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Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-11114

Investigations on the long-term performance of Fluoronitrile-containing gas mixtures in gas-insulated systems

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Motivation

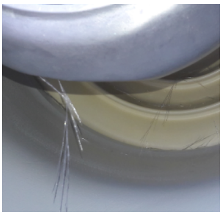
- More eco-friendly alternatives to SF_6 are currently under investigation and already installed in the grid
- Beside natural-origin gases, F-gas based admixtures were considered as potential alternatives to increase the electric strength
- Within government-supported projects the properties of different gases were investigated

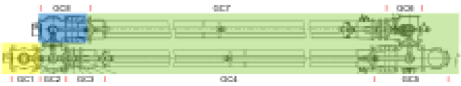
Method/Approach & Test setup

- In addition to different laboratory tests, a long-term test was conducted to estimate the long-term performance of real-sized high-voltage equipment
- Outdoor-installed test setup, consisting of 420 kV GIS/GIL modules, forming a loop of ≈30 m in length
- Gas mixtures of Fluoronitrile (C4-FN, 3M Novec 4710), CO_2 and O_2 were used for this test
- GIS/GIL materials were adapted according to the outcome of material compatibility tests
- High voltage and rated current (in cycles) were applied simultaneously for 3.000 hours, including intermediate impulse voltage tests
- Gas samples were taken and analysed with FTIR and GC/MS. The gas composition was checked at the beginning and at the end of the tests.

Considered alternatives to SF_6

- Scope of research project was on F-gas based alternatives to SF_6
- Fluoronitrile (C4-FN), Fluoroketone, Hydrofluorolefines and new gases were investigated
- A gas mixture of 6% C4-FN / 94% CO_2 was chosen for the long-term test, as it was found to be of comparable electric strength as 20% SF_6 / 80% N_2 at the same pressure





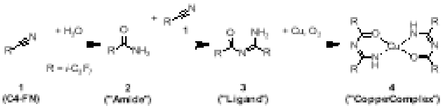
100% SF_6, at 0.6 MPa, with desiccant (SF_6 type)

6% C4-FN / 94% CO_2, at 0.6 MPa, GC2+GC5+GC6 with desiccant (3 A type)

6% C4-FN / 89% CO_2 / 5% O_2, at 0.6 MPa, with desiccant (3 A type)

Test type	Tests and ratings
Initial test	650 kV AC, 1 min 1050 kV SI, 15 Impulses 1425 kV LI, 15 Impulses
Long-term test (first part) 1873 hours	485 kV = 2 p.u. 4000 A = 1 p.u. in cycles (17 h heating / 7 h cooling)
Intermediate test	650 kV AC, 1 min 1050 kV SI, 15 Impulses 1425 kV LI, 15 Impulses
Long-term test (second part) 1287 hours	485 kV = 2 p.u. 4000 A = 1 p.u. in cycles (17 h heating / 7 h cooling)
Final test	650 kV AC, 1 min 1050 kV SI, 15 Impulses 1140 kV LI, 15 Impulses[1]
After test	Visual inspection, analysis of materials, documentation

[1] Limitation due to test system issues



Conclusions

- **No breakdown during this long-term test, temperatures according IEC, unchanged resistance of the loop, stable C4-FN (and O_2) content**
- **Minor decomposition products in the gas detectable only (some amide)**
- **But: Solid crystalline-shaped decomposition products (amide and ligand) found at several locations**
- **Amide type is classified as hazardous and toxic substance, so special care in handling was required**
- **Crystal formation based on chemical reaction of C4-FN with gas moisture, despite dry gas conditions with desiccant; favorable formation conditions due to outdoor installation**
- **Crystals move in an electric field, hard to detect due to low partial-discharge intensity**

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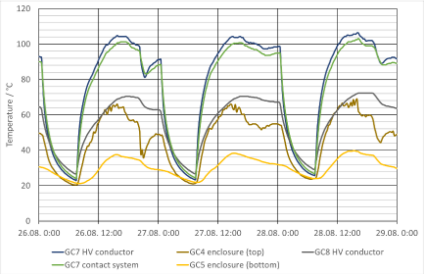
Electric performance

- AC voltage two times service voltage
- Long-term application for >3.000 hours
- Impulse voltage tests with rated voltages conducted
- Tests passed

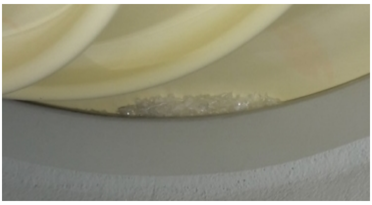
Thermal performance

- 24 hours cycles (17 h heating / 7 h cooling) with rated current
- Additional impact due to outdoor installation
- All temperature values remained within IEC limits



