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WHITE PAPER

Handling Alternative Gases Part 3

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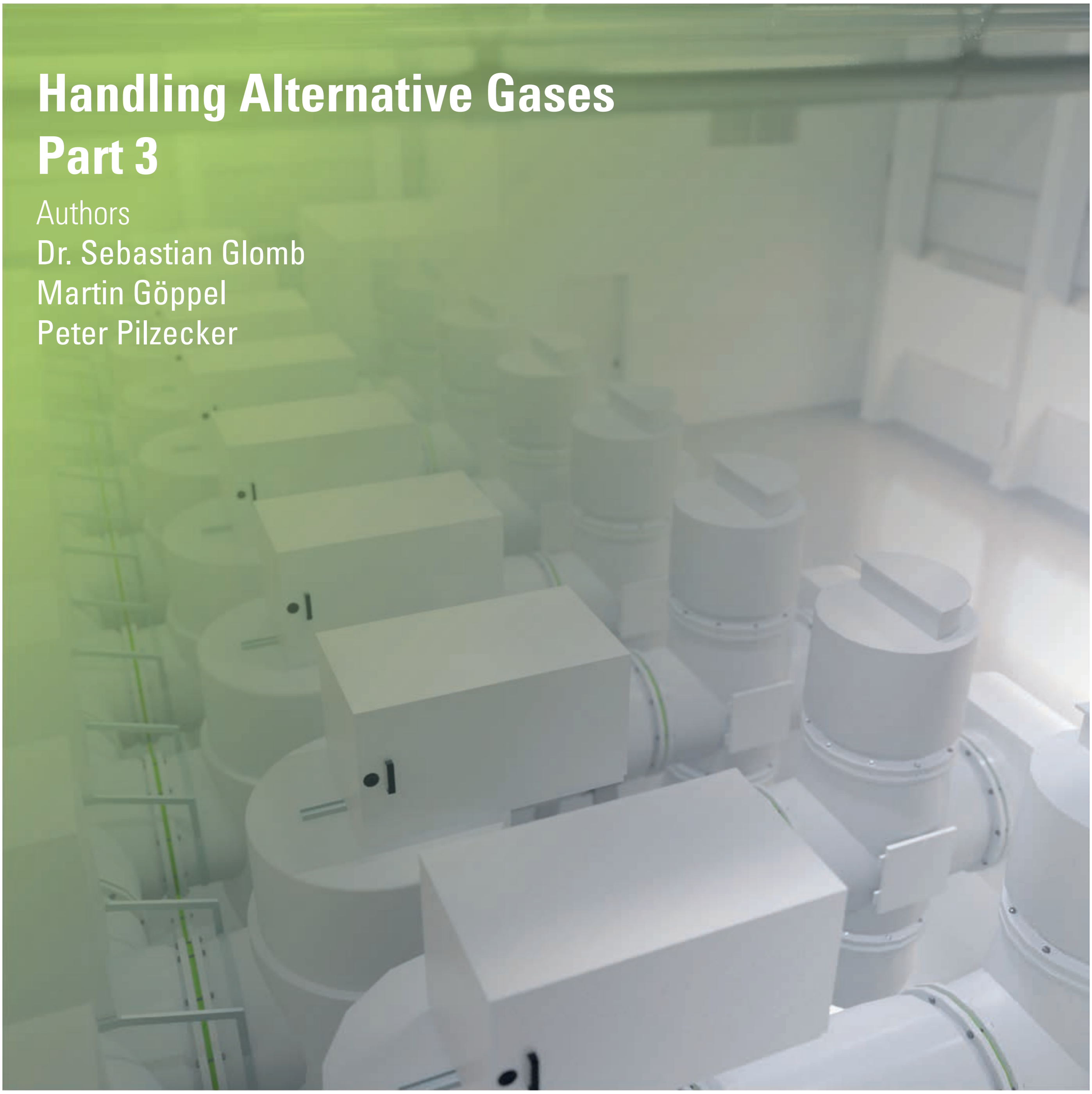

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1. Introduction:

The third part of the guide sets out the major differences between handling Alternative Gases and handling SF_6. In this regard, the focus is on the removal of partially liquefied mixtures from pressure vessels and the associated filling of the equipment as well as the correct course of action in the event of leaks and faults in the operating procedure. In addition, this guide discusses the technical possibilities for ensuring reliable use, in terms of preventing any mix-up of the devices used, when the various gas mixtures are involved in the process.

