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Question: Decomposition of gases may have substantial impact on the long-term performance of gas-insulated systems. Low-GWP gases may be of lower stability compared to SF6. Is there any experience concerning decomposition of low-GWP gases available? How should this aspect be tested to ensure reliability in the long-term range?

Stability of C4-FN in HV Equipment

Stability of SF_6 and SF_6 alternatives

In high-voltage equipment, the technical properties of insulating gas and materials must be stable enough to ensure reliable operation over equipment's service life. SF_6 is very inert and does not easily interact with other materials. Only when subjected to high energy (for example during arcing), reactive intermediate compounds or decomposition products are formed. Guidelines and best practices for gas condition and choice of materials have been established:

- low dew point (humidity control)
- materials selection and qualification (insulation materials, desiccants, lubricants, contact materials, …)

SF_6 alternatives may contain components that can be more reactive overall, like oxygen or decomposition products of fluorinated additives. Several installations with SF_6 alternatives have been commissioned and operated during the last years. Additionally, in CIGRE 2022 session, several contributors share their experience on stability of C4-FN/CO_2/(O_2) insulated equipment:

since 2014 – 72.5 kV CO_2/O_2 life-tank circuit breakers in operation
since 2015 – 170 kV C5-FK/CO_2/O_2 GIS in operation
since 2016 – 420 kV C4-FN/CO_2 GIL in operation

SC B3 report 10672: 145 kV C4-FN/CO_2/O_2 GIS, 2 years grid operation incl. switching showing stable gas composition over time.
SC D1 report 11114: a 420 kV GIL prototype (various mixtures and configurations), operated under thermal cycling and dielectric stress (2 x $U_r/\sqrt{3}$) for 4 months shows stable gas composition and good dielectric performance. Solid C4-FN decomposition products were observed at the visual inspection

Theory and additional experience on C4-FN stability and decomposition

C4-FN is generally quite stable. The theory of its chemical decomposition path is well understood. In the presence of moisture, a hydrolysis reaction can occur, resulting in the formation of $C_3F_7CONH_2$ (Figure 1, amide: white solid crystals). This reaction is strongly temperature dependent. From the amide, further solid decomposition products can be formed but formation of the amide is the critical, time controlling step that must be managed to ensure long product lifetime. Since the hydrolysis reaction depends also on the availability of

moisture, the available moisture within the switchgear needs to be controlled well. The required and recommended levels of moisture for C4-FN containing gas mixtures is comparable to humidity levels required and observed in state-of-the-art SF_6 equipment. Materials selection also plays an important role in ensuring C4-FN stability.

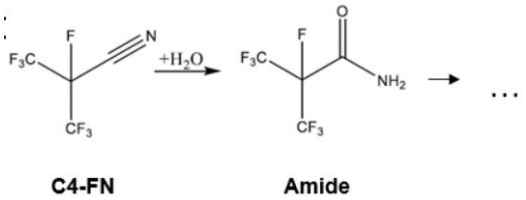

Figure 1. C4-FN reaction with water

Material selection and qualification

Based on solid knowledge of the underlying chemistry and proven test-procedures, materials can be tested against known benchmarks in a controlled environment. One step of the selection and qualification process are thermal aging tests in C4-FN mixture in temperature ranges of 70 – 120 °C, depending on material and target application.

A robust material selection and qualification process will avoid changes in the material properties (example Figure 2) over time as well as mitigating formation of unwanted decomposition products (example Figure 3).

