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GROUP REF. : D1
PREF. SUBJECT : 2
QUESTION N°: 2.03

Long-term stability of SF_6 alternative gas mixtures

The special report of study committee D1 – Materials and emerging test techniques raises the question Q2.03 « Low-GWP gases may be of lower stability compared to SF_6. Is there any experience concerning decomposition of low-GWP gases available? »
This contribution is providing answers to these questions related to the following aspects:

- Stability of the pure insulating gas
- Stability of gas mixture
  - Potential of demixture
  - Formation of by-products

The contribution is focusing on C4-FN and C5-FK as low GWP alternatives to SF_6.

Stability of pure insulating gas

The stability of C4-FN and C5-FK have been assessed using accelerated aging studies to predict the condition of the materials (see Figure 1). The heat aging tests exhibited little change in chemical composition of the materials and remained consistent with the minimum purity requirements specified. Based on the van't Hoff principle this would simulate more than 50 years of aging at room temperature.
Based upon these results the C4-FN and C5-FK have been found to be shelf stable and are expected to perform as dielectric medium throughout the useful life of a properly designed, maintained and operated electrical equipment.

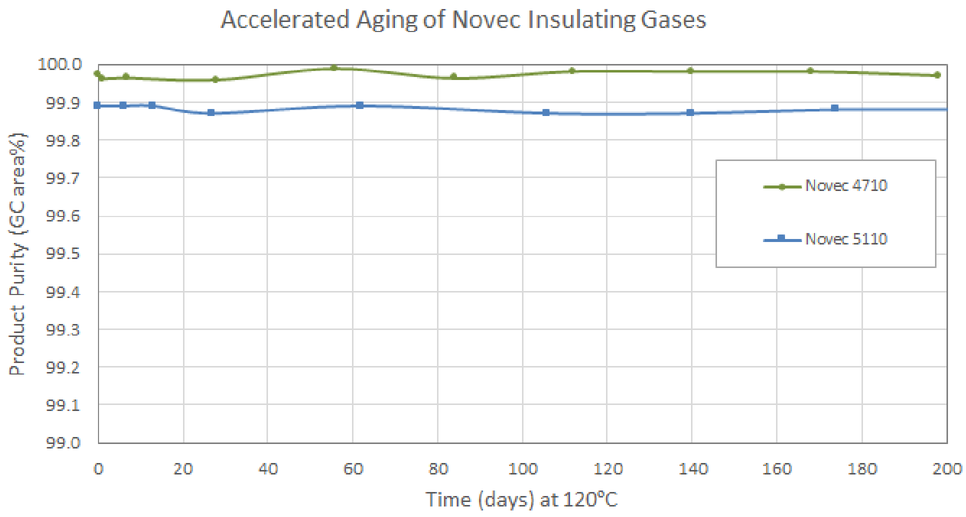

Figure 1. Accelerated aging of C4-FN (3M™ Novec™ 4710 Insulating Gas) and C5-FK (3M™ Novec™ 5110 Insulating Gas)

Stability of gas mixture

Potential of demixture

A question often arises whether these gas mixtures will separate over time. Once gases are combined into a homogeneous mixture, they do not physically separate unless liquefied by cooling below the condensation temperature of the mixture or compressed to very high pressure. This might seem counterintuitive since many people have had experience with a gas of higher density than air settling into lower regions as shown in Figure 2:

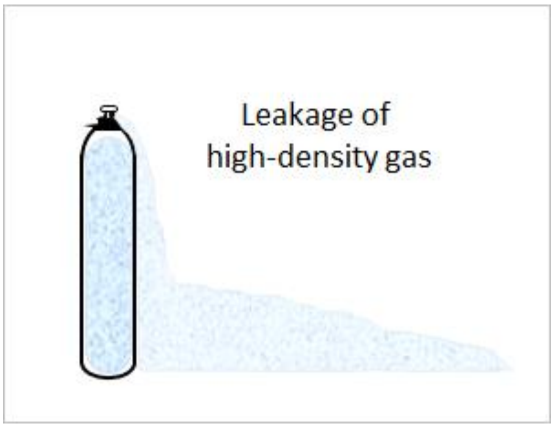

Figure 2: Illustration of high-density gas leakage with gas accumulating at lower heights

The reason this occurs is that the gas initially has a density higher than that of air. However, given enough time, the higher density gas will eventually form a homogenous mixture with air through diffusion and motion of the air. But what about a pre-blended gas mixture within the cylinder or contained in a gas-filled piece of equipment with relatively long vertical height? Will a mixture of gases which have very different molecular weights and in their pure form have very different density remain homogenous if there is no motion of the gas within the volume it fills? The answer is once again that no separation will occur.

Although the gas density will vary with height as shown in the attached Figure 3, within a gas mixture, the column of pressure exerted on any molecule is created by the entire mixture not the individual components. Therefore, since the forces on each molecule are the same, the composition does not change with height.

