C4/C5 Alternative Gas Handling

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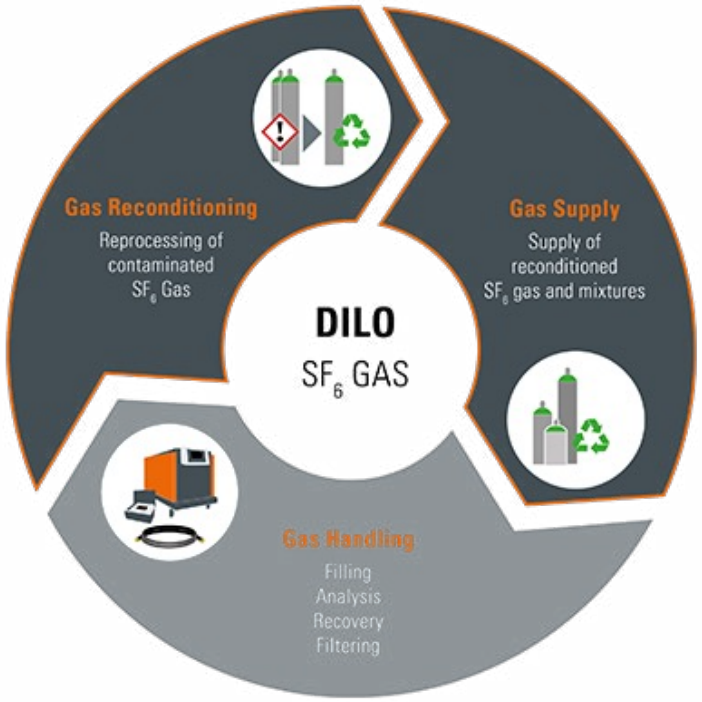
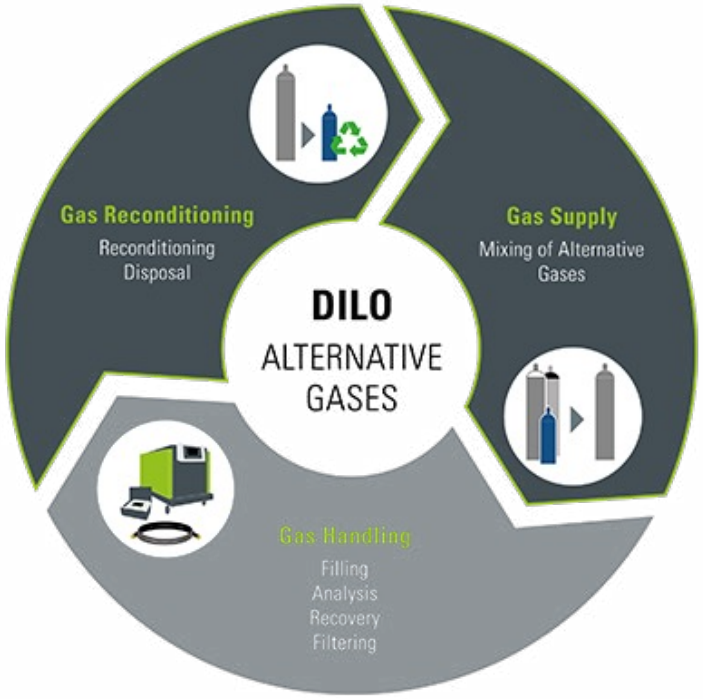
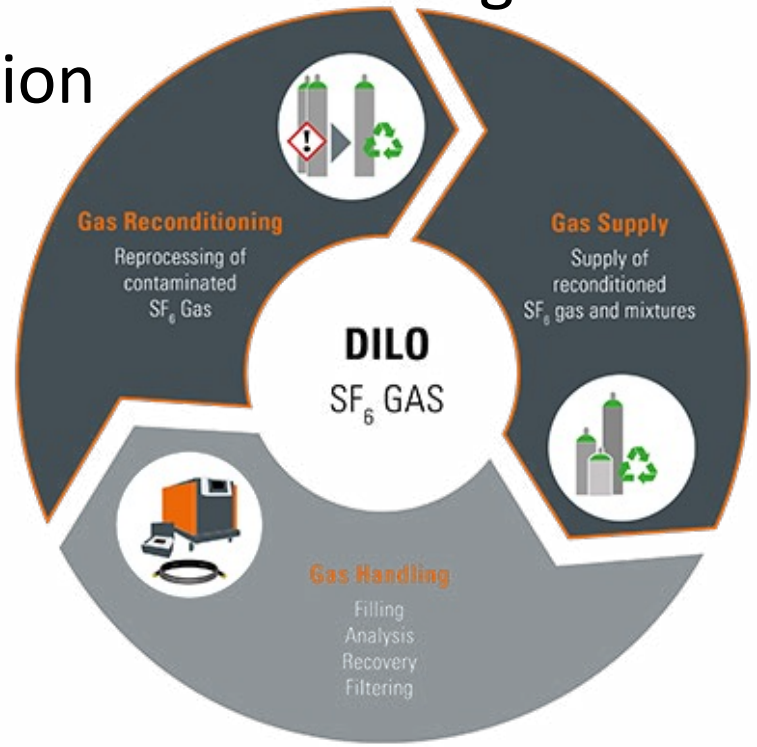




Learning Outcomes

- Identify the differences in handling liquid & vapor gases
- Explain the differences between SF_6 gas handling & C4/C5 Alternative gas handling
- Maintaining a homogenized mixture of gases
- Avoid Cross contamination



History

- DILO has over 70 years of experience providing high-pressure fitting solutions for industrial & specialty gases & liquid applications.
- Over 50 years of knowledge, experience, & expertise in engineering, production, & service of gas handling, field analysis, leak detection, & gas management for gas insulated equipment.