In contrast to SF_6, which is primarily handled as a single component and handled as a gas mixture only in rare cas-es, Alternative Gases for use in gas-insulated equipment usually consist of two or more individual gas components which together form the insulating gas mixture (Guide 1).

The initial filling of a gas compartment with Alternative Gases can be done in different ways (Guide 2). To ensure proper use in the equipment, the individual gases or pre-mixtures must be a uniformly mixed (=homogeneous) mixture following transfer to the gas compartment. The presence of several different components, as well as different requirements vice-versa the composition of the mixtures for the various applications, increases the complexity of the gas handling for Alternative Gases compared to previous tasks involving SF_6 (Figure 1).

Figure 1: Typical service carts for handling SF_6 (left) and Alternative Gases (right).

2. Handling Alternative Gases in equipment

Existing SF_6 service carts are not designed for operation with Alternative Gases and the use of SF_6 service carts with Alternative Gases is strongly discouraged. This is to prevent damage to the devices and unintentional leaks during handling. Due to the different physical and chemical properties (higher pressure, permeability etc.) of the individual components of Alternative Gases and the different requirements vice-versa the functionality of the service cart, a reaction with individual components could oc-cur and thus lead to the destruction of the devices. Leaks potentially resulting from this can put users' health and safety at risk.

The handling of Alternative Gases and the features of the service carts are, in many respects, based on experience gained over decades of gas handling involving SF_6. Nevertheless, fundamental differences exist due to the diversity of Alternative Gases. These differences are explained be-low in more detail:

A major difference compared to gas handling with SF_6 is the filling of equipment with precisely defined, pre-mixed gas mixtures from a partially liquefied state. Partially liquefied storage is primarily used for mixtures with C4-FN and C5-FK (Guide 2). The Alternative Gas is stored in advance in pressure ves-sels under high pressure (> 5 MPa at 20 °C). This enables it to be homogenised at the operating site using a service cart and transferred into the equipment. In this context, there are different ways for homogenisation to take place depending on the mixture and the application. One thing they all have in common is that the partially liquefied mixture is heated in the available pressure vessel prior to being transferred.

The pressure vessel can be heated by means of heat transfer using electrical contact heating or by means of inductive heating. With regard to inductive heating, the pressure vessel is heated contactlessly by an alternating magnetic field, in a similar manner to a microwave. Thanks to the contactless transfer, the heat transfer and the complete removal from the pressure vessel take place 2-3 times faster (Figure 2) than with contact heating. The controller for the heating and the safety-relevant sensors are integrated in the features of the service cart to ensure proper use of the heating (preventing any overheating of the pressure vessel etc.).

