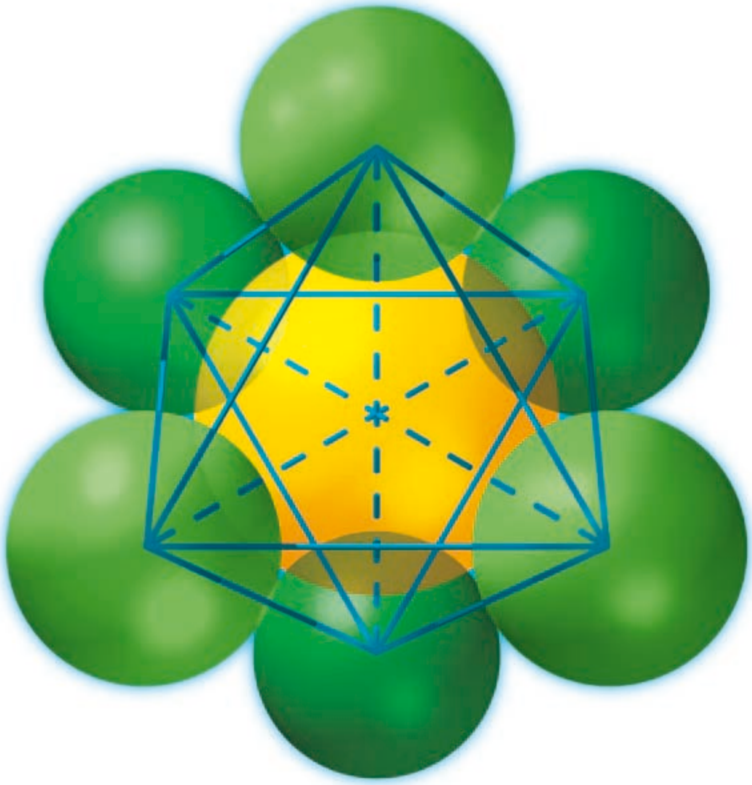
SF_6 – a gas with unusual properties

Solvay's sulphur hexafluoride is a non-toxic, inert, insulating and cooling gas of high dielectric strength and thermal stability.

It is particularly suitable for application in both high-voltage and medium-high voltage power circuit breakers as well as in high-voltage cables, transformers, transducers, particle and electron accelerators, X-ray equipment and UHF transmission systems and as an etching and chamber cleaning gas in the semiconductor industry.

The construction of new equipment with higher capacity and improved performance has been made possible by the excellent electrical, thermal and chemical properties of SF_6. Changing from conventional dielectrics to sulphur hexafluoride – a non-flammable, chemically-inactive and non-toxic heavy gas – results in considerable space and weight savings and improvements in the operational safety of converted equipment.

SF_6 is also used in medical technology: for example as a contrast agent in ultrasonic examinations as well as in ophthalmology, pneumonectomy and diseases of the middle ear, e.g. treating loss of hearing in middle ear infections.



Areas of application for sulphur hexafluoride

Electrical engineering

The use of sulphur hexafluoride in place of solid and liquid insulators offers a number of important advantages:

High dielectric strength at lower cost

When pressurized, sulphur hexafluoride can exhibit the same dielectric strength as liquid insulators. However, the per-unit-volume cost of SF_6 is only a fraction of that of liquid dielectrics.

Regeneration capacity

Following a breakdown, sulphur hexafluoride regenerates itself. Its original strength is spontaneously restored.

Low pressure-increase in the case of breakdown

Due to the very low adiabatic coefficient of sulphur hexafluoride, the pressure rise as a result of thermal expansion following dielectric breakdowns is less than that with other gases and very considerably less than is the case with liquid dielectrics.

Fig. 1 *SF_6-insulated, high-voltage switching station, 500 kV (Siemens, Germany)*

High-voltage switchgear and switching stations

The excellent arc-quenching and insulating properties of sulphur hexafluoride have permitted the construction of completely new types of high-voltage circuit breakers and switching stations with outstanding features: compact and space-saving design, low noise-levels, protection against accidental contact of live parts, against intrusion of foreign matter through the metal cladding and elimination of the fire hazard.

Substations using sulphur hexafluoride for insulation purposes are particularly in demand where, on account of limited space, a compact design is required. These substations occupy only 10 – 15 % of the space required by conventional air-insulated units. New SF_6-filled equipment can thus be installed at distribution points in densely-populated areas where site costs would prohibit the use of traditional methods.

Thanks to their insensitivity to polluted air, enclosed outdoor versions of SF_6-insulated substations are installed in the chemical industry, in desert regions and in coastal areas.

SF_6 is used as a quenching agent both in power circuit breakers for enclosed substations and in circuit breakers for open outdoor substations.

Fig. 2 *SF_6-GIS, ELK-04, 170 kV (ABB, Germany)*

Fig. 3 *Gas insulated, high-voltage switching station, 800 kV (Hyosung, South Korea)*

Fig. 4 *SF_6-insulated hybrid module, 420 kV (Alstom Grid, France)*

Fig. 5 *Gas insulated, high-voltage switching station, 420 kV (Hyundai, South Korea)*

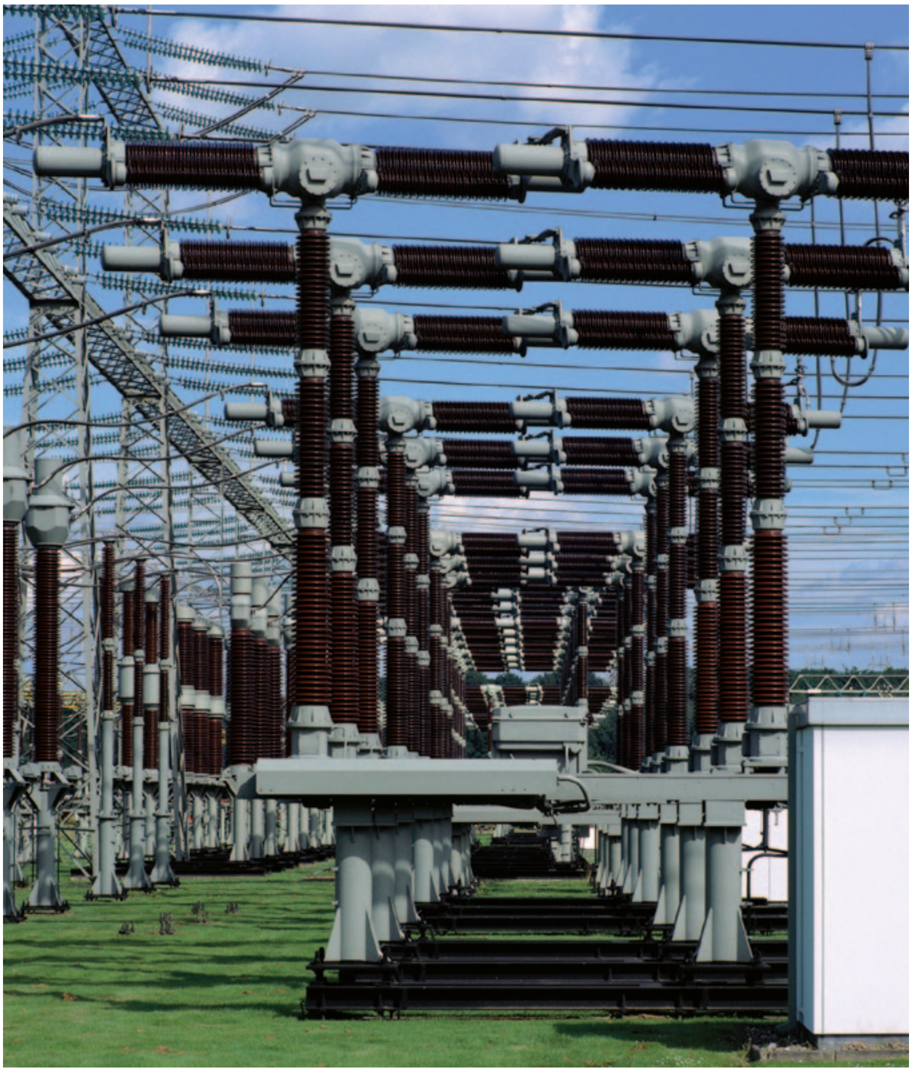


Fig. 6 *Outdoor circuit breaker with SF_6 equipment, 420 kV (Siemens, Germany)*

Fig. 7 *GIS substation, 145 kV (Alstom Grid, Switzerland)*

Fig. 8a *Hydroelectric power station Itaipú, Brazil*

SF_6 for the Itaipú hydroelectric station

Solvay supplied SF_6 for one of the world's largest hydroelectric power stations at Itaipú between Paraguay and Brazil. The output at Itaipú is particularly impressive: 20 turbines (the last 2 installed in 2007) supply 14.000 Mega Watt, equivalent to the output of 11 nuclear power stations. For Paraguay, Itaipú delivers 95% of the country's requirement. One of the largest SF_6-insulated high-voltage switching stations in the world was installed at Itaipú, and contains more than 100 tons of sulphur hexafluoride. The Itaipú dam was elected in 1994 as one of the seven modern Wonders of the World.

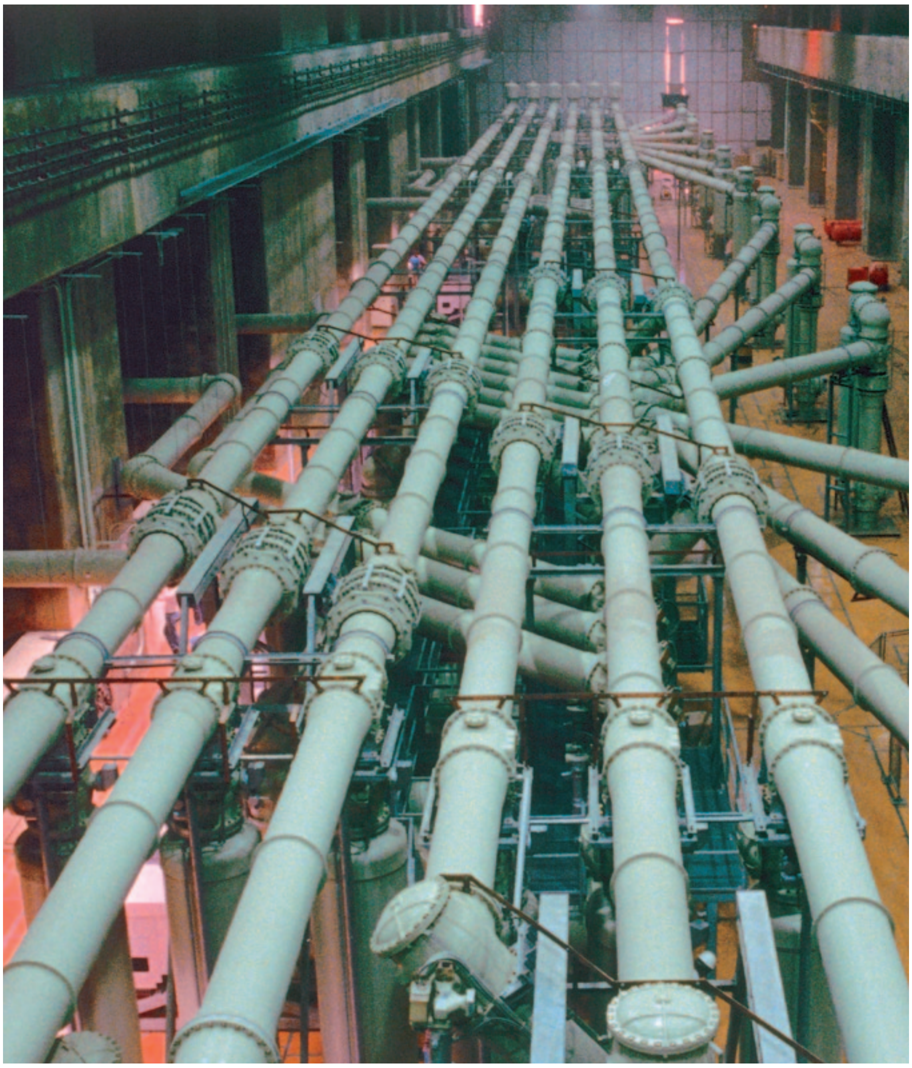


Fig. 8b *550 kV SF_6-insulated high-voltage switching station for the Itaipú hydroelectric power station in Brazil (ABB, Switzerland)*

Gas insulated transmission line (GIL)

Gas insulated transmission lines are particularly well suited for high power transmission. Conventional designs are filled with pure SF_6, and have been operating safely and reliably in all parts of the world for more than 35 years.

Second-generation gas-insulated lines for high power transmission are the best option where environmental or structural considerations rule out the use of overhead transmission lines. The outstanding features of a GIL system[1] are its high transmission capacity (up to 3,700 MVA), superior electromagnetic compatibility (EMC) to any other transmission system, low losses, high safety and flexible installation options. GIL systems at a rated voltage up to 550 KV can be laid above ground, installed in tunnels or buried directly in the soil, depending on individual requirements.

For long distances the replacement of pure SF_6 with more economical SF_6/N_2 mixtures has been researched because the arc extinguishing properties of SF_6 are not relevant in insulating applications.

Today the overall optimization of gas mixtures, gas pressure and dimensions of GIL mean this technology is a highly competitive transmission medium in a broad range of applications.

Our research and application department supports this application with their know-how about the initial production of SF_6/N_2 mixtures through to the separation of SF_6/N_2 mixtures at end of service life or whenever required.

For this long time lasting technology Solvay has developed steps in filling, mixing and separation technology.

Fig. 9 *SF_6/N_2-membrane-separation plant with condenser unit*

Fig. 10 *Polyethylene coated GIL system for direct burial 245 – 550 kV (Siemens, Germany)*

Fig. 11 *Gas insulated line for SF_6/N_2 mixture in a tunnel 245 – 550 kV (Siemens, Germany)*

Fig. 12 *SF_6 -gas-insulated medium voltage switchgear, 12 – 24 kV (Driescher, Germany)*

Medium-voltage switchgear

The advantages of SF_6 technology, in particular its excellent arc-quenching capacity, are also put to good use in circuit breakers for the 10 – 40 kV range. They replace conventional, low-oil-volume circuit breakers and also satisfy heavy-duty requirements such as those occurring under short-circuit conditions and repeated switch-off under load.

As with high-voltage circuit breakers, medium-voltage switchgear requires little maintenance and are particularly suitable for locations where oil-filled equipment is undesirable.

Fig. 13 *Compact SF_6 -gas-insulated medium voltage switchgear, 40.5 kV as double busbar system (Schneider Electric, Germany)*

Fig. 14 *SF_6 -gas-insulated medium voltage switchgear, 24 kV as double busbar system (ABB, Germany)*

Fig. 15 *SF_6 -gas-insulated medium voltage switchgear, for secondary distribution up to 40.5 kV (Ormazabal, Spain)*

High-voltage cables and tubular transmission lines

In recent times, increasing interest has been shown in the application of sulphur hexafluoride in the manufacture of gas-insulated high-voltage cables and tubular transmission lines used for high-power distribution in heavily concentrated industrial areas.

Tubular transmission lines are also used to connect power stations with transformers or switching stations, as for example in the case of underground power stations. Appropriately-dimensioned tubular transmission lines filled with pressurized SF_6 permit unusually high current levels. Compared to those values achieved with conventional types of cables, figures for charging-current and electric loss are insignificant.

In high-frequency carrier sytems, output has been increased almost tenfold through the use of SF_6-filled tubular transmission lines. An advantage from the constructional point of view is the ability to build high-performance UHF transmission stations with greatly reduced dimensions.

Transformers

Its excellent heat-transfer capacity, non-flammability and non-toxicity have also promoted the use of sulphur hexafluoride in the construction of transformers.