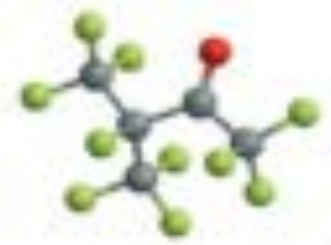
Equipment Overview

- G057 & B095/B093
- C4-3-039R-R502 Analyzer
- C4-3-033-R200 Leak Spy
- Miscellaneous fittings & hoses
- Cylinders of mixed C4/C5 alternative gases & SF_6

SF_6 vs. C4/C5 Alternative Gas Handling Systems

- SF_6

- C4 – Fluoronitrile
  - 3M™ **Novec**™ 4710
- C5 – Fluoroketone
  - 3M™ **Novec**™ 5110

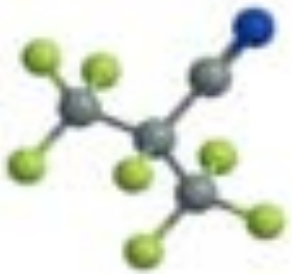


SF_6 vs. C4/C5 Alternative Gas Handling Systems

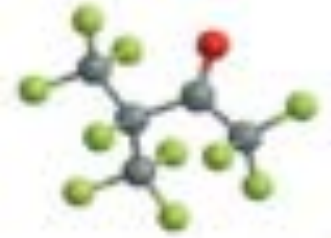
		Sulfur-hexafluoride	C4-Fluoronitrile	C5-Fluroketone
Base Gas	Chemical Formula	SF_6	$(CF_3)_2CFCN$	$(CF_3)_2CFC(O)CF_3$
	$CO2_e$(GWP)	23,500	2,210	1
	Boiling Point	-64°C	-5°C	+27°C
	Dielectric Strength	1.00	2.20	1.70
Gas Mixture	Background (gases)	Pure or with N_2 or CF_4	~90% CO_2	~90% O_2 With N_2 or CO_2
	$CO2_e$(GWP)	23,500	~380	<1
	Lowest Operating Temperature	-30°C *	-30°C	0°C to +5°C -20°C possible
Internal Arc Reaction	Decomposition Products	HF, S_xF_y, SOF_x, F_2, SO_x, CF_4	CO, HF, C_nF_{2n+2}, other Fluorinated Compounds	CO, HF, COF_2, C_xF_y, other Fluorinated Compounds
	Toxicity of Decomposition Products	Slightly toxic (Hodge-Sterner)	Practically non-toxic (Hodge-Sterner)	

- SF_6 – Sulfer Hexaflouride

- C4 – Fluoronitrile



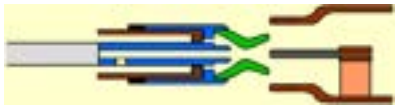
- C5 – Fluoroketone

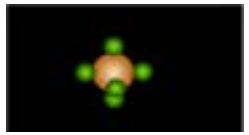


SF_6 vs. C4/C5 Alternative Gas Handling Systems

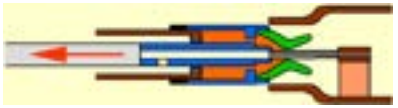
- SF_6 is nonreactive
- Breaks down under high heat & has excellent reassociation ability
  - If moisture is present, by-product will be formed – SO_2
  - SO_2 is acidic & corrosive, but can be filtered onsite – molecular sieve & aluminum oxide (Al2O3) filters
- Brass & Rubber are acceptable

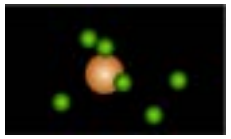
SF_6 vs. C4/C5 Alternative Gas Handling Systems



