Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10129

Simulation of Diffusion Behavior for New Insulating Gases

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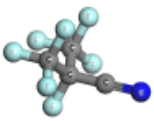
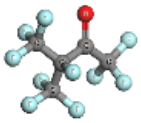
Motivation

- One of the increasingly acute environmental challenges in electric power systems results from the use of sulfur hexafluoride (SF_6) as insulating gas in gas insulated equipment.
- Due to its global warming potential (GWP=23,500) and its atmospheric lifetime (3,200 years), SF_6 is recognized as the most potent greenhouse gas in the Kyoto Protocol.
- In recent years, a fluoroketone and a fluoronitrile have been studied and recognized as new insulating gases that can replace SF_6.



Fluoronitrile



Fluoroketone

- The studies in this article aim to develop finite element analysis (FEA) models for simulating diffusion behavior of fluoronitrile gas.
- This analysis can also model diffusion of potential decomposition products of fluoronitrile in dilute gas mixtures containing CO_2, dry air, and/or nitrogen.

Method/Approach

- Diffusion is a mass transfer phenomenon describing the molecular transport of one substance relative to another substance. This process can make the spatial distribution of chemical substances more uniform over time.
- The mass transfer of a substance is the evolution of its concentration in space and time.
- We built the model based on Fick's law to predict the diffusion of fluoronitrile gas in gas mixture and/or atmospheres.

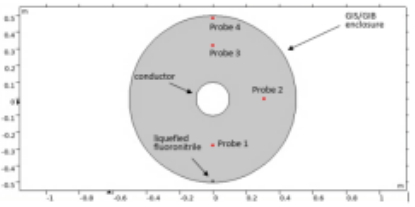
Objects of investigation

- The substance investigated is heptafluoroisobutyronitrile (brand name 3M™ Novec™ 4710 Insulating Gas, often referred to as fluoronitrile or C4-FN) in a gas mixture, such as CO_2 or air

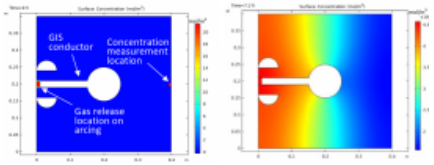
Experimental setup & test results

Three different scenarios for the diffusion of the fluoronitrile gas were modeled:

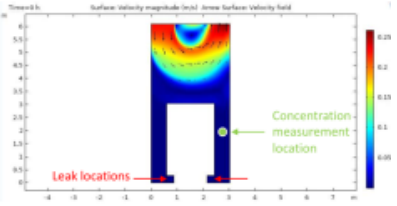
1. **Estimating the diffusion for liquified fluoronitrile in GIS/GIL**



2. **Evaluating the diffusion of potential decomposition products of fluoronitrile in dilute gas mixtures containing CO_2, dry air, and/or nitrogen in GIS**



3. **Assessing the diffusion of fluoronitrile gas in situations such as gas leakage from GIS/GIB in the vault of substation.**



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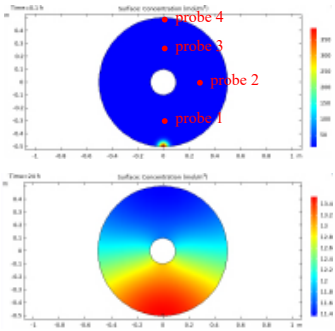
Results

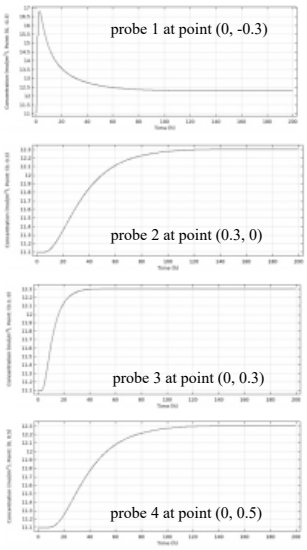
The modeling demonstrates time-dependent diffusion for fluoronitrile in dilute gas mixtures

1. **Estimating the diffusion for liquified fluoronitrile in GIS/GIL:**

- Figure below shows the concentration of fluoronitrile in the enclosure during diffusion from time 0 to 24 hours.