On account of their high operational safety, SF_6-gas transformers are installed in mines and department stores. Their relatively light weight, compact design and low noise levels are decisive advantages.

Fig. 16 *SF_6-insulated high-voltage cable in the JET nuclear-fusion plant (kabelmetal electro, Germany)*

Fig. 17 *SF_6-insulated transformer, 23 – 107 kV (Fuji, Japan)*

Other high-voltage applications

The use of sulphur hexafluoride has also established itself in the insulation of super-voltage generators in particle-accelerating machines, such as in Van de Graaf accelerators, betatrons, neutron generators and other such equipment used for radiation applications in scientific institutions, medicine and industry.

By virtue of the high dielectric strength of the gas, pressure vessels can be constructed in considerably lighter fashion. The use of SF_6 in older units, previously insulated with mixtures of air and carbon dioxide, has resulted in a marked increase in efficiency.

SF_6 fulfills a similar function in voltage stabilizers for electron microscopes and in X-ray equipment used in production control and the non-destructive testing of materials.

Parallel to the development of SF_6 plant technology in the high-voltage sector, SF_6-insulated, high-voltage measuring instruments and calibrated power sources have also been produced. SF_6-fillings are also used in instrument transformers, pressurized gas capacitors and surge arresters for super voltages.

Fig. 18 *SF_6 instrument-transformer, 420 kV (Trench Germany)*

SF_6 for particle and electron accelerators

Nowadays particle accelerators are intended more and more for industrial processes besides their common application in research.

Several complete processes including one or more electron accelerators have been put on the market for property enhancement of polymeric materials[2]. Low-energy (75 KeV to 300 KeV) electron accelerators are used to cure (polymerize, copolymerization and crosslink) coatings, adhesives and inks on paper, plastic and metal substrates. High energy (up to 10 MeV) accelerators are used to cure fiber reinforced composite materials or to modify plastics and their surfaces by Graft polymerization. One of the first commercial applications of radiation cross linking was the improvement of the insulation on electrical wires and the jackets on multi conductor cables (1950). For environmental remediation electron beams were used for water and effluents treatment. Purification of flue gases, from nitrogen oxide and sulfuric oxide by precipitation with ammonia from oil- or coal-fired power plans (deNox / deSox) are established. Accelerator systems for health application as sterilization of medical supplies, decontamination of wastes or sanitation of food products are also installed.

A French based manufacturer of accelerators is currently commissioning one of the world most powerful systems in this range. This machine requires an amount of 5 tons of SF_6 and could be used for the stated applications.

Fig. 20 *300 kW electron processing system consisting of two 3 MeV accelerators (Vivirad, France)*

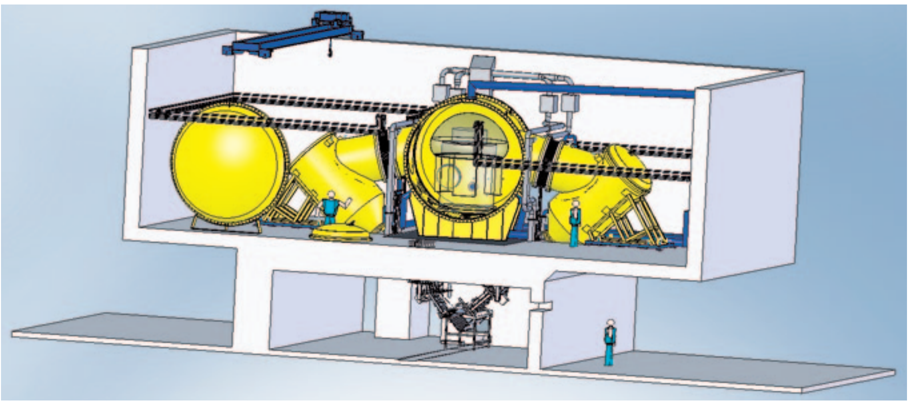


Fig. 19 *Scheme of an electron accelerator (Vivirad, France)*

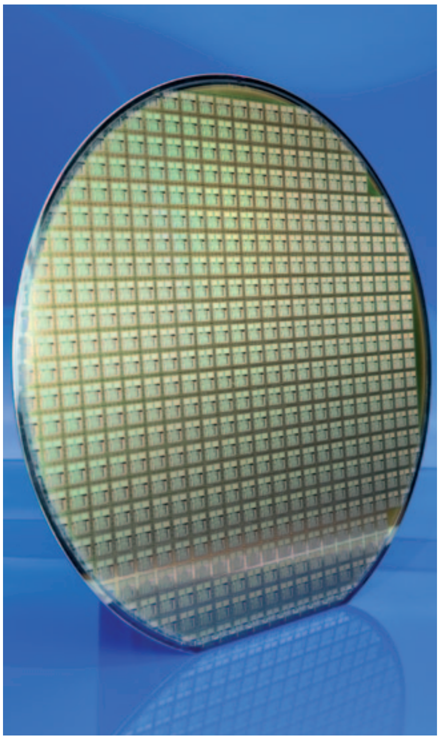


Fig. 21 *Silicon wafer*

SF_6 as a process gas in the semiconductor industry

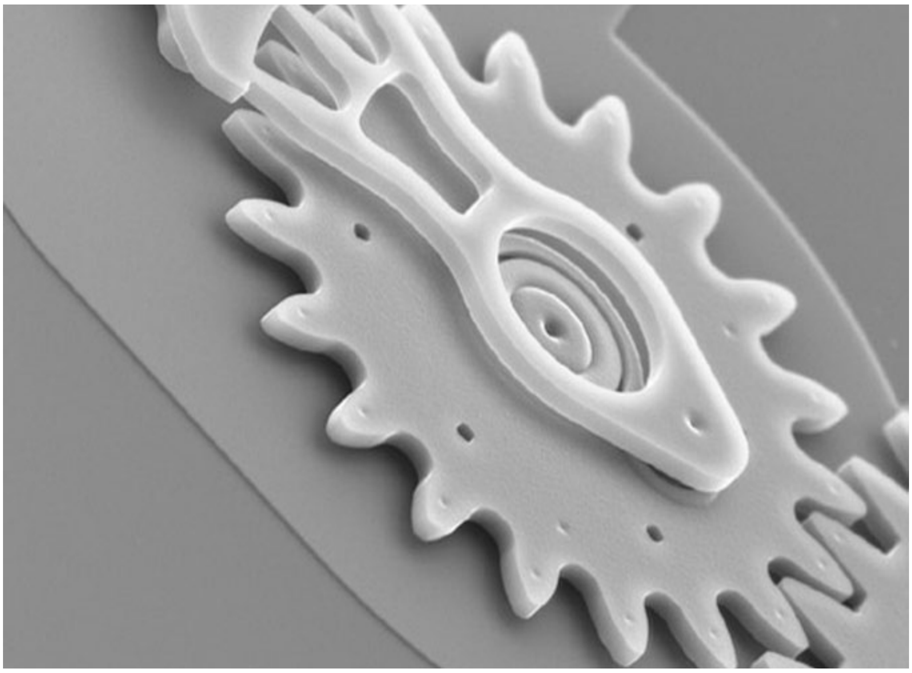
Sulphur hexafluoride is more and more used for the manufacturing of semiconductor devices such as IC (integrated circuits), flat panels, photovoltaic panels and MEMS (Micro-Electro-Mechanical-Systems). It is used to produce chips (processors and memories) on mono-crystalline silicon wafers, or solar cells on poly-crystalline wafers. On a different substrate, e.g. glass, those silicon circuits are manufactured on thin deposited films of different silicon materials and take the more familiar form of solar panels or flat screen TVs.

Fluorinated gases, such as sulphur hexafluoride (SF_6), play two very important roles in the manufacturing of silicon devices.

Firstly, they are used to selectively remove materials through a process which is called 'etching'. The fluorinated gases are activated in plasma and the fluorine radicals that are generated react with the silicon giving volatile species. In this way they pattern the different elements of the circuit on the base. SF_6 is especially efficient in the production of MEMS (Micro Electro Mechanical Systems), because the high energy and reactivity of its ions allow an unbeatable etching rate. SF_6 is employed in the production of integrated circuits for the so called 'isotropic etching', because it reacts in any direction and can pattern round cavities.

Secondly, fluorinated gases are used to clean the production tools from unwanted Si-based layers and particles. SF_6 is an optimum gas to generate the F radicals that etch and thus efficiently remove the deposits on the walls of the plasma chamber. This process is known as 'chamber cleaning'.

Gas purity is of key importance in this market segment, because any possibility of contamination has to be minimized. For this purpose Solvay offers N5.0 material.



Courtesy of Sandia National Laboratories, SUMMiT(TM) Technologies, www.mems.sandia.gov

Fig. 22 *Micro-Electro-Mechanical-Systems*

Electrical properties

Electron affinity

The excellent insulating properties of sulphur hexafluoride are attributable to the strong electron affinity (electronegativity) of the SF_6 molecule. This is based mainly on two mechanisms, resonance capture and dissociative attachment of electrons, in accordance with the equations:

$$SF_6 + e^- \longrightarrow SF_6^- \qquad (1)$$

$$SF_6 + e^- \longrightarrow SF_5^- + F \qquad (2)$$

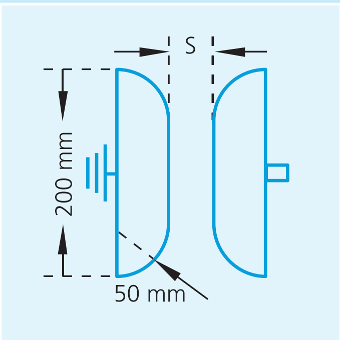
The process represented by equation (1) applies to electron energies of 0.1 eV with an energy range of 0.05 eV, and that represented by equation (2) applies to an energy range of 0.1 eV [3].

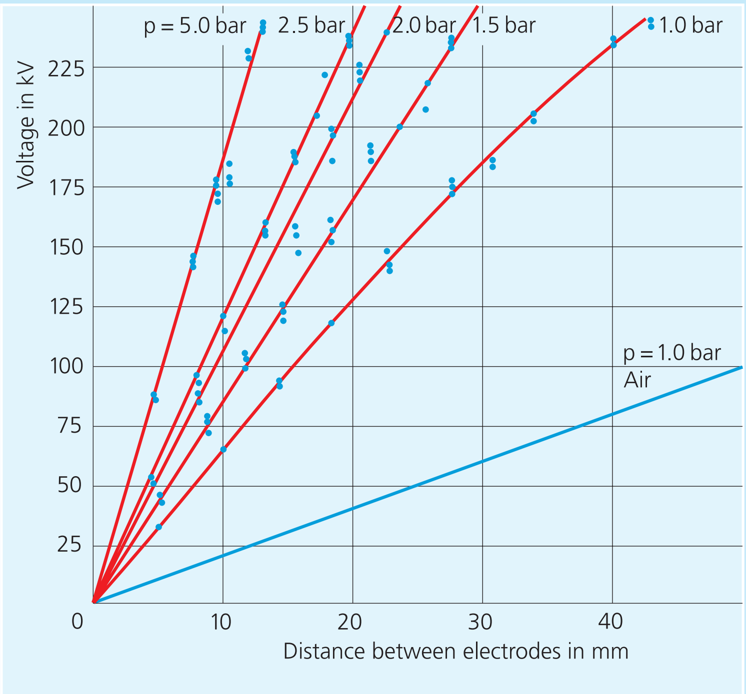
Permittivity

The permittivity has a value of 1.0021 at 20 °C, 1.0133 bar and 23.340 MHz; a rise in pressure to 20 bar leads to an increase of about 6 % in this value.

At -50 °C, the permittivity of liquid sulphur hexafluoride throughout the range from 10 to 500 kHz remains unchanged at 1.81 ± 0.02 [4].

Fig. 23 *50 Hz breakdown voltage of SF_6 in a homogeneous field as a function of the distance between electrodes at various gas pressures (ETZ Supplement 3 [1966])*





Dielectric strength

The strong interaction of high-energy electrons with the polyatomic SF_6 molecule causes their rapid deceleration to the lower energy of electron capture and dissociative attachment. SF_6-breakdown is therefore only possible at relatively high field strengths.

The breakdown voltages at 50 Hz and 1 bar in a homogenous field are thus 2.5 to 3 times higher than the corresponding values for air or nitrogen (Fig. 23).

Figure 24 shows the relationship of breakdown voltage to pressure in a non-homogeneous field in comparison with that of a N_2/CO_2 mixture.

The breakdown strength of air is dramatically increased by the addition of small quantities of SF_6. In contrast, air has only a limited influence on the breakdown strength of sulphur hexafluoride. The addition of 10 % of air by volume reduces the breakdown voltage of SF_6 by about 3 %, the addition of 30 % air by about 10 %.

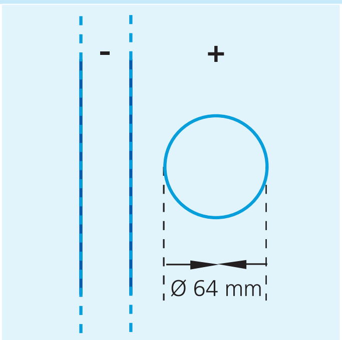
The breakdown voltage of SF_6 reaches that of transformer oil at a pressure of only 3 bar (Fig. 25).

The behaviour of sulphur hexafluoride conforms over a wide range of pressures to Paschen's Law: at higher pressures, however, deviations have been observed under certain conditions [5,6,7].

The breakdown strength of SF_6 is independent of frequency: it is therefore an ideal insulating gas for UHF equipment [8].

The Corona-onset voltage using SF_6 in non-homogeneous fields is also considerably higher than that using air. Figures 26 and 27 show the respective dependence on pressure and radius of curvature of the electrodes in the case of SF_6 and air in a point-to-plane electrode system.