A similar conclusion was reached in the 1982 EPRI Report EL-2620 [1]: "In the absence of condensation, a gas mixture will not separate into its component gases over a short or long period of time even when the molecular weights of the component gases are markedly different

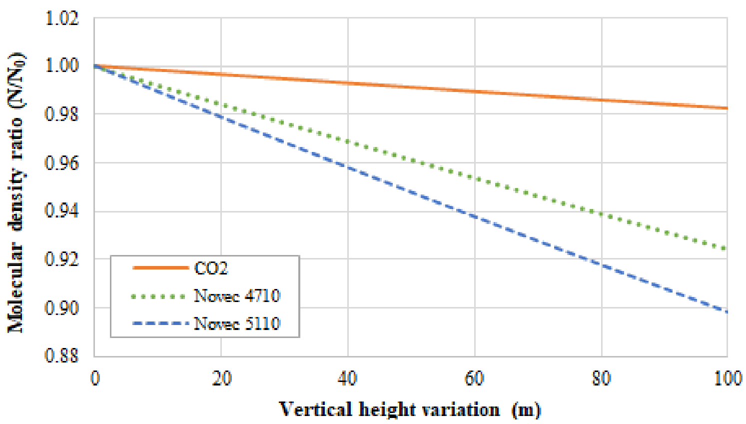

Figure 3. Molecular density ratio of pure gases CO2, C4-FN (3M™ Novec™ 4710 Insulating Gas) and C5-FK (3M™ Novec™ 5110 Insulating Gas) as the function of vertical height

Formation of by-products

The formation of by-products and their influence on the lifetime of a switchgear has been assessed already in multiple publications.
For example, the CIGRE 2020 publication A3-117 [2] concludes that “as in SF_6, the limit of lifetime in high voltage circuit breaker will always be reached first because of contacts and PTFE parts erosion. The evolution is illustrated in the figure 10”

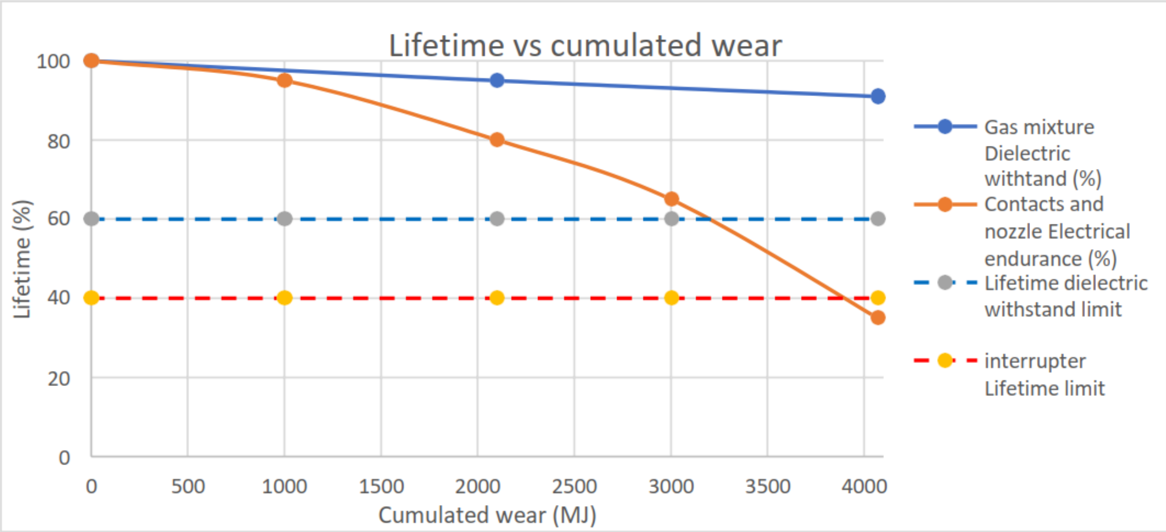

Fig 10 : lifetime evolution compared to cumulated wear for dielectric and breaking performance

Also, the recent CIGRE Technical Brochure 871 – Current Interruption in SF6-free Switchgear [3] has been assessing the decomposition of C4-FN and C5-FK gas mixtures:
“A new factor to consider is decomposition of C4-FN / C5-FK by arcing. This “gas wear mechanism” is numerically compared with the wear of arcing contacts and nozzle (as usual in SF_6 breakers). With the knowledge so far, it is concluded that gas decomposition in properly designed equipment is not a lifetime limiting factor compared to other degradation mechanisms”
Various environment, health, and safety aspects of the by-products created by arcing in new fluorinated mixtures are presented. It is argued that in normal operation the by-products created by arcing fall in the same acute toxicity classification as arced SF6.▪
Key conclusion: The operability, performance, maintenance, and lifetime of alternative gases appear to be similar to SF6.”

The CIGRE brochure further provides an example for C5-FK degradation in a GIS Circuit Breaker [4]concluding that “The C5-FK content in this example (green curve) only reduced slightly by a few percent which does not endanger dielectric integrity or the arc extinction process.”