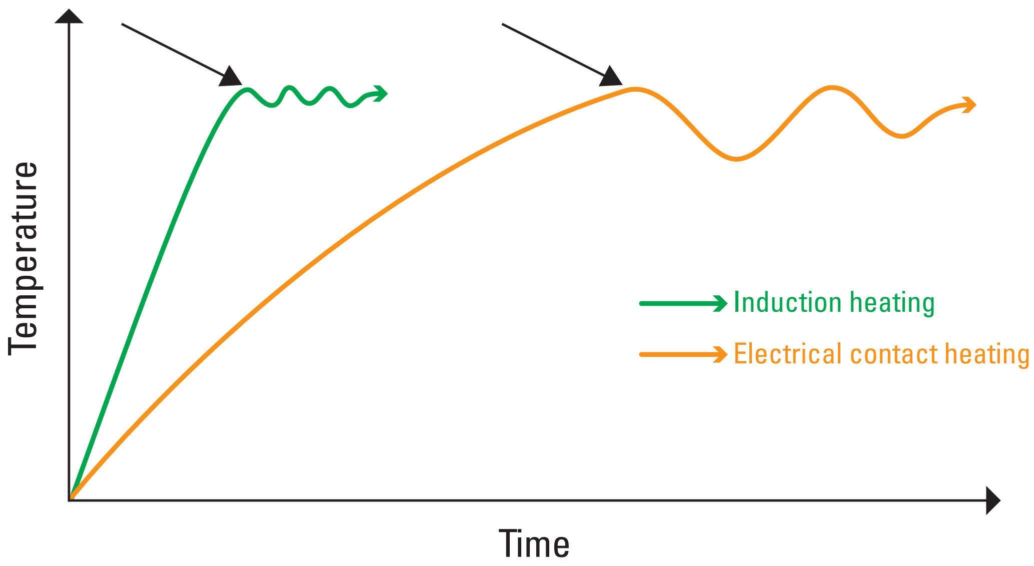

Figure 2: Comparison of the time required to reach the target temperature when heating a pressure vessel using induction (green) and electrical contact heating (orange). The arrows mark the point in time at which the filling procedure was started.

One option for homogenising the liquefied mixture is the complete emptying of the heated pressure vessel into a buffer tank with a larger volume, in which the gas mixture is then homogeneously gaseous. In this procedure, the heating of the pressure vessel serves to increase the speed at which the complete mixture is removed. The buffer tank is usually integrated in the service cart and its volume selected such that the complete gas quantity of the pressure vessel to be heated can be filled into said buffer tank (Figure 3). If the gas mixture is present in the buffer tank in homogenised gaseous form, it can then be used at any time – even without additional heating – for filling gas-filled equipment with different volumes and pressures.

Figure 3: Illustration of the operating principle of a service cart with integrated buffer tank for the removal of partially liquefied mixtures from a heated pressure vessel.

Another way for homogenisation to occur is the complete heating of the pressure vessel and the gas-conveying lines of the service cart to convert the carrier gas of the mixture into a supercritical state. The solubility of the carrier gas is significantly increased in this state of aggregation. In turn, this leads to a complete mixing of all components in the pressure vessel. The gas compartment is then filled directly from the pressure vessel via the heated lines. The carrier gas used in this procedure is carbon dioxide (CO_2). As a component of the mixture, it first needs to be heated above its supercritical point at 31 °C and 73 bar. The homogeneous state is then only stable at increased temperatures. The temperature must be kept constant throughout the entire filling process. Here, it is always necessary to reheat the pressure vessel as well as the connecting lines. [1] In this regard, it is possible that the filling process will need to be interrupted briefly, which can cause problems particularly when filling small gas compartments.

When using gas mixtures in which it is not possible to liquefy the individual components under normal working conditions (e.g. synthetic air), the gas is removed from pressure vessels using a gas refill device. The mixture is in a homogeneous, gaseous state throughout the entire process and does not need to be additionally heated for removal.

3. Leaks and other faults in the operating procedure

During operation of gas-filled plants, various faults in the operating procedure could occur in the form of leaks or the formation of decomposition products after discharges. Below is a list of potential faults along with an explanation of viable solutions to remedy such faults:

Gas-insulated equipment in which the gas mixture escapes in a uniform composition due to a leak and the mixing ratio in the gas compartment thereby remains unchanged, can be refilled with the relevant Alternative Gas after the leak has been repaired in the ways explained previously (Guide 2). Appropriate measuring devices should be used to check whether the quality of the gas mixture in the equipment after the leak continues to meet the requirements specified by the manufacturers (Guide 4).

Special attention must be paid to leaks in gas-insulated equipment with C4-FN and C5-FK mixtures. This is because a precisely defined mixing ratio is usually specified to en-sure the proper use of such mixtures in the gas compartment. The mixture itself is homogenised. However, uneven leakage could occur depending on the nature of the leak (diffusion through sealing material or even substan-tial leakage). Individual components of the mixture can escape faster or slower, such that a different mixing ratio is subsequently present in the gas compartment. Similarly, in the event of a leak causing moisture and air to penetrate the gas compartment, the percentage of C4-FN and C5-FK can be reduced such that it is no longer possible to ensure the full insulating capacity of the mixture. If it is still possible to remove the moisture that has penetrated with special filter systems designed for the alternative gas used, the oxygen and nitrogen that have penetrated with the air cannot be removed. In the event of any devi-ation from the concentration limits specified by the man-ufacturer for individual gas components, the gas mixture should not be used any further in the equipment and complete replacement should be considered following consultation with the manufacturer.