Fig. 24 *Relation of breakdown voltage to pressure (IEEE Trans. Pow. App. Syst. 66 [1963] 357) Comparison SF_6 and N_2/CO_2-mixtures*



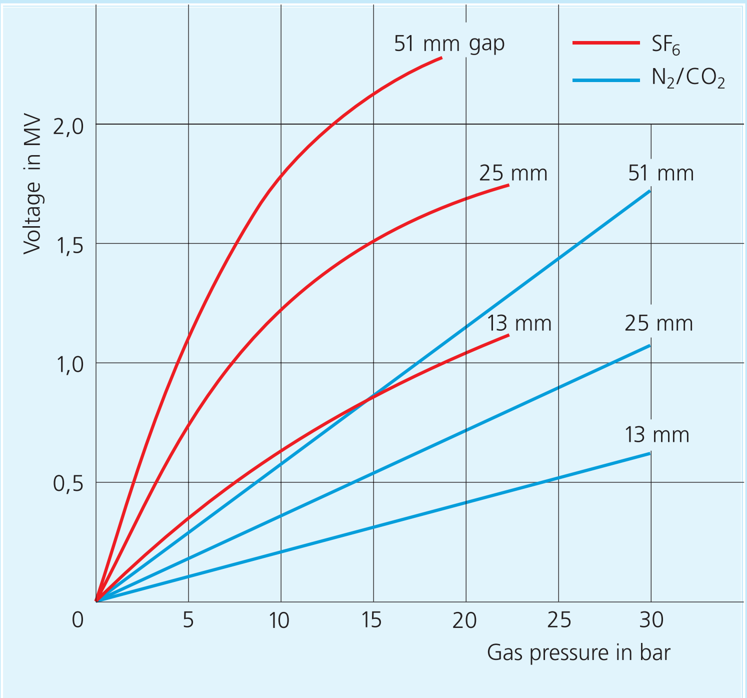
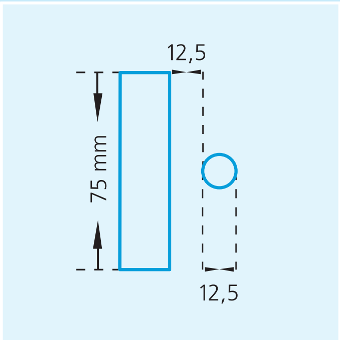


Fig. 25 *Breakdown strength of transformer oil, air and SF_6 as a function of gas pressure (Kali und Steinsalz, 3, issue 10 [1963] 319)*



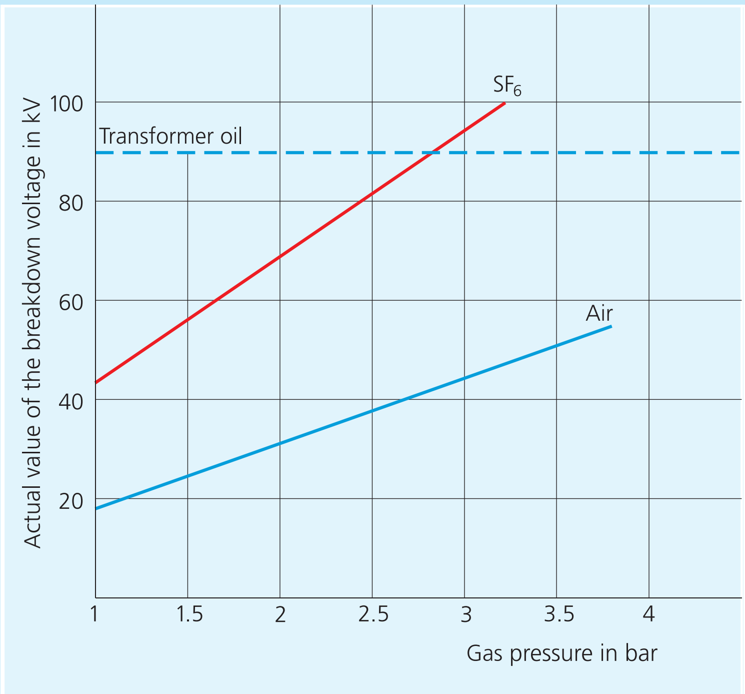
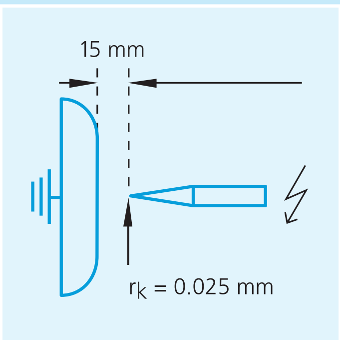
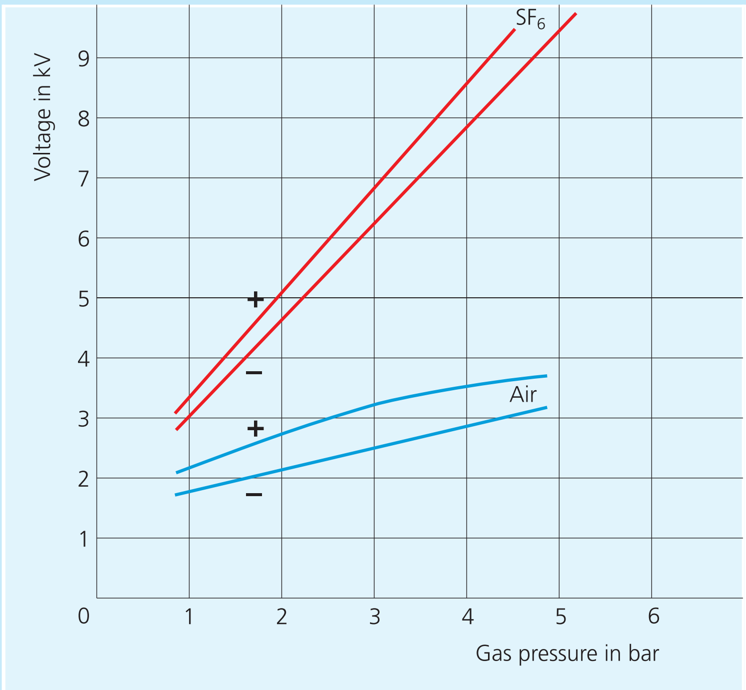


Fig. 26 *Dependence on pressure of the Corona-onset voltage in SF_6 and air (ETZ, Supplement 3 [1966])*





Arc-quenching capacity

On account of its thermal properties and low ionisation temperature, sulphur hexafluoride exhibits outstanding characteristics for the extinguishing of electric arcs (Fig. 28).

All other conditions being equal, the arc-quenching time using SF_6 is about 100 times less than that using air [9].

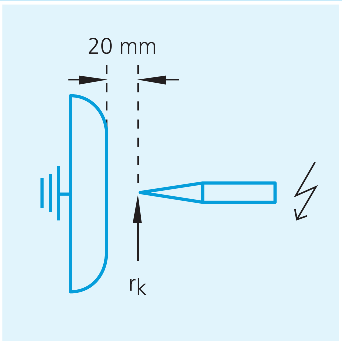
The superior arc-quenching performance of SF_6 compared with other gases is impressively illustrated in figure 29.

Loss factor

The loss factor, tan ∂ of sulphur hexafluoride is extremely low (less than $2.0 \cdot 10^{-7}$). A value of tan $\partial < 10^{-3}$ was determined for liquid SF_6 at –50 °C [4].

Diagrams and data pertinent to the electrical properties of sulphur hexafluoride may be found in the Milek „Sulphur hexafluoride data sheets“ [10].

Fig. 27 *Corona-onset voltages for SF_6 and air as a function of the radius of curvature rK at atmospheric pressure (ETZ, Supplement 3, [1966])*



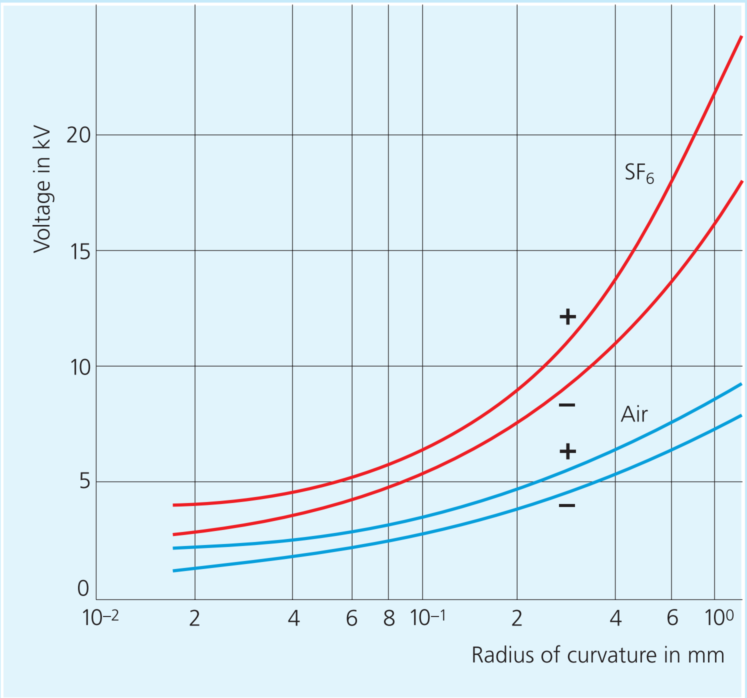


Fig. 28 *Radial temperature profile in SF_6 and N_2 electric arcs (schematic representation: from Z. Angew. Physik 12, [1960] 5, pp 231 to 237)*

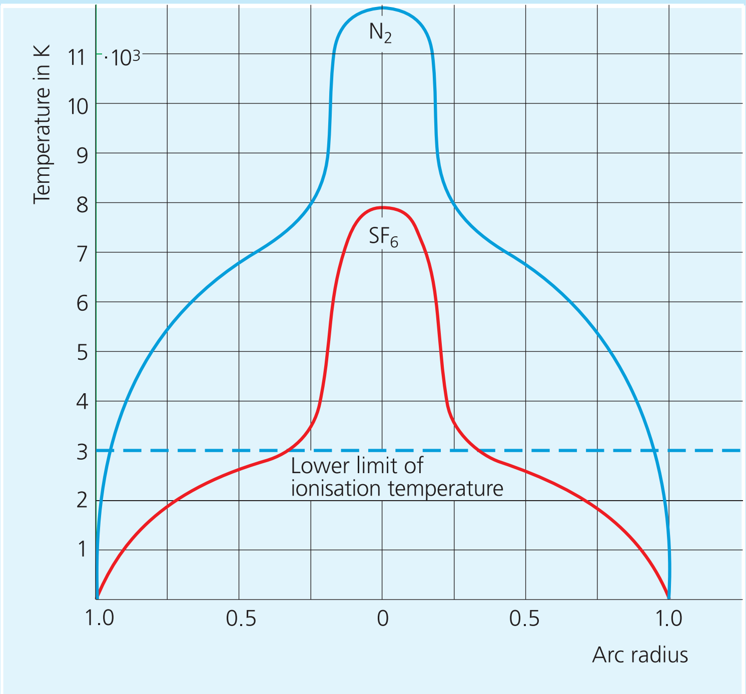
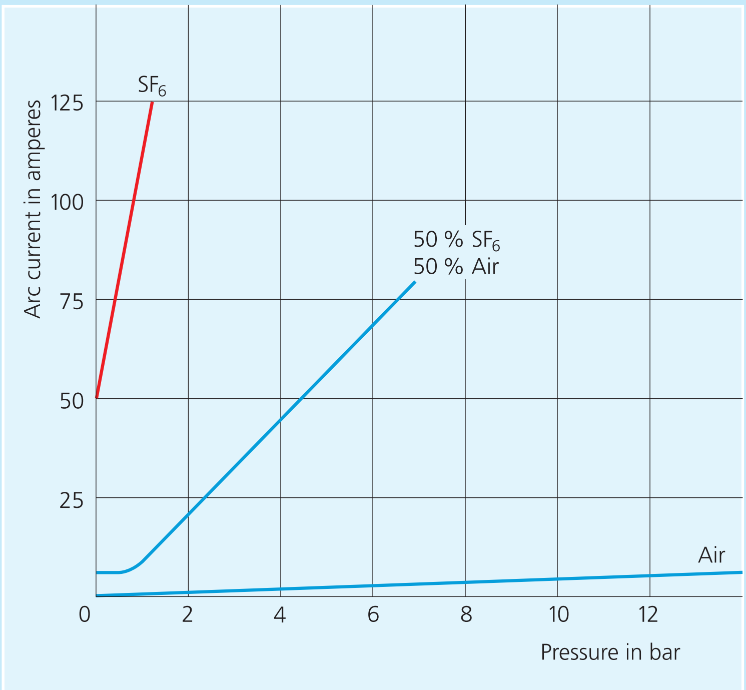


Fig. 29 *Quenching capacity of SF_6, air and a mixture of both gases (Insulating Materials for Design and Engineering Practice, N.Y. [1962], p. 116)*



Other physical properties

Sulphur hexafluoride is a colourless, odourless, non-toxic and non-flammable gas. With a molecular weight of 146.05, SF_6 is about 5 times heavier than air and one of the heaviest known gases.

Mechanical and caloric data

Sublimation point (1.0133 bar)	–63.9 °C			
Melting point (2.26 bar)	–50.8 °C			
Vapour pressure	see page 24			
Heat of sublimation	153.2 kJ/kg			
Heat of fusion	34.37 kJ/kg			
Heat of vaporization [11]:				
Temperature (°C)	–20	0	+20	+40
Heat of vaporization (kJ/kg)	91.71	78.96	62.54	34.08
Critical data [11]:				
Critical temperature	45.58 °C			
Critical pressure	37.59 bar			
Critical density	0.74 kg/l			
Density:	(see Figs. 30 and 32)			
Gas density (20 °C, 1 bar)	6.07 g/l			
Liquid density (0 °C, 12.65 bar)	1.56 kg/l			
Solid density (–100 °C) [12]	2.77 kg/l			
Viscosity	(see Fig. 33)			
Thermal conductivity	(see Fig. 34)			
Heat transfer capacity	(see Fig. 35)			
Acoustic velocity in SF_6 (0 °C, 1.0 bar)	129.06 m/sec.			
Isentropic exponent (κ) [11]: The dynamic compressibility of SF_6 is particularly high on account of the low value of the isentropic exponent:	κ = 1.08 (30 °C, 1.0 bar)			
Heat of formation (Δ HB, 25 °C)*	–1221.58 ± 1.0 kJ/mol			
Entropy of reaction (Δ SB, 25 °C)*	– 349.01 J/mol k			

* for formation from rhombic sulphur and gaseous fluorine [12].

Solubility

Solubility in water [13]

Gas volume corrected
to 0 °C, 1.0133 bar

Temperature (°C)	5	10	15	20	25	30	40	50
Solubility (cm^3 SF_6/kg H_2O)	11.39	9.11	7.48	6.31	5.44	4.79	3.96	3.52

Solubility in transformer oil [14]

(Esso-Univolt 35)
Gas volume under 0 °C, 1.0133 bar

Temperature (°C)	27	50	70
Solubility (cm^3 SF_6/cm^3 oil)	0.408	0.344	0.302

Specific heat (c_p)

Solid and liquid phase [15]

Temperature (K)	200	210	220	225	230
Specific heat (J / mol K)	104.17	116.60	184.22	110.95	119.58

Gas phase (1 bar) [12, 16]

Temperature (K)	298	373	400	473	500	573	600	673	700	773	1273
Specific heat (J / mol K)	97.26	112.45	116.39	125.89	128.54	134.51	136.07	140.21	141.1	144.35	152.62

Vapour pressure

(cf. Fig. 30)

Temperature (°C)	−50	−45	−40	−35	−30	−25	−20	−15	−10	−5
Pressure (bar)	2.34	2.87	3.49	4.20	5.02	5.95	7.01	8.19	9.52	11.01
Temperature (°C)	0	+5	+10	+15	+20	+25	+30	+35	+40	+45
Pressure (bar)	12.65	14.47	16.47	18.67	21.08	23.72	26.62	29.79	33.27	37.13