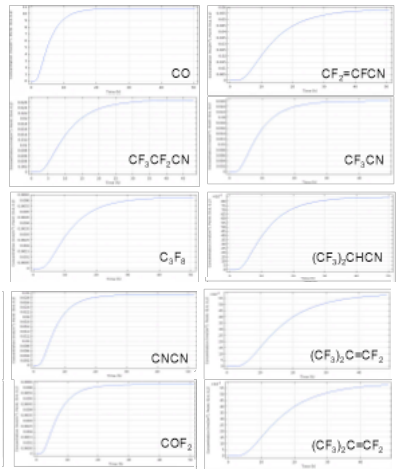
- Figure below shows the fluoronitrile concentration verse time at the probe location points.



2. **Assessing the diffusion of fluoronitrile gas in situations such as gas leakage from GIS/GIB in the vault of substation.**

- Figure below displays the concentration of decomposition compounds vs. time at the measurement location.
- It appears that even for the higher molecular weight degradation products, the mixture will be approximately 80-90% of the way toward a completely homogeneous mixture after 24 hours.
– E.g. carbon monoxide (CO) as one of decomposition products of fluoronitrile/CO_2 gas mixture will be approximately 90% of the way to homogeneity in 24 hours and essentially 100% in about 36 hours inside a sealed test vessel with cross-section surface area 0.16 m^2.

Compounds	Concentration [ppmv]
$(CF_3)_2CFCN$	55200
CO	19100
C_3F_8	2228
CF_3-CF_2-CN	35
CF_3-CN	120
CN-CN	20
COF_2	166
CF_2=CF-CN	38
$(CF_3)_2C=CF_2$	1.2
$(CF_3)_2CHCN$	1.3



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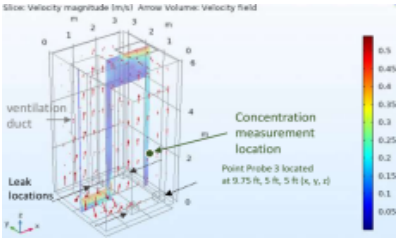
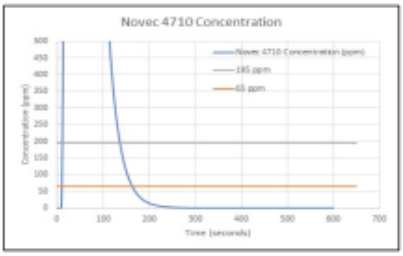
(continued)

Results (continued)

3. **Assessing the diffusion of fluoronitrile gas in situations such as gas leakage from GIS/GIB in the vault of substation.**

   - Figures below show the results of 3D modeling. The calculations verify that a ventilation duct will be very important for efficient removal of gas from a vault in which the only outlet for gas is the top of the enclosure.
   - With a ventilation duct the concentration of C4-FN in can be lower than the 8-hour time weighted average (TWA) occupational exposure limit (OEL) of 65 ppm in only 150s, significantly reduced from 300 hours in the scenario without a ventilation duct.





Conclusion

The results of this research will enable equipment designers and operators to better understand the diffusion process of the new insulating gases within gas mixtures, thereby improving the safety, stability and accuracy of the operation and maintenance of new gas-insulated power equipment.

The modeling demonstrates time-dependent diffusion for fluoronitrile in dilute gas mixtures under different scenarios such as those encountered with gas insulated equipment.

- Diffusion back to homogenous mixture under isothermal conditions with no heating or external temperature changes after liquification
- The diffusion behavior of decomposition products of C4-FN after arcing events in gas insulated switchgear

These models can also be applied to industrial hygiene assessments to understand the diffusion processes of these gas mixtures in the work environment and to optimize ventilation systems

- In the analyzed example the C4-FN concentration can be reduced below the OEL of 65 ppmv in only 150 seconds when the ventilation duct is properly installed.