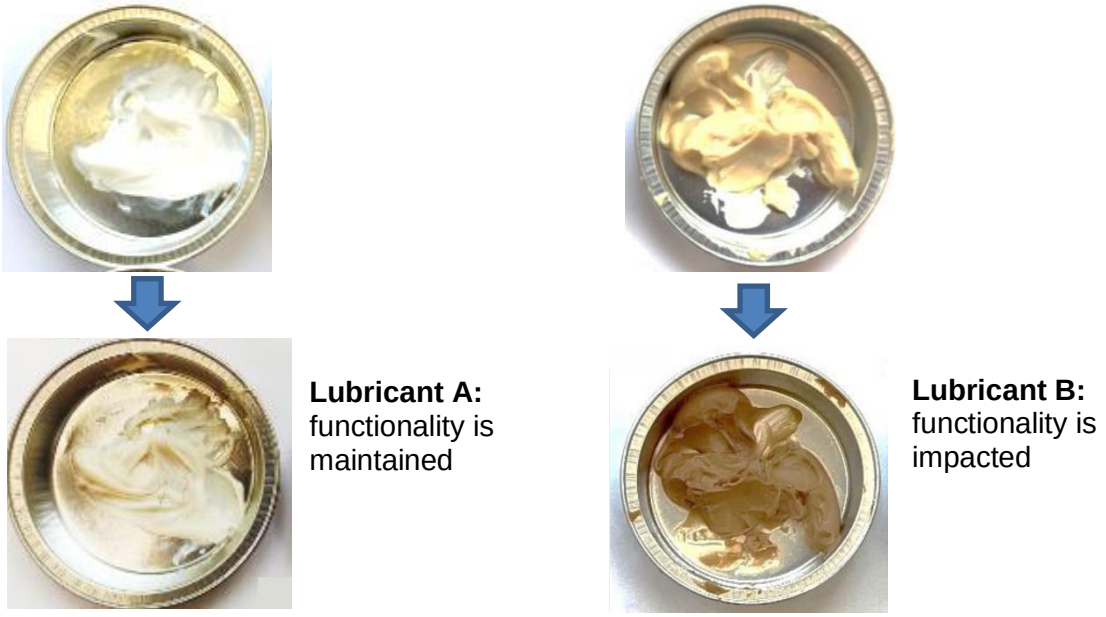

Figure 2. Thermal aging of two lubricants in C4-FN mixture: top line: before aging, bottom line: after aging

Desiccant A: no solid decomposition products in gas compartment

Desiccant B: formation of solid decomposition products

Figure 3. Two desiccants after thermal aging in C4-FN mixture

Summary

It has been shown that control of humidity inside the equipment is important to ensure gas stability. A similar level of humidity as in state-of-the art SF_6 equipment is needed to avoid excessive gas decomposition. Proper material qualification and selection procedures avoid formation of solid decomposition products.

Effectiveness of both measures are demonstrated by full-scale ageing tests (Figure 4, up to 6 months, up to 100 °C, also thermal cycling with rated current). If the measures are not adhered to, discolorations or solid decomposition products might form, without immediate criticality for functionality of the equipment. High-voltage equipment using C4-FN/CO_2/O_2 with comparable, but slightly adapted measures will reach similar lifetime as state of the art for today's SF_6 equipment.

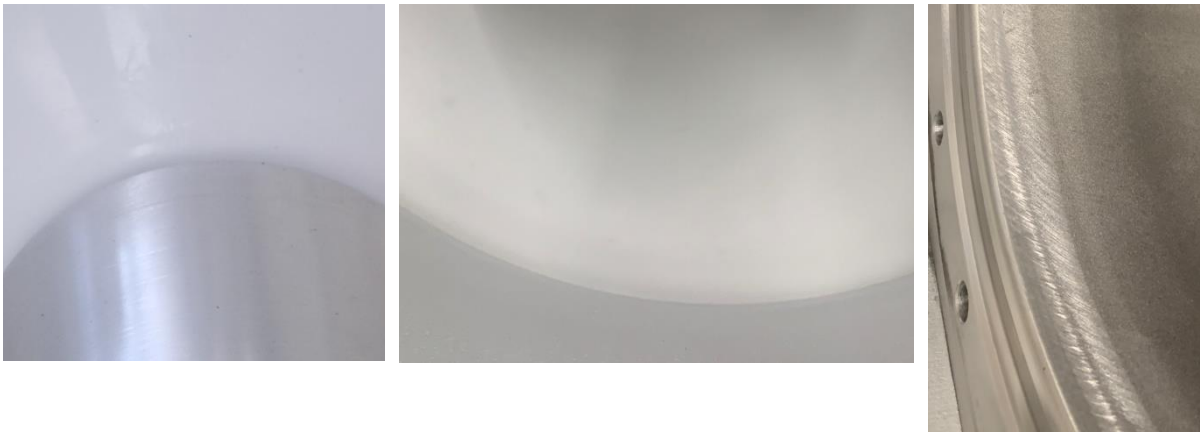

Figure 4. Impressions from visual inspection after thermal aging tests, no solid decomposition products, dielectric tests passed