Fig. 30 *Vapour pressure curve: lines of equivalent gas density of SF_6*

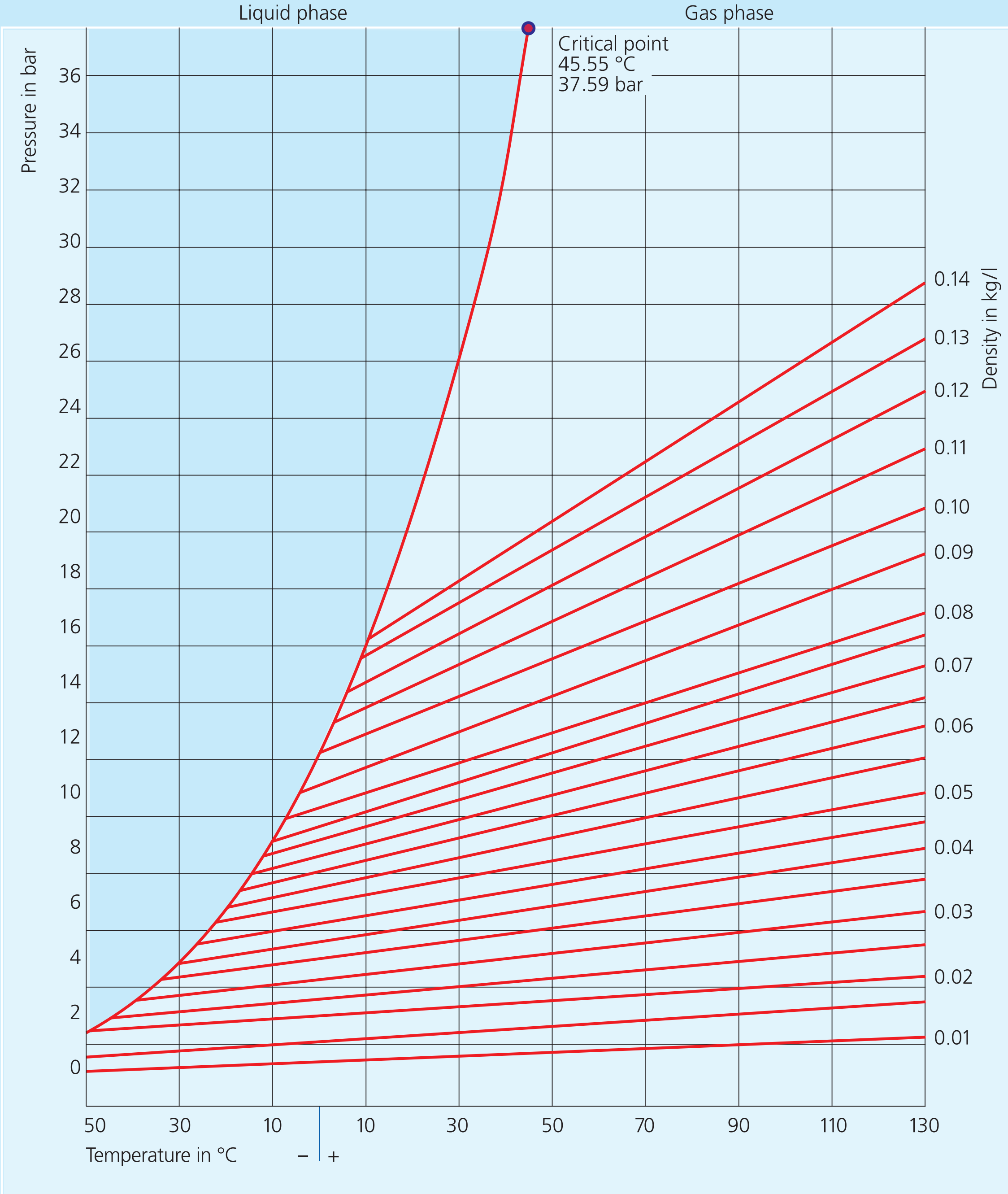
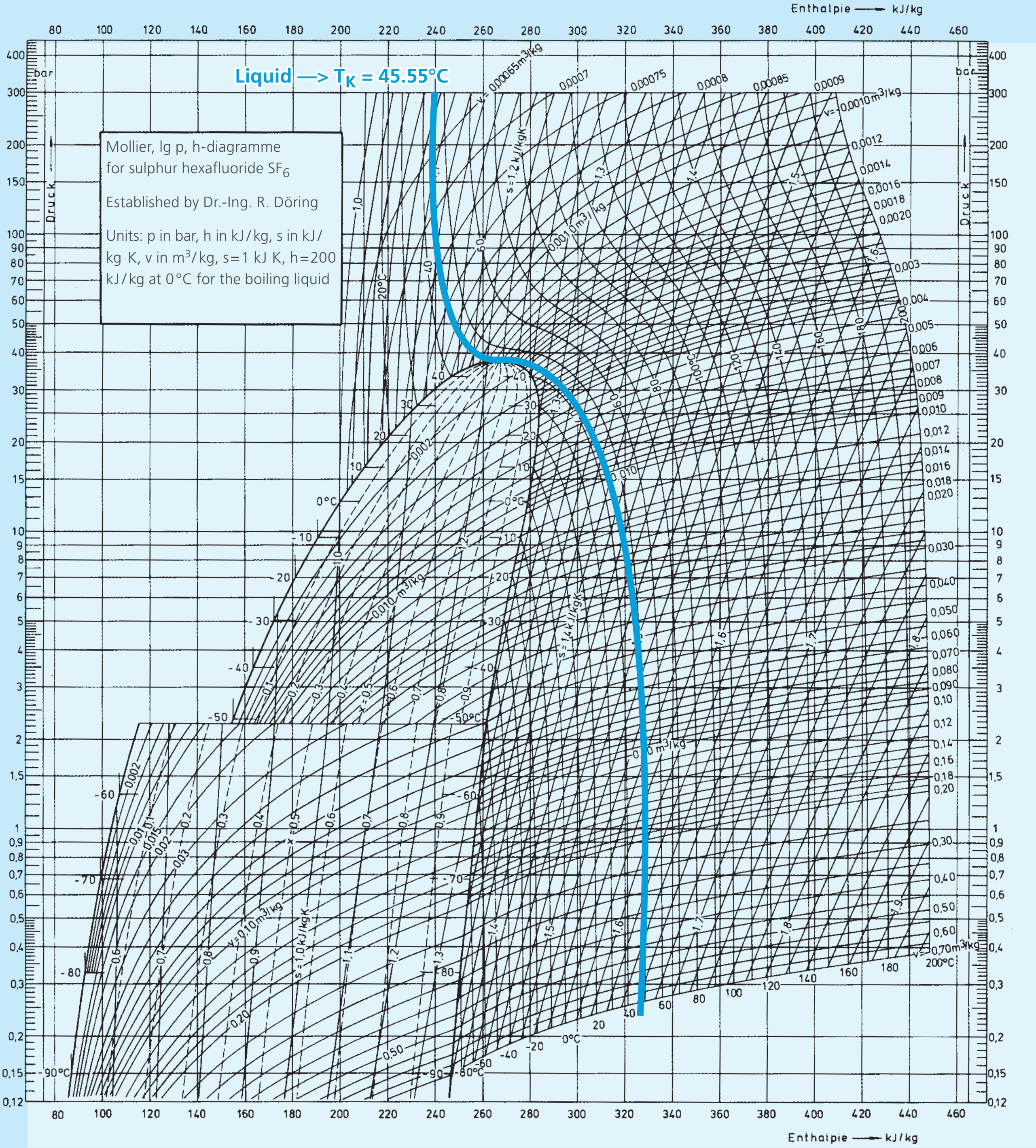


Fig. 31 *Mollier, lg p, h-diagram for sulphur hexafluoride*



Internal pressure in SF_6 tank

as a function of temperature and density (kg SF_6 / l tank volume)

Determined from experimental values[11]

Pressure in bar

Density kg/l	5 °C	10 °C	15 °C	20 °C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C
0.940										43.1	49.3	55.5	61.8	68.3
0.960										43.6	50.1	56.5	63.1	69.6
0.980										44.2	50.9	57.7	64.3	71.2
1.000										44.8	51.8	58.8	65.8	73.0
1.020										45.6	52.9	60.1	67.4	74.8
1.040										46.4	54.0	61.1	69.2	77.0
1.060										47.4	55.3	63.3	71.3	79.4
1.080										48.4	56.7	65.0	73.7	82.1
1.200										49.8	58.5	67.3	76.2	85.2
1.120								33.7	42.5	51.3	60.3	69.5	78.9	88.5
1.140								34.9	44.1	53.3	62.7	72.4	82.2	92.1
1.160								36.5	46.0	55.5	65.5	75.5	85.6	96.1
1.180								38.0	48.1	58.2	68.5	79.0	89.7	100.6
1.200								40.1	50.7	61.3	72.2	83.2	94.3	105.6
1.220								42.6	53.7	64.8	76.2	87.7	99.5	111.3
1.240								45.3	57.1	68.8	80.7	92.8	105.3	117.6
1.260								48.6	61.0	73.5	85.9	98.6	111.7	124.4
1.280						27.0	39.7	52.5	65.6	78.7	91.9	105.0	118.9	132.2
1.300						30.3	43.7	57.1	70.9	84.6	98.4	112.2	126.4	140.5
1.320						34.3	48.3	62.4	76.8	91.2	105.7	120.2	134.9	149.9
1.340						38.8	53.7	68.5	83.5	98.6	113.7	129.0	144.4	159.8
1.360						43.9	59.6	75.3	90.9	106.5	122.6	138.8	154.6	170.8
1.380						49.9	66.4	82.9	99.2	115.6	132.5	149.5	166.0	183.0
1.400				24.0	40.5	56.9	74.0	91.4	108.5	125.8	143.6	161.4	178.9	196.5
1.420				30.7	47.9	65.0	83.1	101.3	119.2	137.2	155.8	174.6	193.2	(211.8)
1.440			20.9	38.2	56.2	74.5	93.5	112.4	131.3	150.2	169.4	189.0	(209.2)	(229.5)
1.460			27.9	46.8	66.0	85.4	105.2	125.0	144.9	164.9	185.0	(205.4)	(226.7)	
1.480		16.4	36.5	56.7	77.1	97.6	118.2	139.1	160.2	181.4	(202.5)	(223.6)		
1.500		25.4	46.8	68.1	89.5	111.1	132.7	154.6	176.8	(199.1)				
1.520	(14.8)	36.8	59.0	81.3	103.8	126.4	149.2	172.1	(195.3)	(218.4)				
1.540	(27.5)	50.4	73.5	96.7	120.1	143.8	167.7	191.6	(215.6)	(239.5)				

Fig. 32 *Pressure/temperature curves for SF_6 (from Z. Phys. Chem., New Series 23 [1960] 96). (1at = 0.9800665 bar)*

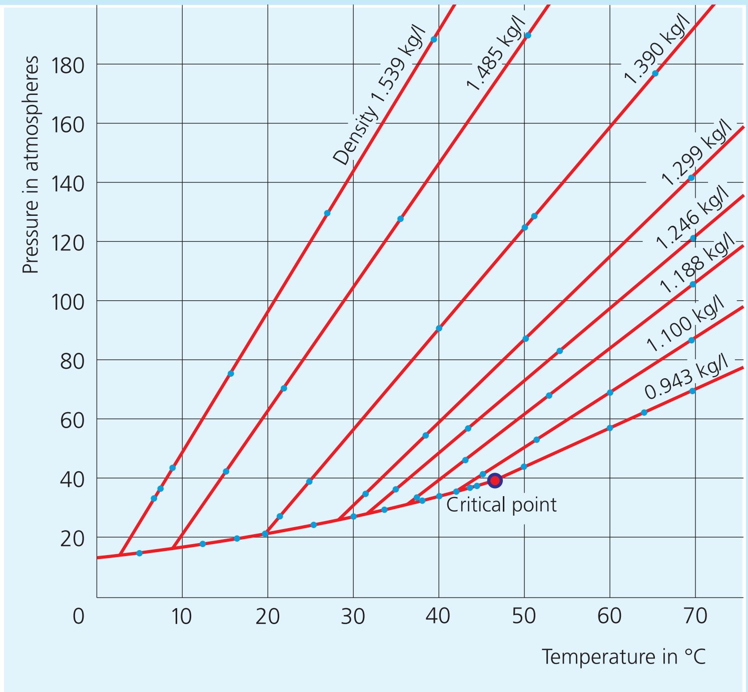


Fig. 33 *Viscosity of SF_6 as a function of temperature at atmospheric pressure* [12]

Temperature [°C]	Viscosity [mPa·s]
0	0.0141
25	0.0153
100	0.0186
200	0.0228
300	0.0266
400	0.0302
500	0.0335

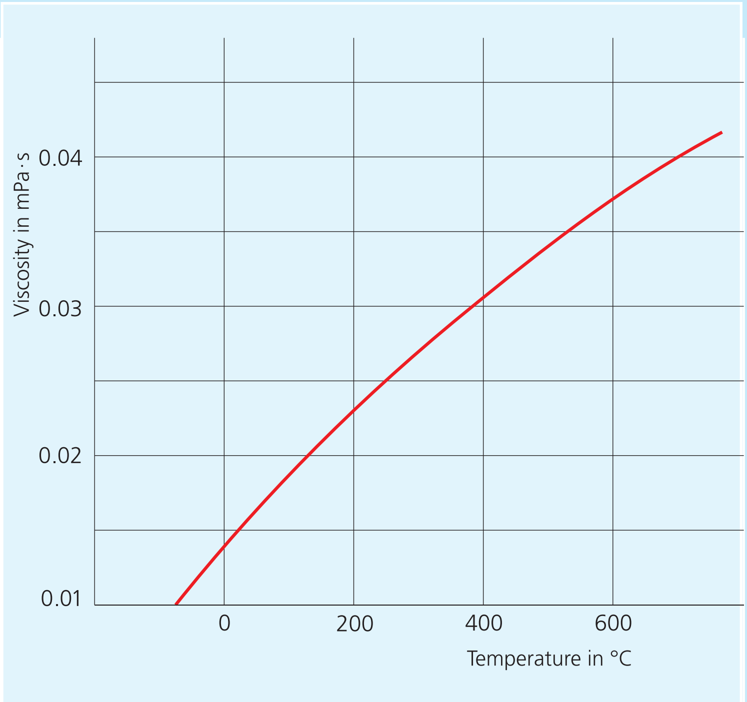


Fig. 34 *Thermal conductivity of SF_6 at atmospheric pressure*[12]

Temperature [°C]	Thermal conductivity [W/cm·K]
0	1.0
25	1.3
100	1.9
200	2.5
300	3.1
400	3.6
500	4.1

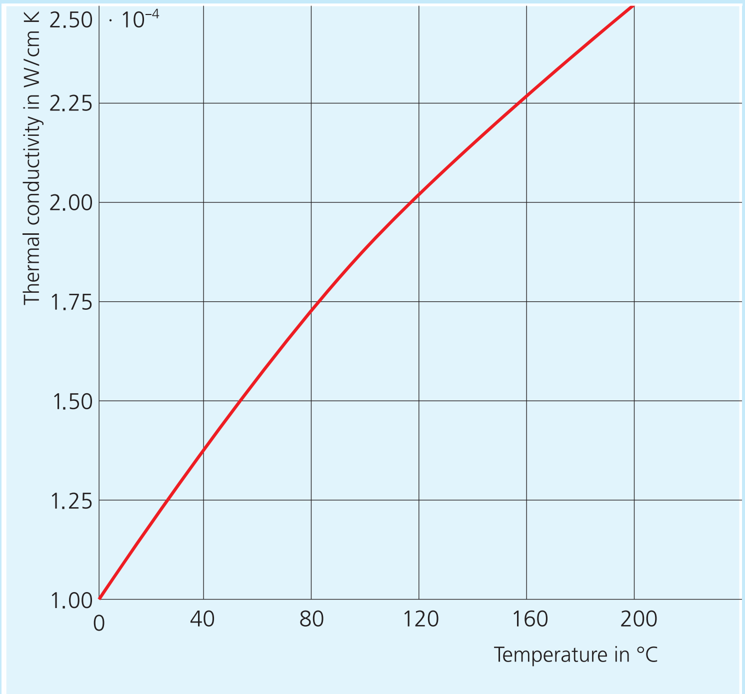
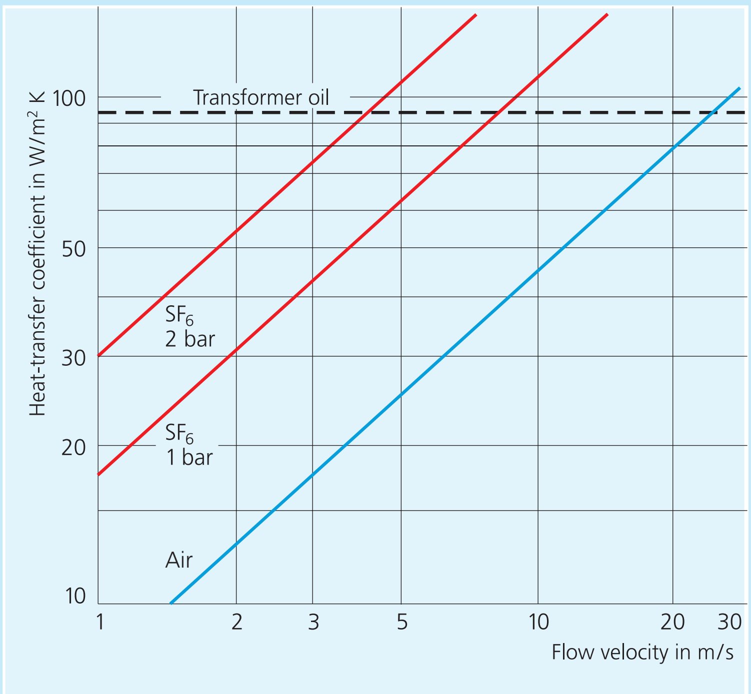