Observations after test

- After test, the test setup was opened for inspection
- At several locations two different types of crystal-shaped solid decomposition products were found



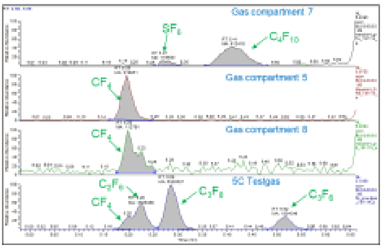
Gas quality analysis

- Gas quality checks during test
- Dry conditions in gas compartments (GC) with desiccant, slightly increased humidity in gas compartments w/o desiccant
- Stable conditions during test

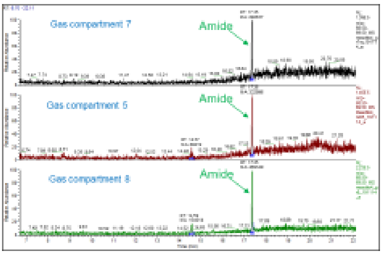
	C4-FN ratio (%vol) / frost point (humidity (calculated))		
	start of test	intermediate	end of test
GC2	6.1% / -60 °C (1 ppm_v)	6.2% / -49 °C (7 ppm_v)	6.1% / -52 °C (5 ppm_v)
GC4	5.7% / -28 °C (78 ppm_v)	5.8% / -23 °C (129 ppm_v)	5.6% / -30 °C (63 ppm_v)
GC8	5.7% / -60 °C (1 ppm_v)	5.8% / -48 °C (8 ppm_v)	5.7% / -56 °C (3 ppm_v)

GC2: C4-FN/CO_2, desiccant GC8: C4-FN/CO_2/O_2, desiccant
GC4: C4-FN/CO_2, w/o desiccant

- Small amounts (up to 100 ppm) of decomposition products were identified with GC/MS



Amide was found in all samples, with low amount (2 ppm), potentially due to vapor pressure conditions



- Further, FTIR was applied:
  - C4-FN content in line with online measurement
  - Minor amounts of decomposition products
  - C3F7H seems to be an indicator for amide

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Material compatibility

- Several materials stored in the long-term test setup
- Specific material properties were determined before and after the test
- No major material ageing found
- Small crystals observed on polymeric and copper samples

Physical and health properties of decomposition products

- Two different types of crystals: “amide” and “ligand”
- Sublimation of amide at approximately 20 °C under normal pressure
- Amide classified as acute toxic → safety measures recommended when handling test setups, also without arcs or partial discharges

- Sublimation of ligand at 135 °C up to >170 °C (stable under atmospheric conditions)
- Properties of ligand concerning health are unknown

Influencing factors on decomposition

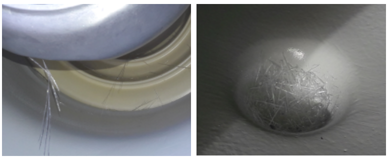
- Gas moisture, also in low ppm range
- Moisture ingress at a sealing potentially accelerated the amide formation
- Unequal temperature distribution (outdoor conditions)
- Desiccant position (in conjunction with temperature)
- Gas composition
- Presence of copper (purple dust)
- Potentially further material interaction

Tests on reproducibility

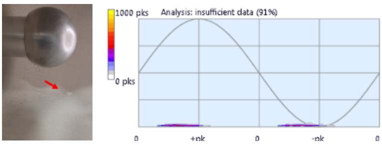
- Tests in a climatic test chamber, without high voltage but with current and temperature cycles
- The formation of small-sized crystals was observed, dependent on the specific conditions

Electric properties of crystals

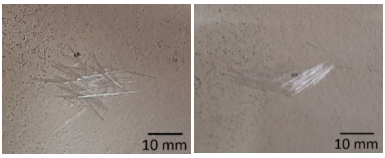
- Electric properties are essential for the integrity of gas-insulated systems in service
- Solid decomposition products reduce the C4-FN in the gas (not significant in our test)
- Long-extended crystals broke down into smaller pieces during AC high-voltage (HV) application



- Further AC voltage HV tests + UHF PD measurement, with ligand type only (due to sublimation of amide)
- 10-20 mm long crystals placed in a 245 kV GIS, filled with 6% C4-FN / 94% CO_2 at 0.6 MPa



- At approximately 300 kV some crystals started to move, and an orientation of the crystals was observed; no breakdown up to 400 kV



- PD were measurable at ≥400 kV only (stronger movement and orientation in the electric field)
- As a conclusion, the detection of crystals in the electric field and its movement with PD measurements requires a very high sensitivity of the PD system