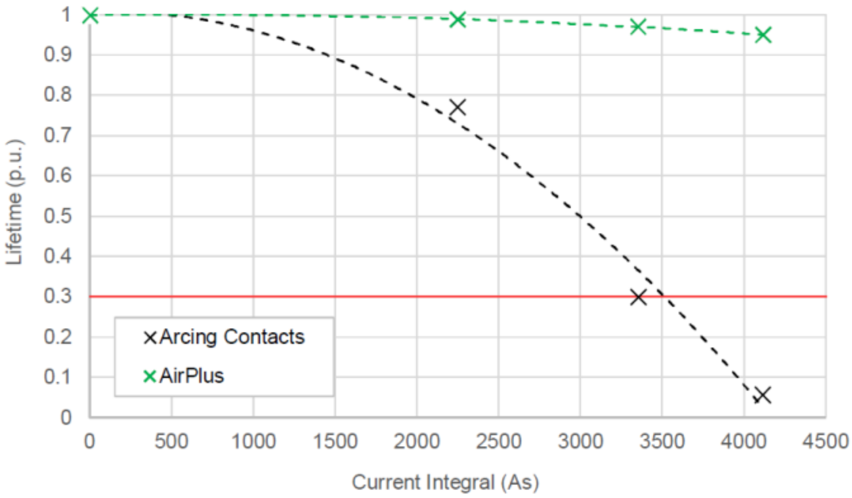

Figure 3.16 - Example of lifetime limiting factors for a 245 kV 50 kA circuit breaker with a C5-FK mixture (‘AirPlus’) [132]

Finally, the Technical Brochure also assesses the Health & Safety of new and arced gas mixture via their LC50 values and their classification according to the Global Harmonized System (GHS). The conclusion is that “In general, SF_6 and its alternatives would fall in the same classification categories when in new or arced conditions.”

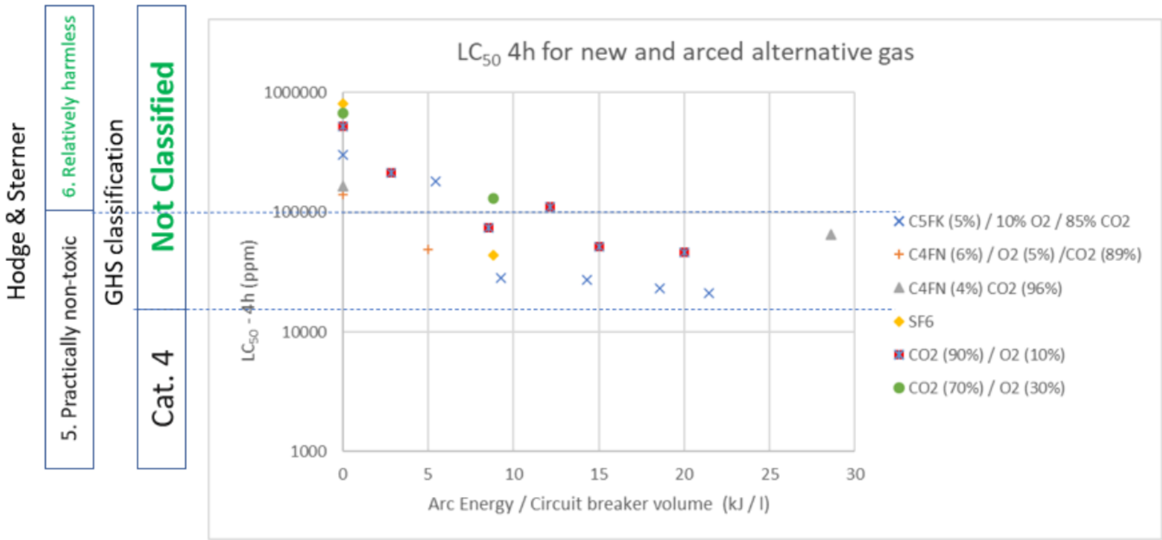

Figure 3.20 - LC50 (4 hrs) for new and arced gas depending on the arc energy over volume ratio [70], [86], [129], [139], [140]

Conclusion

The provided contribution shows that significant data exists demonstrating sufficient long-term stability of C4-FN and C5-FK in SF_6 alternative gas mixtures.

References

[1] EPRI, «Gases superior to SF6 for insulation and interruption,» EPRI report EL-2620, 1982.

[2] J. Ozil et al., «Return of experience of the SF6-free solution by the use of Fluoronitrile gas mixture and progress on coverage of full range of transmission equipment,» *CIGRE 2020, A3-117*, 2020.

[3] CIGRE WG A3.41 (Convenor R. Smeets), «TB871 - Current Interruption in SF6-free Switchgear,» CIGRE, 2022.

[4] J. D. Mantilla, M. Claessens, and M. Kriegel, «Physical Aspects of Arc Interruption in CO2/O2/Fluoroketones Gas Mixtures',» *CIGRE 2018 A3-305*, 2018.