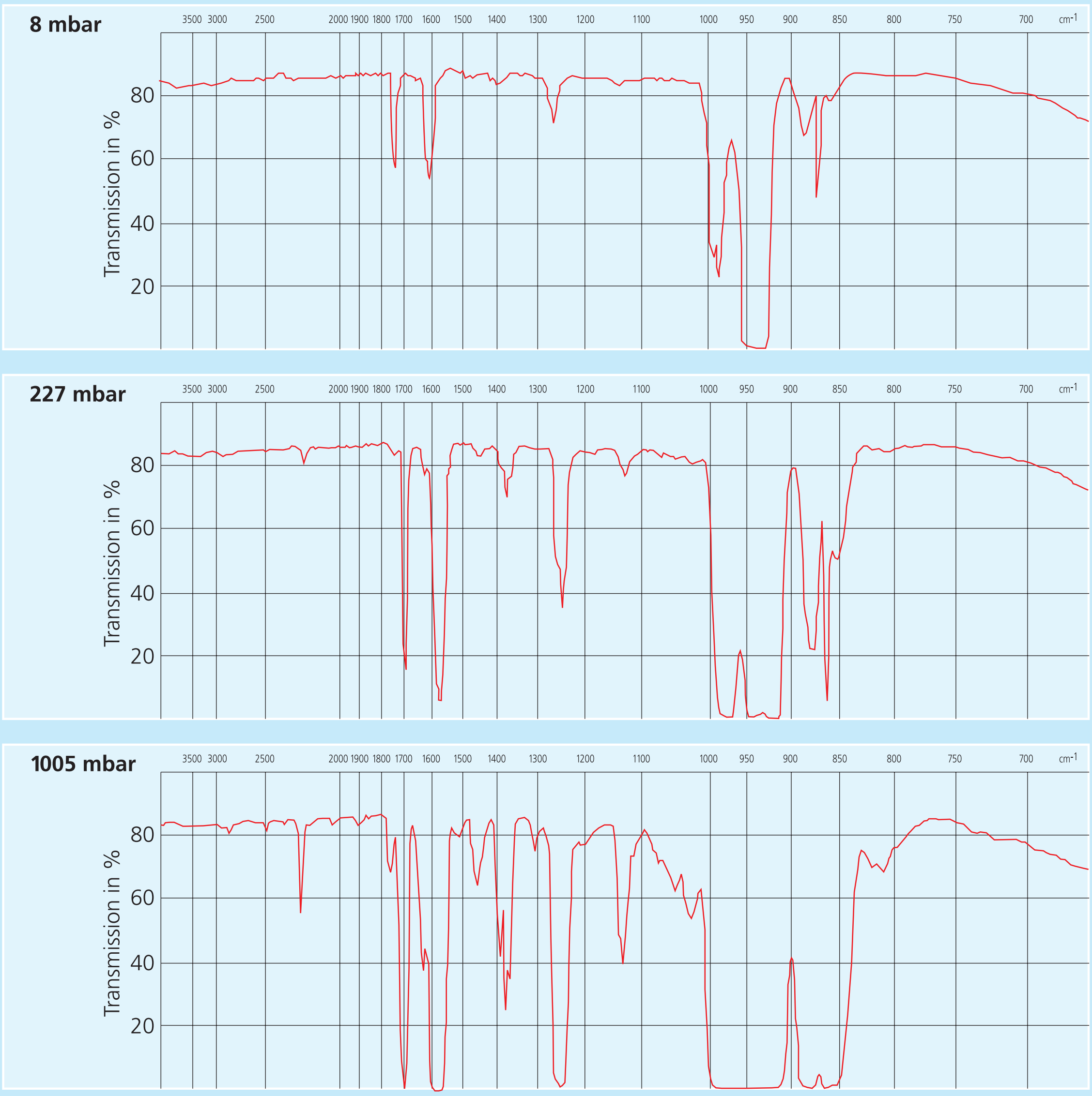
Fig. 35 *Heat-transfer coefficients of air and SF_6 (for comparison – transformer oil under natural convection) (Conti-Elektro-Berichte, July/September 1966, p 189)*



Optical properties

Refractive index[17]	n_D (0 °C) 1.0133 bar	1.000 783

Fig. 36 *Infrared spectrum of SF_6 recorded for three different concentrations (Leitz M 3, NaCl prism)*



Chemical behaviour

Under normal conditions, sulphur hexafluoride is chemically inert and stable; its reactivity is among the lowest of all substances.

Behaviour at elevated temperatures

SF_6 can be heated to 500 °C in quartz containers without any decomposition occurring. At temperatures of up to approximately 150 °C, generally used materials such as metals, ceramics, glass, rubber and cast resins are completely stable in the presence of sulphur hexafluoride. Not until the temperature exceeds 200 °C do some metals begin to have a decomposing effect on SF_6; however, the usual working metals and alloys do not have a significant decomposing effect until the temperature reaches 400 to 600 °C.

Behaviour under the influence of electrical discharges [18]

Electrical discharges cause a decomposition of the gas to an extent proportional to the converted energy. Under the influence of an electric arc, part of the sulphur hexafluoride is dissociated into its atomic constituents, as shown in the following equation:

$$SF_6 \underset{}{\overset{\Delta E}{\rightleftharpoons}} S + 6F$$

This reaction is reversible. After the discharge, the dissociation products recombine, provided that no secondary reactions with vaporized electrode metal, the container wall or other constructional components occur.

Both solid and gaseous products can result from these secondary reactions:

- metal fluorides, metal sulphides and metal oxides
- sulphur fluorides such as SF_4
- sulphur oxyfluorides such as SOF_2, SO_2F_2, SOF_4

Such decomposition products resulting from high-energy discharges are also good dielectrics, so that dust-like deposits on the surface of insulators do not impair the operational efficiency of affected equipment.

However, this applies only if the humidity in the gas chamber is very low. If exposed to moisture, the above-mentioned decomposition products hydrolyse and form secondary products, for example as illustrated in the following equations:

$$CuF_2 + H_2O \longrightarrow CuO + 2HF$$

$$SF_4 + H_2O \longrightarrow SOF_2 + 2HF$$

The hydrogen fluoride (HF) formed in these reactions vigorously attacks any materials containing silicon dioxide (SiO_2) (e.g. glass and porcelain). The use of these materials in equipment in which SF_6 is to be used for arc-quenching is therefore only suitable under certain conditions.

Corrosion characteristics of SF_6 and its decomposition products

As already indicated, pure SF_6 is chemically inert: it cannot, therefore, cause corrosion.

In the presence of moisture, however, the primary and secondary decomposition products of sulphur hexafluoride form corrosive electrolytes which may cause damage and operational failure, particularly in electrical equipment. If the formation of decomposition products cannot be avoided by the use of appropriate construction methods, corrosion can be largely eliminated by the careful exclusion of moisture and the employment of suitable materials.

Commonly used metals such as aluminium, steel, copper and brass remain virtually free of attack. In contrast, materials such as glass, porcelain, insulating paper and similar materials may be severely damaged, depending on the concentration of the corrosive substances. Insulating materials such as epoxy-resin, PTFE, polyethylene, polyvinyl chloride and polymethylene oxide are either only slightly or undetectably affected [19].

Measures for the removal of corrosive constituents

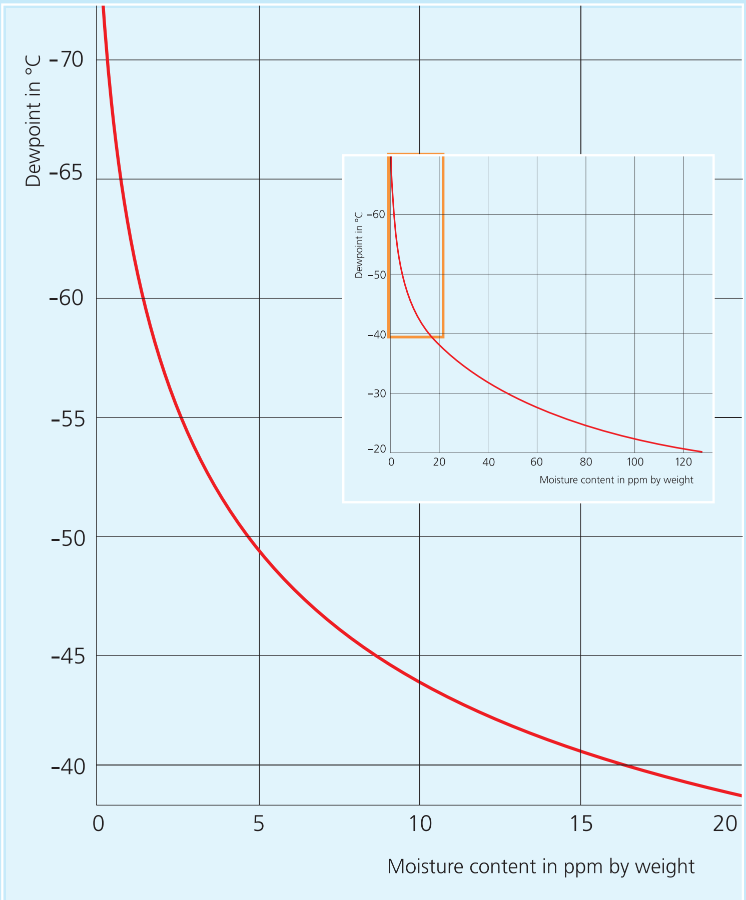
Both moisture and the decomposition products of sulphur hexafluoride can be relatively easily removed by adsorption agents. Aluminium oxide and molecular sieves or mixtures of these materials are all suitable for this purpose. They very effectively and practically irreversibly adsorb the acidic and gaseous products. At the same time they also ensure maintaining a low dew-point in the gas filling.

Especially suitable are adsorbing agents in the form of filter fillings, through which the gas is pumped in a circulation. This method is employed for example in the case of SF_6 power circuit breakers, where considerable concentrations of decomposition products can occur in arc quenching. In many cases, however, static filters provide adequate protection.

Figure 37 shows the dew-point as a function of the gas moisture content.

Fig. 37 *Dew-point as a function of the moisture content of SF_6 (sample from liquid phase)*

Dew-point [°C]	Moisture content [ppm by weight]
–75	0.148
–70	0.32
–65	0.65
–64	0.75
–63	0.86
–62	1.0
–61	1.15
–60	1.3
–59	1.5
–58	1.7
–57	2.0
–56	2.2
–55	2.5
–54	2.9
–53	3.3
–52	3.6
–51	4.2
–50	4.8
–49	5.4
–48	6.1
–47	6.9
–46	7.8
–45	8.7
–44	10.0
–43	11.0
–42	12.0
–41	14.0
–40	16.0
–39	17.0
–38	20.0



Toxicity

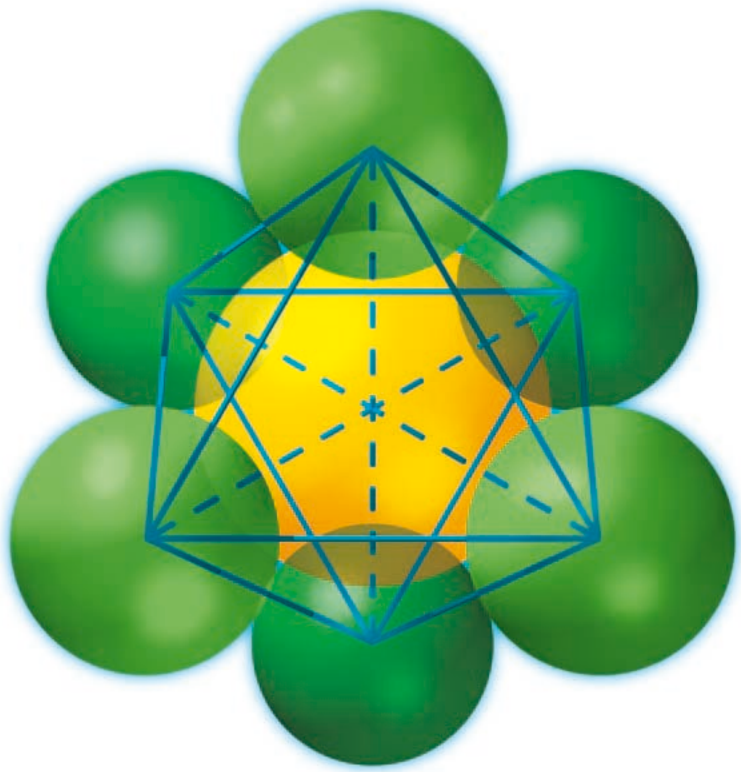
New SF_6

Pure sulphur hexafluoride is non-toxic. The by-products arising during production of the gas are completely removed during subsequent purification operations.

Solvay sulphur hexafluoride is constantly tested for the presence of toxic constituents according to IEC 60376.

In places where work involving large quantities of sulphur hexafluoride in containers and in enclosed areas is carried out, the safety regulations should take into account the potential asphyxiation hazard arising from oxygen deficiency, as, due to its high density, the gas can displace air from lower-lying regions of enclosed areas (pits, sumps etc). This hazard can, however, be easily countered by the provision of adequate ventilation. Measuring instruments functioning on the principles of thermal conductivity can be installed to check the SF_6 content of air.

The existing TLV in Germany for sulphur hexafluoride is 6,000 mg/m^3 = 1,000 ppm.



Contaminated SF_6

As mentioned previously, electrical discharges (e.g. switching processes, fault electric arcs) lead to the formation of gaseous decomposition products and dusty metal compounds. Gaseous decomposition products of SF_6 exhibit very characteristic warning signs even at low concentrations. These warning signs are for example pungent or unpleasant odours (like "rotten eggs"), or irritation of nose, mouth and eyes. Such irritation occurs within seconds, well in advance of any danger arising from poisoning.

When handling contaminated SF_6 care must be taken not to breathe in gaseous or dusty decomposition products. In case this cannot be achieved by technical safety measures, i.e. ventilation, personal protective equipment must be worn. Personal protective equipment consists of items of protection for the eyes, body and breathing. More detailed information on handling SF_6 is given in the information leaflet BGI 753 "SF_6 plant" (Trade Association for Precision Mechanics and Electrical Engineering) and in the DIN Standard IEC 60 480 and VDE 0373, Part 2/2005-08.

SF_6 handling procedures

SF_6 can be removed from its pressurized gas containers either in the gaseous or in the liquid phase. During the removal of SF_6 in the gaseous phase, the pressure-regulator can be connected directly to the cylinder valve. If the SF_6 is removed in the liquid phase, then a vaporizer must be installed between the container and the regulator.

Filling an enclosed system

Normally, equipment is first evacuated and then filled with SF_6 under pressure. In this process, the feed line from the gas cylinder to the unit to be filled is provided with a branch line incorporating a shut-off valve. This branch line leads to a vacuum pump. Before filling with SF_6 commences, the complete system up to the cylinder valve is evacuated. After the valve in the branch line has been closed, both the cylinder and the regulator are gradually opened.