When using Synthetic Air as an insulating gas, moisture that has penetrated can also be removed by existing filter systems for Alternative Gases. As the composition of the ambient air that has penetrated is similar to the composition of the Synthetic Air, the mixing ratio in the equipment is not changed significantly. It would not be necessary to replace the gas mixture.

Faults can occur in the operating procedure during operation of a gas-insulated plant with Alternative Gases. Analogous to SF_6-filled plants, such faults can cause discharges and thus decomposition of the gas. When using synthetic air as an insulating gas, nitrogen oxides (NO_x) can occur as the main decomposition products in low concentrations after discharges. These oxides can be removed by filter systems and subsequently have no further influence on the mixing ratio present or on the insulation properties.[2]

With regard to gas mixtures with C4-FN or C5-FK, the decomposition products are more diverse and heavily dependent both on the nature and strength of the discharge and the moisture present in the gas compartment. C4-FN and C5-FK are largely non-recombinable after decomposition by arc discharges, while SF_6 is able to recombine independently (reassemble to form SF_6).
Once they have been decomposed, they no longer exist in the gas compartment in their original chemical structure (Figure 4). The proportion of C4-FN/C5-FK in the gas mixture is reduced and a change in the insulation properties is to be expected as of a certain concentration.

Carbon monoxide (CO) can be considered as an indicator of the occurrence of discharges and the presence of decompo-sition products in mixtures with C4-FN and C5-FK. CO is a colourless and odourless gas which can result from the incomplete combustion of carbonaceous substances, for example. CO is classified as a toxic gas and has a TLV for example in Germany of 30 ul/l.

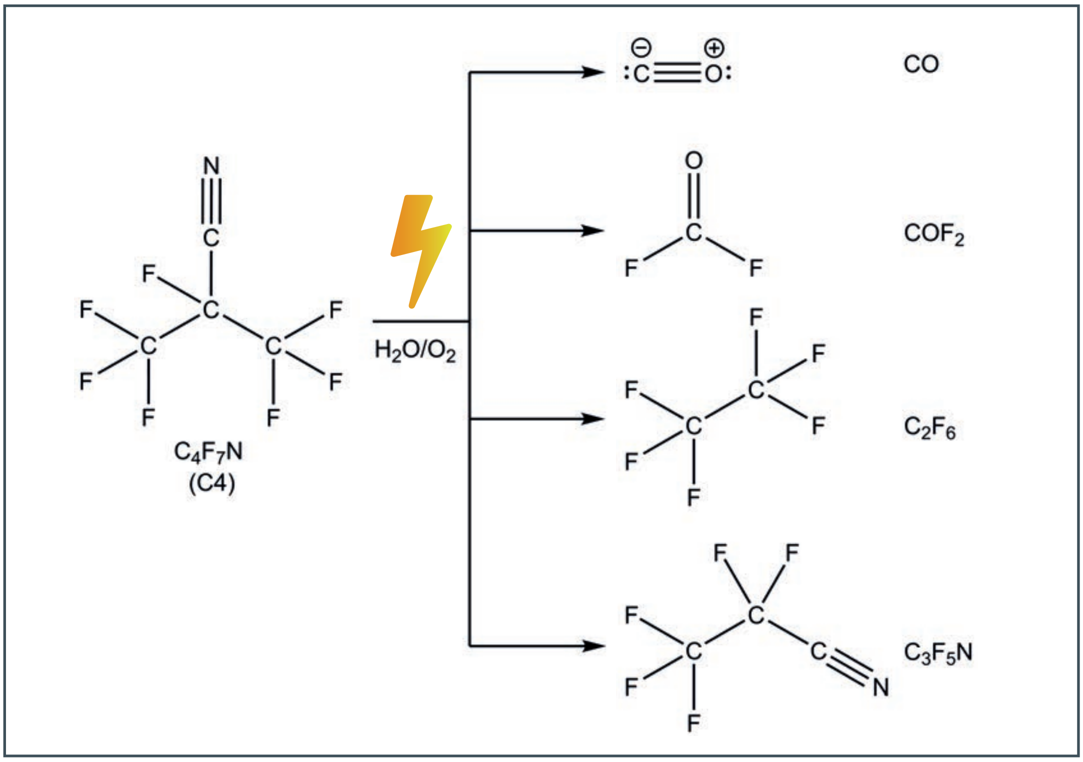

Figure 4: Schematic illustration of selected decomposition products of C4-FN in the presence of moisture and oxygen during a discharge.