It is advisable to observe the progress of the entire filling operation on an appropriate pressure gauge (centre-zero). The final pressure of the gas in the filled unit will depend upon temperature. On account of the fact that the gas undergoes a cooling process on leaving the steel cylinder, the pressure reading immediately following the completion of the filling operation will be less than that shown after the gas temperature has risen to the ambient level. This subsequent rise in pressure must be taken into account.

Fig. 38 *Leak testing of a GIS aluminium housing (ABB, Switzerland)*

Fig. 39 *SF_6 servicing unit (DILO, Germany)*

Temporary storage during service and maintenance

Temporary storage of SF_6 during service and maintenance is highly recommended in regard to SF_6 ReUse and as a preventive measure for environmental protection.

Suitable service equipment and / or ReUse pressure drums should be available for performing gas operations during temporary storage.

Handling of SF_6 service equipment

This kind of equipment consists of main components such as SF_6 compressor, vaccuum pump, storage tank, evaporator and filter unit, which are piped together with valves and fittings. According to the size of the switch gear the appropriate equipment with sufficient storage capacity and performance is selected. SF_6 gas handling in such equipment is only carried out in closed cycles.

Every component within this cycle (SF_6 compressors and diaphragm compressors) are dry-running and therefore absolutely oil-free, excluding the risk of SF_6 gas contamination. The built-in filters provide for the drying and cleaning of the SF_6 gas during each gas operation. SF_6 valves, couplings and fittings guarantee a high degree of leak-tightness and operational safety.

The connecting couplings should be self-closing in order to avoid air and moisture penetrating into the lines.

When selecting service equipment, handling should be as easy as possible to avoid unnecessary faults. Maintenance equipment with automatic sequences is the state-of-the-art and is preferred because of its high degree of operational safety.

Fig. 40 *SF_6 measuring devices (WIKA, Germany)*

Fig. 41 *SF_6 measuring devices (DILO, Germany)*

Safety instructions

Storage

Sulphur hexafluoride is transported as a pressurized liquified gas. The local safety precautions and handling practices i.e. TRG in Germany and KGS in Korea must be met.

The packaging should not be exposed to direct sunlight and must be secured against overturning or rolling.

Storage and work areas must be well ventilated. In particular, ventilation must be effective at ground level on account of the fact that SF_6 vapour is heavier than air. If the gas is stored underground, appropriate forced ventilation must be provided.

Wherever SF_6 is handled, there must be no open flames (e.g. welding flames) or hot metal surfaces (e.g. infrared equipment). Eating, drinking and smoking whilst working with SF_6 is strictly forbidden.

Although SF_6 is recognized as being physiologically safe, certain precautions have to be taken in order to guarantee a safe handling of this substance. An important precondition is a strict adherence to the threshold limit value (TLV).

Wherever this cannot be achieved pertinent safety measures must be selected according to the degree of potential danger. For safety precautions and additional information in handling SF_6 please see the safety data sheet.

New SF_6

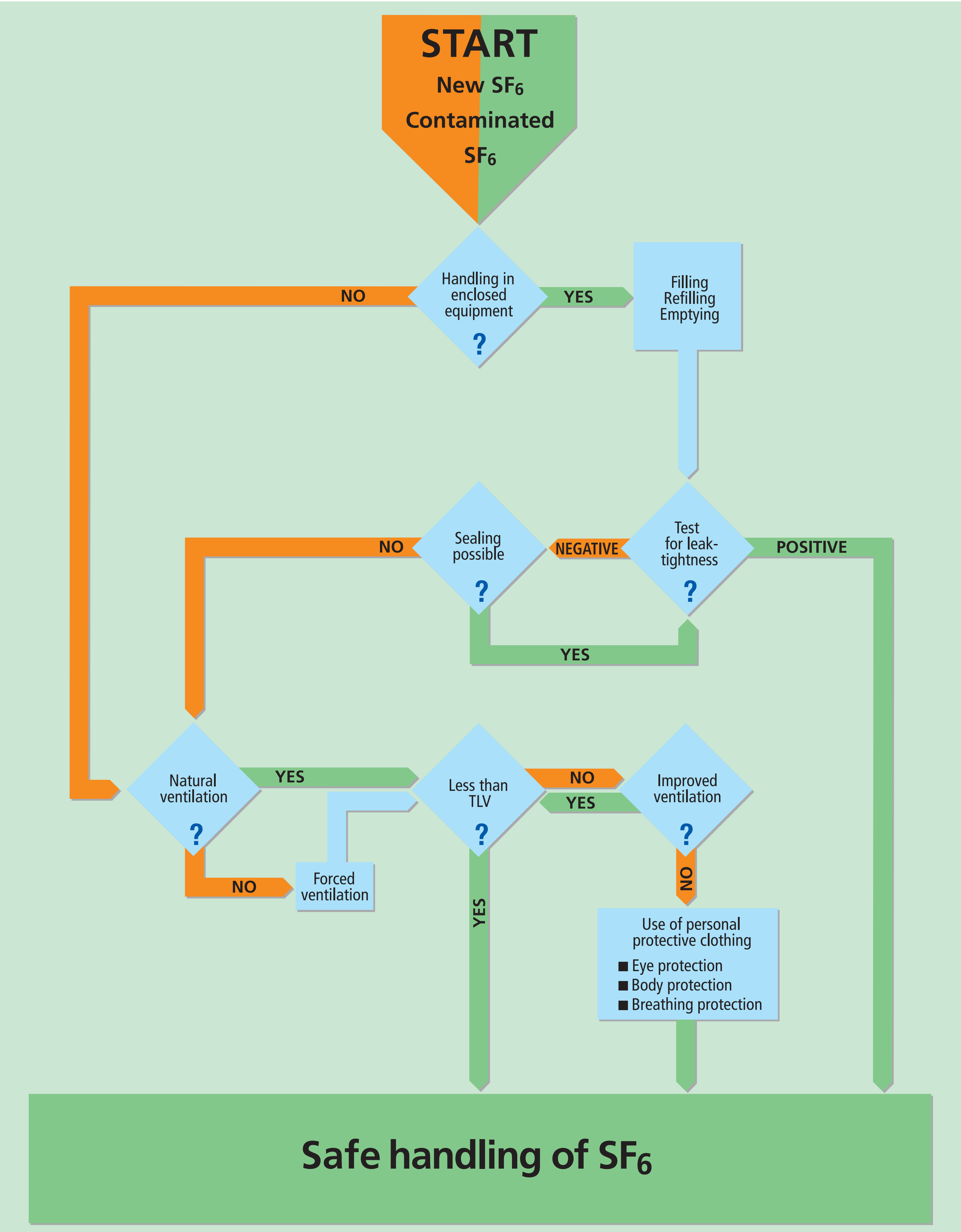
- SF_6 to IEC 60376
- Potential hazard:
  asphyxiation
- Protective measures:
  Natural and forced ventilation

Contaminated SF_6

- SF_6 is contaminated with dangerous substances
- Potential hazard:
  The SF_6 decomposition products have an irritating or corrosive effect on eyes, skin and respiratory system
  Warning signals in the form of a pungent and unpleasant odour.
  Irritation occurs within seconds, well in advance of any danger arising from poisoning.
- Protective measures:
  Personal protective clothing comprising eye-, body- and breathing protection must be worn.

Additional organisational safety measures include the display of operational instructions and an annual seminar on the potential hazards and the safety precautions to be adopted when handling SF_6 which is contaminated with irritating and corrosive substances.

If SF_6 does not contain any hazardous substances its potential hazards are comparable to those of new SF_6.


START
New SF6
Contaminated
SF6
Handling in enclosed equipment ?
NO
YES
Filling
Refilling
Emptying
Sealing possible ?
NO
NEGATIVE
Test for leak-tightness ?
POSITIVE
YES
Natural ventilation ?
YES
NO
Forced ventilation
Less than TLV ?
NO
YES
Improved ventilation ?
NO
YES
Use of personal protective clothing
■ Eye protection
■ Body protection
■ Breathing protection
Safe handling of SF6

Specifications

Solvay's plants in South Korea and Germany produce SF_6 in a consistent quality with a purity of min. 99.993 %.

It corresponds to the following guarantee-analysis which in turn conforms to IEC 60376:2005 and to VDE 0373, Part 1:2005 (according to this standard all values apply to the composition of the liquid phase).

In general, the impurities in Solvay sulphur hexafluoride are substantially less than the maximum values specified in the guarantee-analysis.

The table below shows Solvay's typical quality standards specification.

Prior to shipment, every batch of SF_6 is tested for physiological safety (cf. Toxicity).

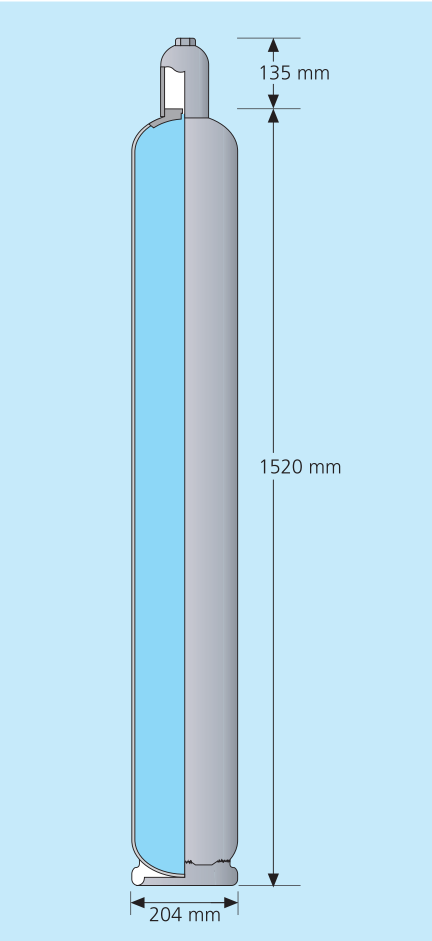
	Solvay specification	**IEC 60376 specification**	**ASTM D2472-00 specification**
Assay	99.993 % wt	> 99.7 % wt	99.8 % wt
Air	50 ppm wt	2000 ppm wt 0.20 % wt	500 ppm wt 0.05 % wt
CF_4	10 ppm wt	2400 ppm wt	500 ppm wt 0.05 % wt
Water	0.65 ppm wt (Dew point – 65 °C)	25 ppm wt (Dew point –36 °C)	1.0 ppm wt (Dew point – 62 °C)
Oil Content	1 ppm wt	10 ppm wt	not specified
Acidity (as HF)	0.3 ppm wt	1.0 ppm wt	0.3 ppm wt*
Hydrolyzable Fluoride (as HF)	1 ppm wt	not specified	not specified
Toxicity	Non-toxic, acc.to IEC 60376	Not listed as a specification but required to be determinded non-toxic by the supplier	not specified

** The standard method for hydrolysable fluorides mentioned in ASTM D2472 refers to ASTM D2284, which describes the determination of acidity expressed as HF. ASTM D2472 has no specific standard specification for hydrolysable fluorides, as described in IEC 60376.*

Packaging for new SF_6 according to IEC 60376

Fig. 42 *SF_6 cylinders and special high capacity pressure drum 5 l, 10 l, 20 l, 40 l, 43.5 l and 600 l from Bad Wimpfen plant*

Fig. 43 *Steel cylinder for SF_6 test pressure 300 bar capacity 40 l, tare Ø 48 kg**



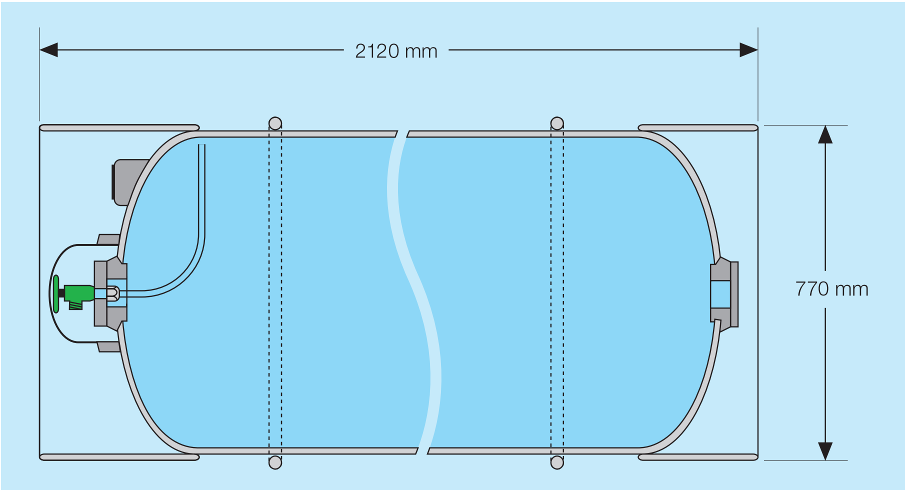


Fig. 44 *Special high-capacity pressure drum for SF_6: test pressure 70 bar capacity 600 l, tare Ø 460 kg**

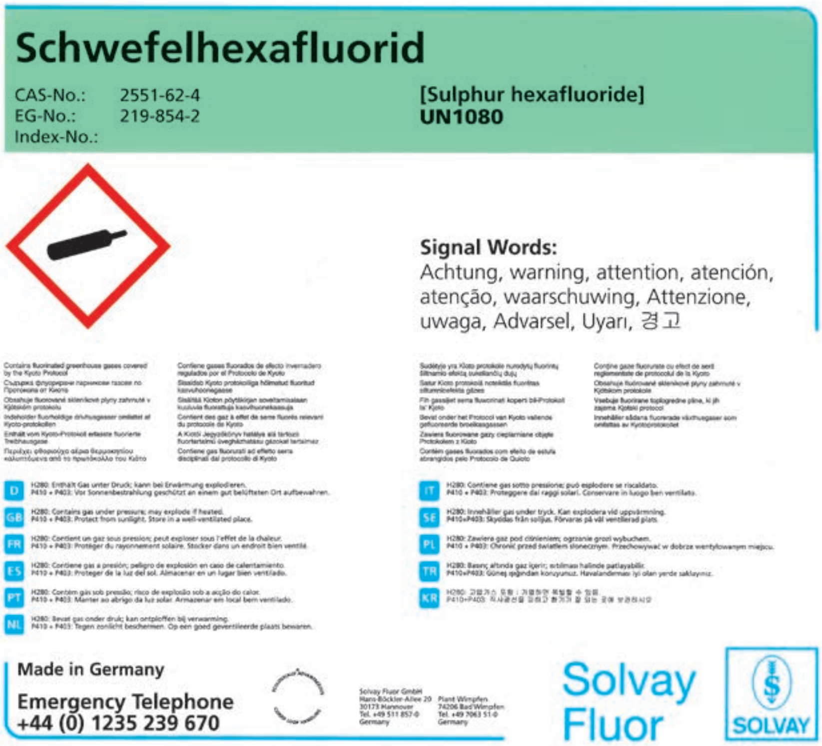
** All measurements are approximate values.*

Solvay sulphur hexafluoride is shipped as a pressure-liquefied gas in steel cylinders of various sizes. The filling level of SF_6 per litre of packaging volume can vary between 1.06 kg and 1.38 kg (depending on the test pressure of the packaging).

SF_6 is supplied in steel cylinders of 5, 10, 20, 40, 43.5 and 600 l capacity (Fig. 42). For larger quantities, special high-capacity pressure drums are available. These have a capacity of 600 kg SF_6 (Fig. 44). Tube trailers (Fig. 46) with a capacity of up to 13 t are also available.

The pressurized packaging with TPED-approval is equipped with a special gas-cylinder valve. The valves have an external threaded port on the side with the designation W 21.8 x 1/14“ (connection No. 6 in DIN 477).

This side-connection piece is protected from contamination and damage by a hexagon cap nut. The screw-on safety cap protects the valve from mechanical damage and contamination. To avoid any backflow of other gases, SF_6 pressurised gas packaging should never be emptied so far that a partial vacuum develops. The valve must be closed immediately after the packaging has been emptied.



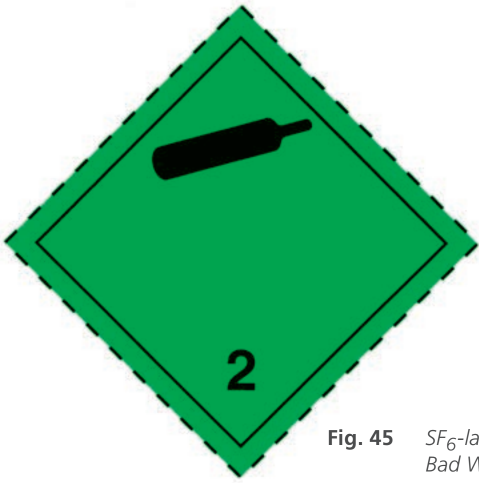


Fig. 45 *SF_6-label from Bad Wimpfen plant*

		Cylinder				Pressure Drum	Cylinder
Approval - Permit		TPED (PI)				TPED (PI)	DOT
Capacity	litre	5	10	20	40	600	43.5
Max. fill weight	kg	6.5	13.0	26.0	52.0	600	52.0
Height with cap	mm	605	960	970	1,670	2,120 long	1,705
Outer diameter	mm	140	140	204	204	770	204
Tare with cap	kg	9	14	29	48	460	35
Test pressure	bar	300	300	300	300	70	115
Valve connection		W 21.8 x 1/14“ DIN 477/6					0.965-14NGO-LH-INT CGA 590

All measurements are approximate values.

Fig. 46 *Tube trailer for SF_6*

Fig. 47 and Fig 48 *SF_6-cylinders 47 l and 10 l from Onsan plant*

Fig. 49 *SF_6-pressure drums 600 l from Onsan plant*

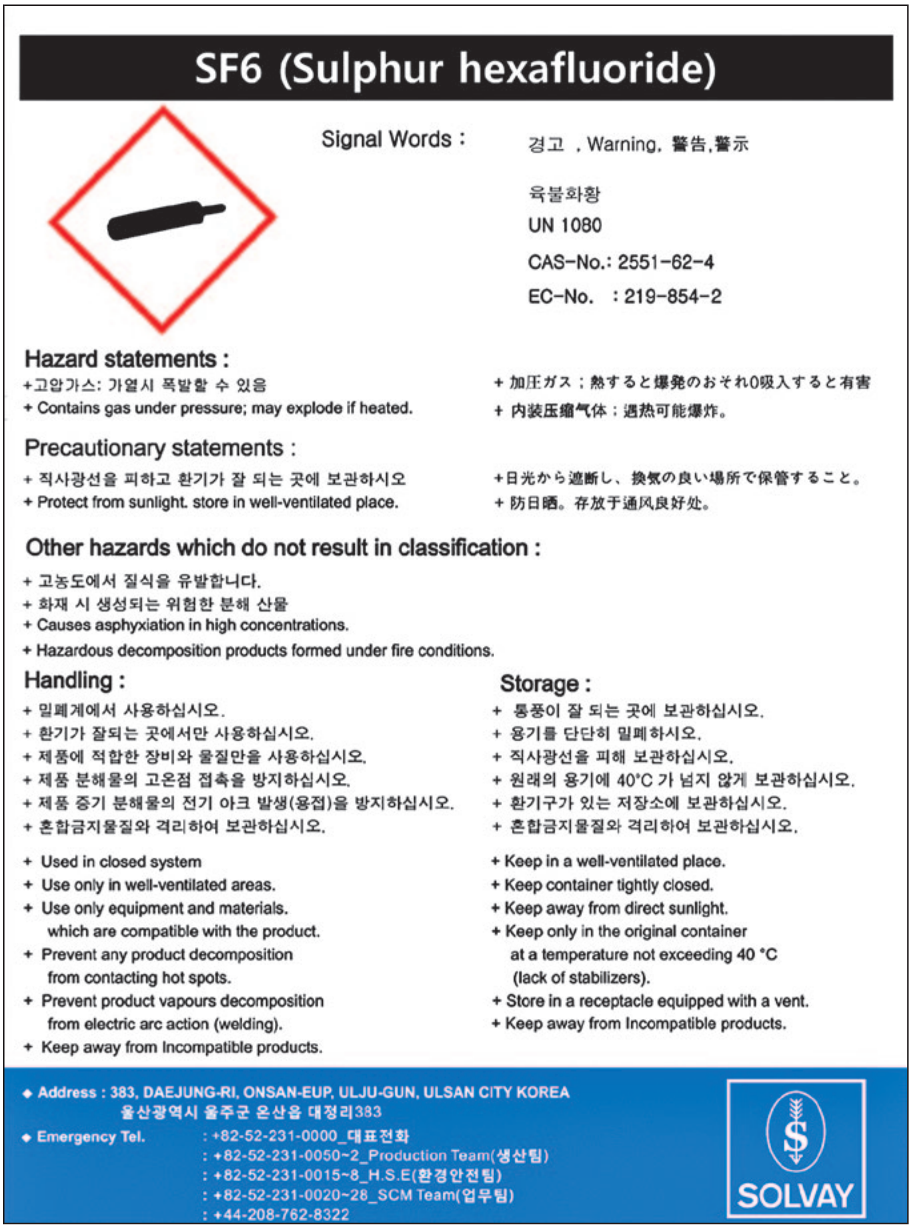


Fig. 50 *SF_6-label from Onsan plant*

Solvay's Responsible Care Programme for SF_6

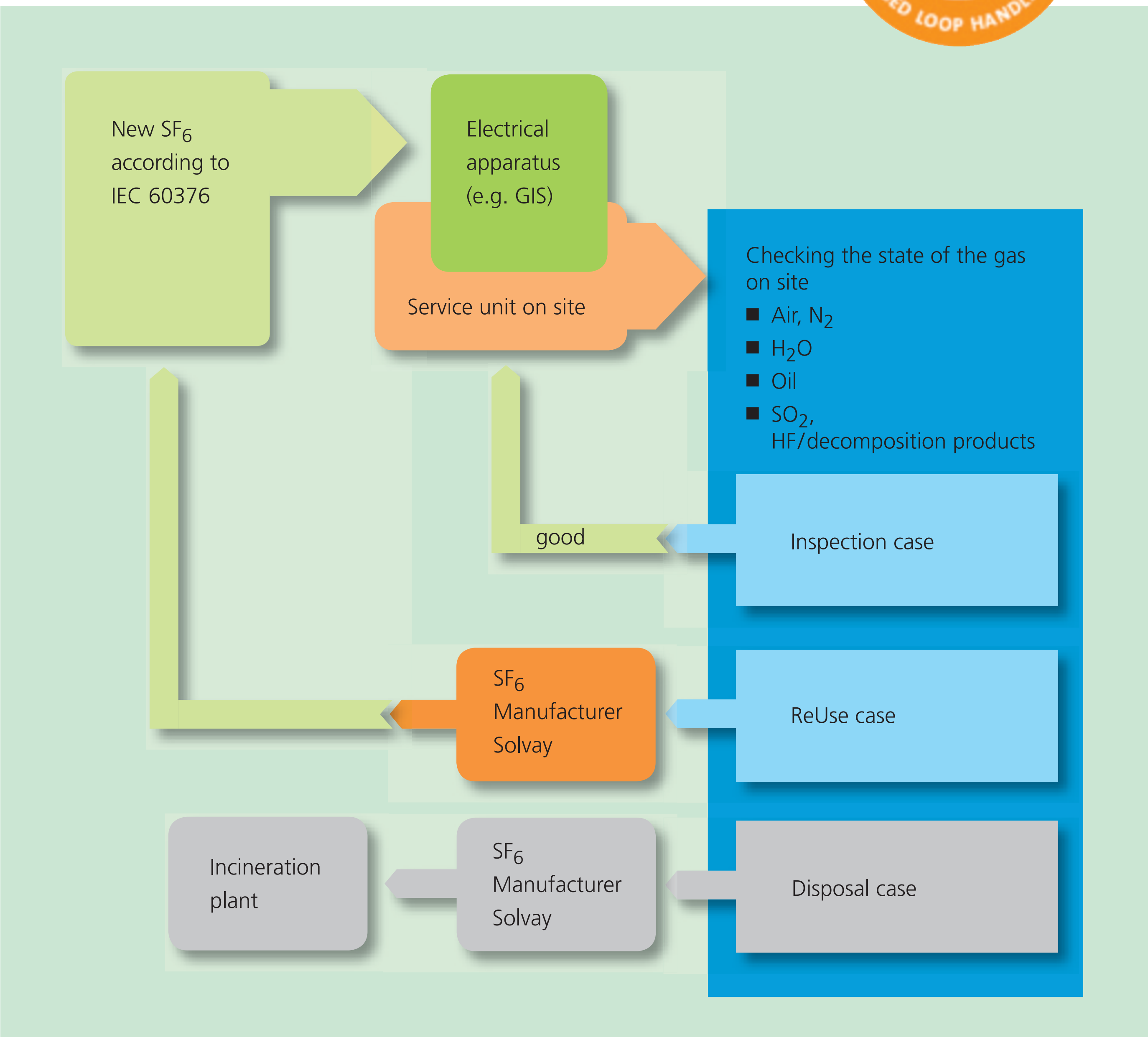
SF_6 – a reusable commodity

SF_6 is a user-friendly product which besides its many other positive characteristics can be recycled as well. This is increasingly important, particularly today.

This is why Solvay together with a producer of SF_6 maintenance equipment developed a process for the ReUse of SF_6, based on many years of experience.

The practical side of this approach is illustrated by the following diagram.

You will find further information in the brochure "The SF_6-ReUse-Process – a contribution on the sustainability of SF_6", available upon request.



Transport of used SF_6

Transport by Road

40 l steel cylinders and 600 l high-capacity pressure drums (see Fig. 51) are available. The pressurized packaging are fitted with a special stainless steel gas-cylinder valve, external threaded port connection No. 8 (to DIN 477). This is necessary because corrosive decomposition products could be present.

In documents, the product has to be declared as follows:

Liquefied gas, toxic, corrosive, n.o.s. (mixture contains Sulphur hexafluoride and Hydrofluoric acid)

Sulphur hexafluoride	>95.0 wt %
Hydrogen fluoride	≤0.1 wt %
Thionyl fluoride	≤2.0 wt %
Disulphur decafluoride	<1.0 wt %
Carbon tetrafluoride	≤3.0 wt %

International transport regulations ADR & RID

UN No.: 3308

Class: 2

Danger label: 2.3 – Toxic gas,
8 – Corrosive

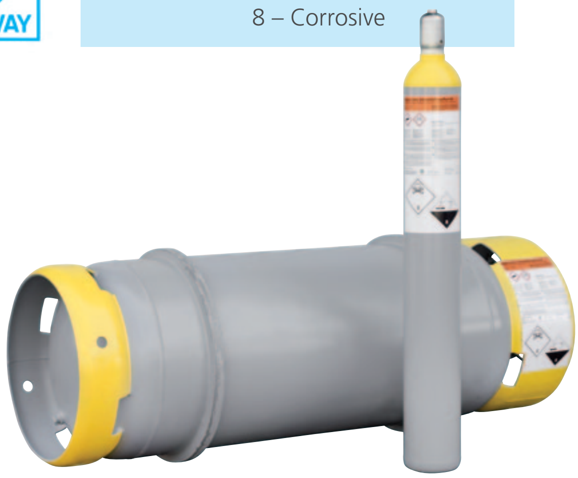


Fig. 51 *Packaging for used SF_6*

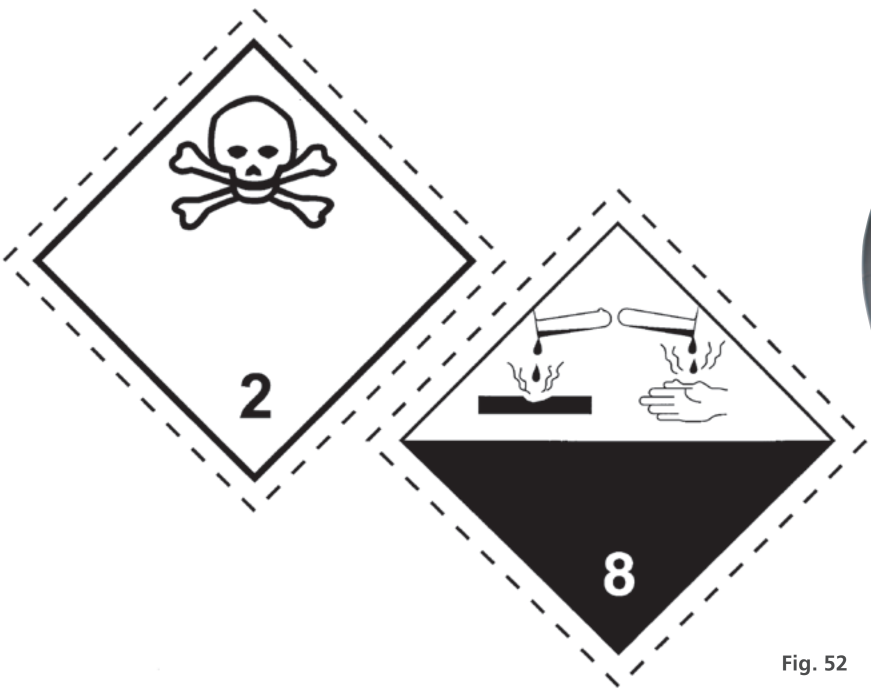


Fig. 52 *Label for used SF_6 from Bad Wimpfen plant*

Life cycle assessment studies for the use of SF_6 in high and medium-voltage applications

Solvay, as a producer of SF_6 and the manufacturers and operators of SF_6 switchgear take the ecological issues associated with the use of this product very seriously. Because of this, switchgear manufacturers, power generation companies, trade associations and Solvay established an SF_6 ReUse process several years ago, which meets the basic requirements for the implementation of a closed product cycle for the majority of SF_6 in use.

With respect to the Kyoto Protocol, switchgear manufacturers, operators and SF_6 producers saw the necessity of going one step further with regard to their product responsibility. For the first time, they quantified the environmental profile of the use of SF_6 as an insulating and arc-quenching medium in high and medium-voltage circuit breakers and switchgear by means of life cycle assessments.

One of the main reasons behind this was the need to get away from the prevailing, one-sided focus on the substance-related global warming potential of SF_6 by analysing all the relevant environmental criteria in connection with the use of SF_6 in the power generation industry. Criteria for this comparison include the potential environmental effects, primary energy requirements, space requirements, global warming potential, acidification potential and nutrification potential.

The life cycle assessments were performed according to the ISO 14040–43 standards by a working group including scientists and other stakeholders, as well as a critical review by an external, independent verifier from TÜV NORD CERT.

Fig. 53 *The SF_6-ReUse-Process*

Life cycle assessment study for SF_6 in high-voltage applications

„Power supply using SF_6 technology"

The study was carried out as a joint project by ABB, PreussenElektra Netz, RWE Energie, Siemens and Solvay Fluor und Derivate and relates to conditions in Germany.

In the study, conventional and SF_6 technologies were compared on a switchpanel level. The study also compared urban power supplies using air-insulated and SF_6 gas-insulated switchgear with no change in the quality of the supply.

The use of GIS switchgear in the public grid reduced all the potential environmental effects that were investigated. Figure 54 shows the relative potential environmental effects in the first year of using the grid variants (blue bar = AIS variant, green bar = GIS/SF_6 variant). Increasing the supply to the grid by around 50 per cent (that is, improving grid capacity utilisation) led to a further reduction for the parameters of primary energy requirements, global warming potential (GWP), acidification potential (AP) and nutrification potential (NP) of around 5 per cent in each case as a result of the SF_6 technology.