In existing filter units for Alternative Gases, the focus is on the removal of corrosive and toxic decomposition products, which can directly affect an employee's health and the functionality of service carts. An exact analysis of the resulting decomposition products as a function of the type and strength of the discharge can be performed in specially equipped laboratories using gas chromatography. No further listing is given at this point due to the diverse use of mixing ratios and different gases.

Given the narrow concentration range for the functionality of mixtures with Alternative Gases in equipment, regular monitoring of the mixing ratio and the proportion of moisture and decomposition products is there-fore even more important than when using SF_6. Such monitoring is necessary in order to detect and eliminate possible contamination and discharges in a timely manner.

The recovery of Alternative Gases of insufficient gas quality from the gas-filled equipment can be performed with a service cart, which is also used for filling, or with a suction device that is suitable for the mixed gas (Figure 5). Both devices are designed in such a way that the contaminated gas can be stored under high pressure in external pressure vessels, up to partial liquefaction. The recovered gas can then be reconditioned or disposed of externally. In contrast to SF_6, which can be cleaned to a certain purity degree by drying and removing the decomposition products directly on site and then reused as "used SF_6",[3] there are still no uniform rules and standards for Alternative Gases vice-versa the limit values for re-use.

Figure 5: Mixed gas recovery device for Alternative Gases.

4. Mix-up prevention

In practice, it is still frequently the case that SF_6 and Alternative Gases are handled at the same time. Different thread sizes are used on the couplings to prevent any mix-up of devices and to prevent the wrong gas or gas mixture being filled. While couplings of size M26x1.5, M45x2 and M76x2 are used on service carts and hoses in the SF_6 area, couplings of size M28x1.5, M48x2, M78x2 and M24x1.5, M43x2 and M74x2 respectively are used for mixtures with C4-FN and C5-FK (Table 1). The connections are not compatible with each other or with SF_6. This should ensure that the different gas mixtures do not accidentally come in contact with residual gas still present in components and cause unintentional mixing/contamination.

Table 1: Overview of couplings of size DN8, DN20 and DN40 used for SF_6 and Alternative Gases.

Size	SF_6	C4-FN	C5-FK
DN8	M26x1,5	M28x1,5	M24x1,5
DN20	M45x2	M48x2	M43x2
DN40	M76x2	M78x2	M74x2

In this context, it is also recommended that the same pressure vessels not be used for the different Alternative Gases and for SF_6 without thorough cleaning when using Alternative Gases. As despite standard recovery below 1 mbar, a small amount of residual gas always remains in the pressure vessels and connections and it is therefore not possible to prevent contamination with other gas mixtures or with SF_6.

Specially designed service carts are already in use today for gas handling of Alternative Gases. These carts are used during the filling of gas-insulated equipment, recovery and cleaning on site after leaks and discharges. A major difference in handling compared to SF_6 is the filling of gas compartments from partially liquefied gas mixtures. Technical solutions to prevent accidental contamination from the use of incorrect equipment are already available today. Such solutions include using different thread sizes for the different Alternative Gases and SF_6.

The fourth and final part of the guide will focus on the measurement of gas quality, the various measurement parameters, and on the sustainable reconditioning and reuse of Alternative Gases.

5. References

(1) Cigré WG B3.45 „Application of non SF_6 gases or gas mixtures in medium voltage and high voltage GIS".

(2) Bernhard Lutz, Alternative Lösung Clean Air; DILO SF_6-Anwendenderkonferenz; Berlin, 2019.

(3) Specifications for the re-use of sulphur hexafluoride (SF6) and its mixtures in electrical equipment, 2020 (DIN EN IEC 60480 VDE0373-2).

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