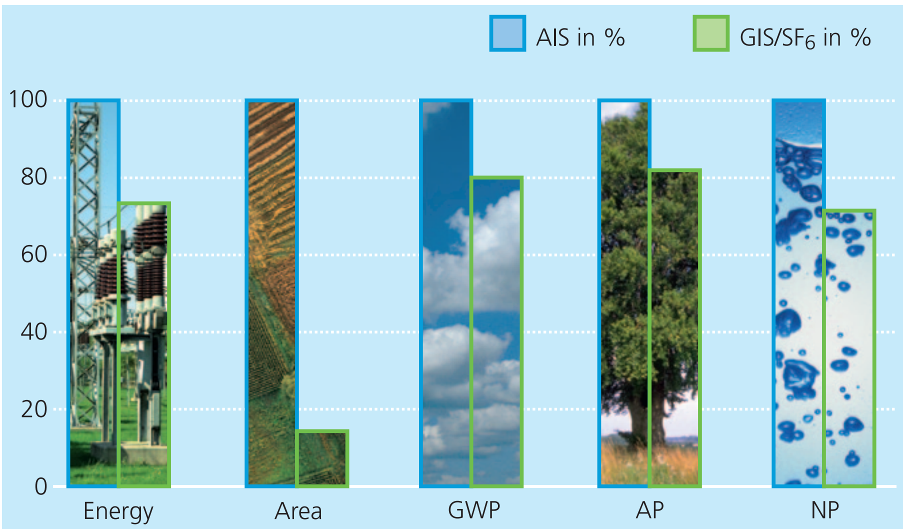


Fig. 54 *Potential environmental effects for SF_6 in high-voltage applications for AIS and GIS*

Life cycle assessment study for SF_6 in medium-voltage applications

„SF_6 GIS technology in energy distribution"

The study was commissioned as a joint project by ABB, AREVA T&D (formerly ALSTOM), SIEMENS, EnBW, E.ON Hanse, RWE and Solvay.

During the study, data was gathered for a representative mix of medium-voltage switchgear: transformer stations, ring-main units (RMU, network stations) and customer substations. The data included electrical key figures (in particular ohmic loss), material data from disassembly analyses as well as load ratios and life times.

To determine the quantity structures, the systems were examined at both a grid and a switchgear level.

Grid level – contribution of the public grid to the greenhouse effect

When the contribution made by distribution grids to the greenhouse effect (Global Warming Potential, GWP) in Germany is analysed, it can be seen that by far the greatest share of this can be attributed to ohmic losses in cables, transmission lines and transformers (Fig. 55). At present, SF_6 emissions from medium-voltage switchgear contribute less than 0.005 % to the greenhouse effect in Germany.

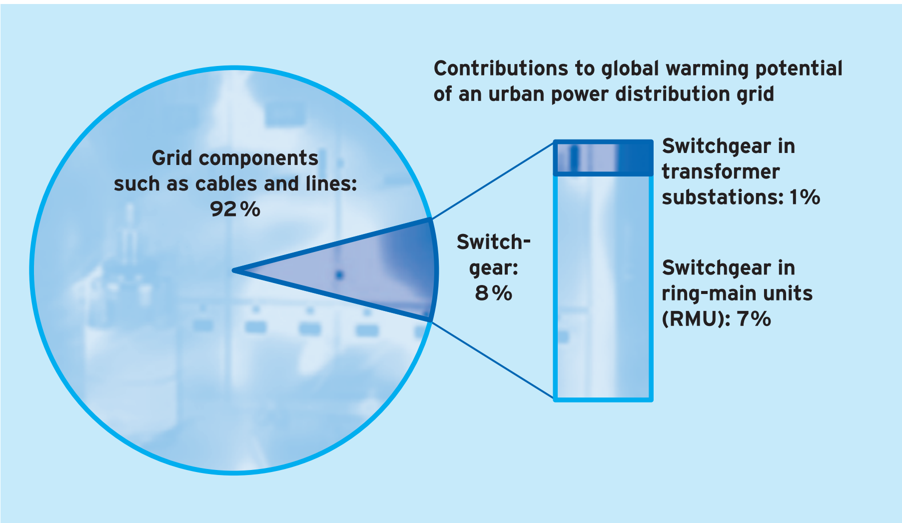


Fig. 55 *Observation of the total global warming potential (GWP) of a representative urban grid*

Switchgear level – comparison between AIS and GIS technologies

Analysis of the switchgear level in figure 56 comparing air-insulated (AIS) and SF_6 insulated technologies, illustrates the advantages of the SF_6 GIS technology with regard to primary energy requirements, acidification potential (acid rain), nutrification potential (over-fertilisation of waterways) and global warming potential (GWP). It was shown that the determining factors impacting on the greenhouse effect are in fact the load ratios in the grid and the switchgear. The current trend towards higher capacity utilisation of the grids increases the advantages of SF_6-insulated switchgear. Thus, to develop any noticeable climatic protection potential it would appear that load flow management in grids is a further way of optimising switchgear design.

In principle, the results of this life cycle assessment could be transferred to other European countries. A sensitivity analysis shows that the selection of primary energy carriers used for electricity generation (as the most significant regional impacting factor) only has minor effects on the results.

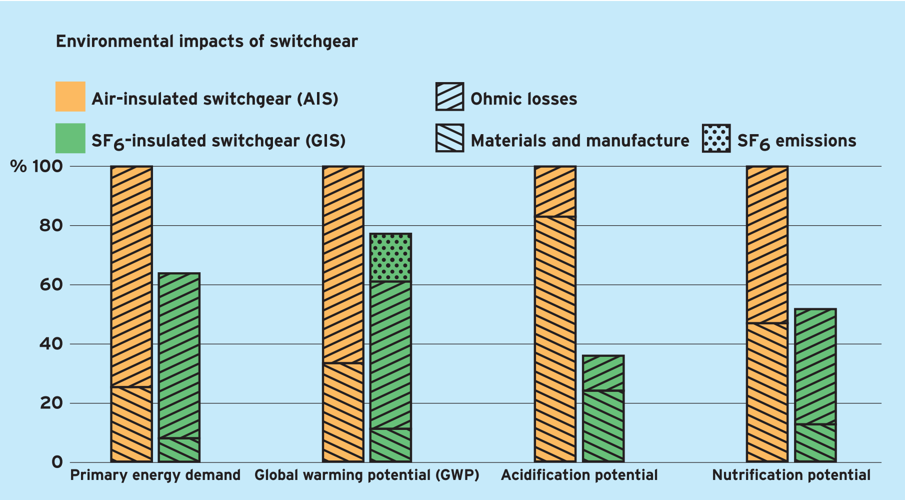


Fig. 56 *Overview of the environmental categories that were examined in the study at switchgear level.*

Summary of life cycle assessment studies

The use of SF_6 technology provides ecological advantages compared with the use of SF_6-free switchgear and equipment. One condition for this is that GIS switchgear guaranteing the corresponding low SF_6 emissions is used, and on the other hand, it is important that the SF_6 ReUse process for a closed SF_6 cycle is applied consistently.

A narrow-based environmental study focussed exclusively on the global warming potential of SF_6 is not sufficient to provide an ecological assessment of the use of SF_6 in high and medium-voltage technologies. As a result of the life cycle assessments that were carried out, it can be seen that bans and application restrictions on the use of SF_6-insulated high and medium-voltage switchgear cannot be justified from an ecological point of view.

Product stewardship for SF_6

Solvay – well known as a global supplier of new SF_6 gas according to IEC 60376 – cares for the environment. We are your partner for the SF_6 ReUse process and full technical services.

The SF_6 ReUse process of Solvay includes:

- environmental consulting
- analytical services of used SF_6
- packaging and transport of used SF_6
- reclaiming of used SF_6

Solvay is the only company worldwide delivering such a complete range, to fullfil the requirements of the responsible care programme.

For further information, please refer to our SF_6 ReUse Folder.

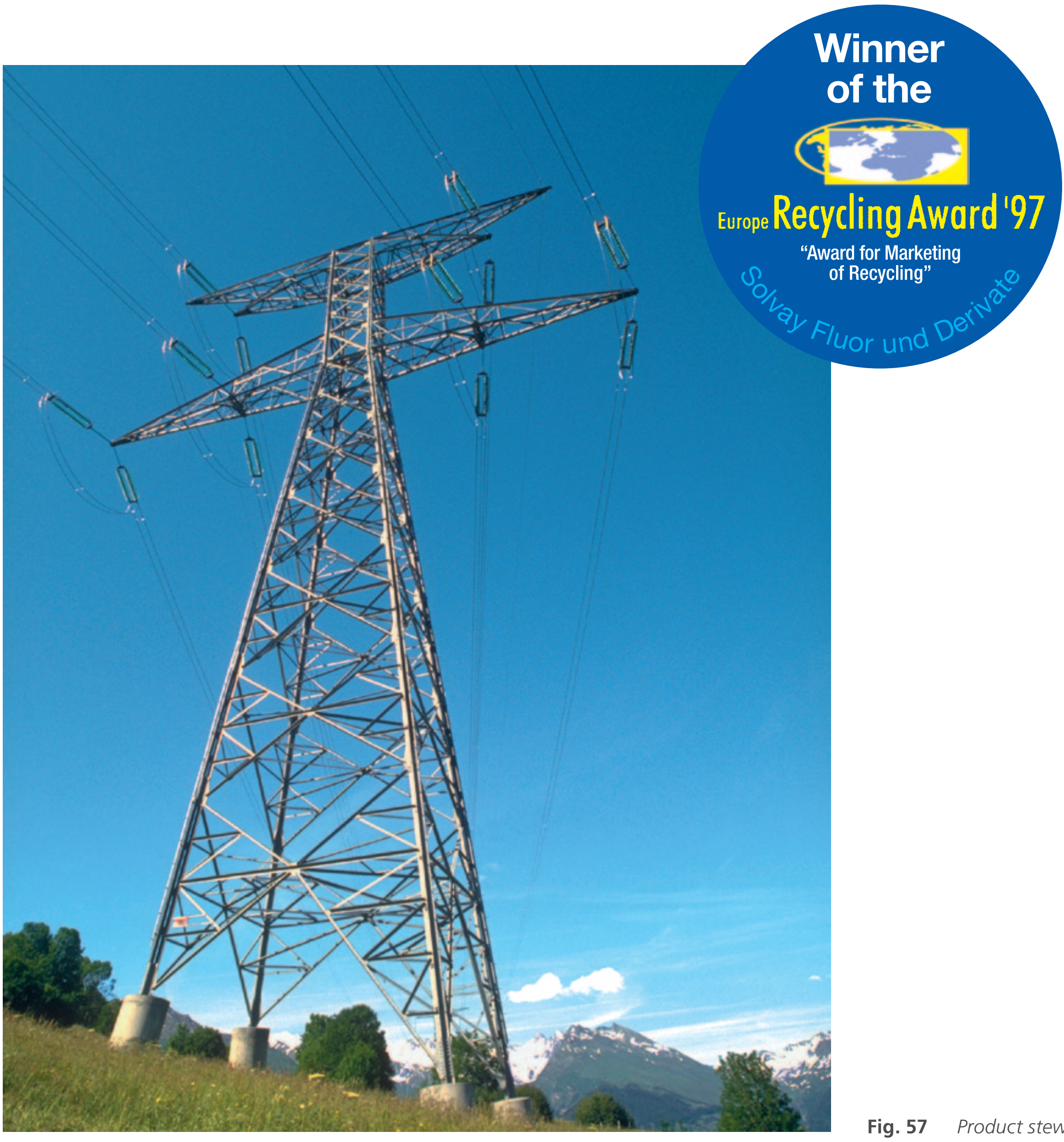


Fig. 57 *Product stewardship for SF_6*

Fluorine compounds from Solvay

Professional Fluorochemistry

With more than 1,000 talented employees Solvay serves customers with fluorine products manufactured at many locations worldwide. The organizational structure provides rapid and flexible responses to the demands of international markets – for the benefit of our clients.

Solvay stands for a professional team of experienced chemists and a sales staff committed to taking on any challenge and to solving problems in close co-operation with our clients. With our state-of-the-art application technologies we offer a full range of fluorochemicals, using fluorspar produced in-house. In line with our commitment to managing challenges we further focus our Fluor business on high value-added specialty products to bring value to our customers.

Fig. 58 *Plant Bad Wimpfen, Germany*

Fig. 59 *Plant Onsan, South Korea*

Product range of fluorine compounds

Product Range Hydrofluoroalkanes

- Solkaflam® 125
  Solkaflam® 227
- Solkane® 125
  Solkane® 134 a
  Solkane® 143 a
  Solkane® 227 pharma
  Solkane® 134 a pharma
  Solkane® 227 tech
  Solkane® 365/227*
  Solkane® 365mfc*
  Solkane® 404A*
  Solkane® 407C*
  Solkane® 410*
  Solkane® 507
  Solkane® 22 L
  Solkane® 22 M
  Solkane® 141 b
  Solkane® 142 b
- Solkatherm® SES36
- Solvokane™
  Solvokane™ S
  Solvokane™ E1.5

Brominated Polyols

- IXOL® B 251
  IXOL® M 125

HF and Inorganic Fluorides

- Ammonium hydrogenfluoride
- Barium fluoride
- Calcium fluoride
- Cryolite, synth powder
- Fluoroboric acid
- Hydrofluoric acid
- Hydrogen fluoride
- Lithium cryolite
- Potassium cryolite
- Potassium fluoroaluminate
- Potassium fluoride solution
- Potassium fluoroborate
- Potassium hydrogenfluoride
- Sodium hydrogenfluoride

Aluminium Brazing Fluxes

- NOCOLOK® Flux
  NOCOLOK® CB Flux
  NOCOLOK® Cs Flux
  NOCOLOK® Sil Flux
  NOCOLOK® Zn Flux
  NOCOLOK® Flux Drystatic
  NOCOLOK® Li Flux
  NOCOLOK® Li Flux Drystatic
  NOCOLOK® Binder
  NOCOLOK® System Binder
  NOCOLOK® Flux-binder mixture
  NOCOLOK® Thickener
- Cesium fluoroaluminates
- Potassium fluoroaluminates
- ANTAROX BL-225
- NOCOLOK® Ultra Flux Paste
- NOCOLOK® Braze Paste

Fluorine Specialties

- Carbonyl difluoride COF_2
- Elemental Fluorine (F_2)
  Elemental Fluorine (F_2), electronic grade
- Iodine pentafluoride (IF_5)
- SIFREN® 46, electronic grade
- Sulphur Hexafluoride (SF_6)
  Sulphur Hexafluoride (SF_6), electronic grade

Materials for Lithium Ion Batteries

- Monofluoroethylene carbonate (F1EC)

Organic Intermediates

- CF_3 Molecules:
  4-Ethoxy-1,1,1-trifluoro-3-buten-2-one (ETFBO)
  Trifluoroacetic acid (TFA)
  Trifluoroacetylchloride (TFAC)
  Trifluoroacetic anhydride (TFAH)
  Trifluoroacetic acid ethylester (TFAEt)
  1,1,1-Trifluoroacetone (TFK)
  Trifluoroacetic acid methylester (TFAMe)
  Trifluoroacetic acid isopropylester (TFAiP)
- CF_2 Molecules:
  Chlorodifluoro-acetylchloride (CDFAC)
  1H-Pyrazole-4-carboxylic-3-(difluoromethyl)-1-methyl-ethylester (DFMMP)

*Please refer to our disclaimer and patent notes: www.solvay-fluor.com/products

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