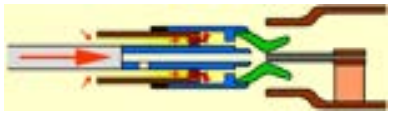


1 – Breaker Open

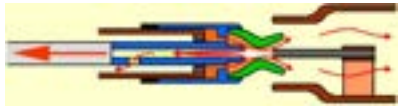


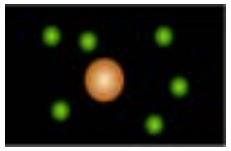


4 – Breaker Opening / Commutation

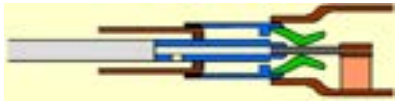


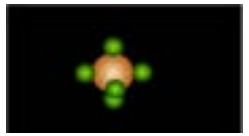
2 – Breaker closing



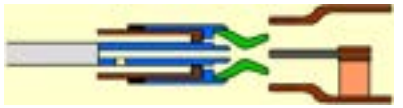


5 – Breaker Opening / Arc Quenching

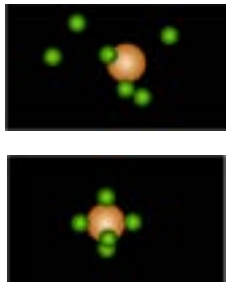




3 – Breaker closed



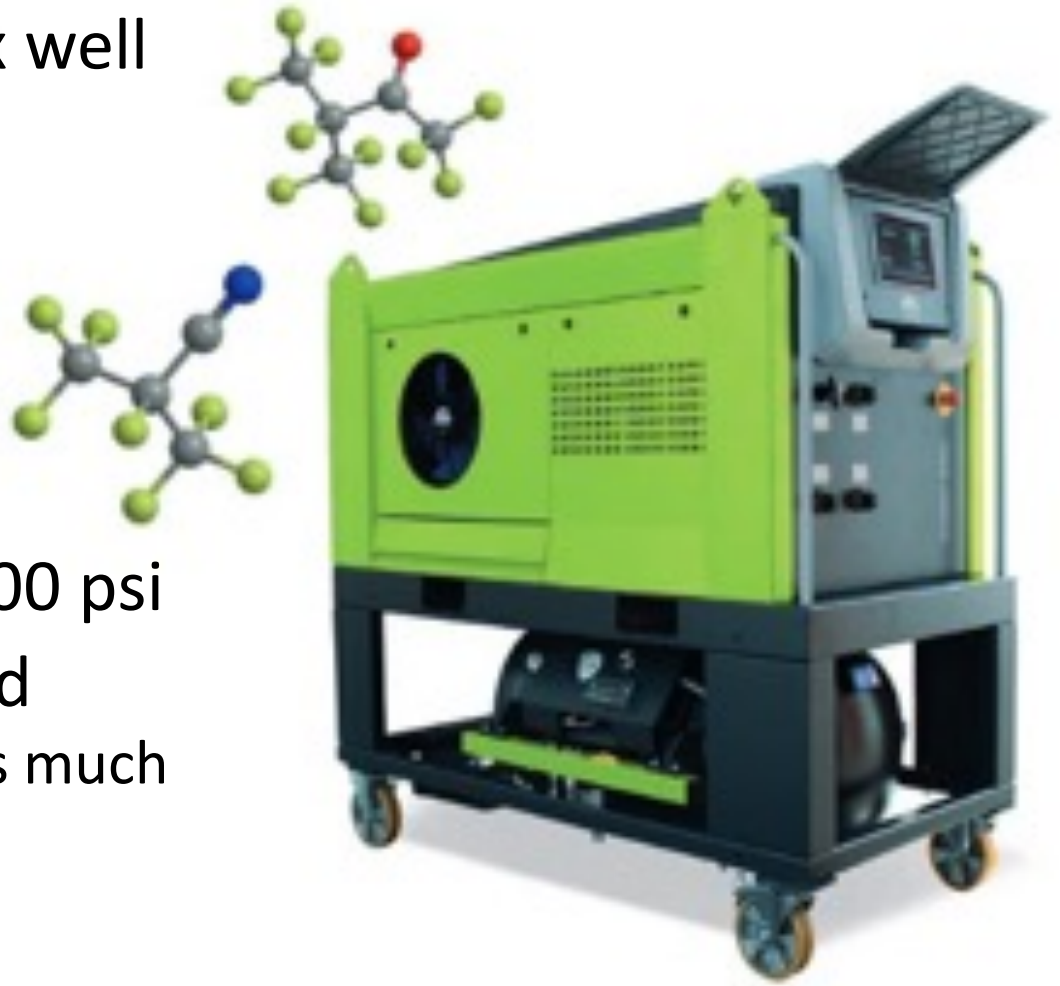
6 – Breaker Open



Basic process of SF6 gas operation in a circuit breaker

SF_6 vs. C4/C5 Alternative Gas Handling Systems

- C4 & C5 gases and moisture do not mix well
  - Create corrosive mixture if left in system
- Eliminated rubber seals
- No use of rubber hoses
- All internal stainless-steel fittings, connections, & tubing
- Much higher pressures – 100 bar – 1,500 psi
- Pressure & Temperature directly related
  - Cooling system capacity on C4/C5 systems much more advanced



SF_6 vs. C4/C5 Alternative Gas Handling Systems

- SF_6 – One system to do it all!
  - Filters contain Aluminum oxide & molecular sieve
- C4/C5
  - Economy-Series – Clean gas
  - Extraction unit – Recovery of bad gas
  - Filters contain only molecular sieve

Liquid vs. Vapor Gas Handling

- SF_6
  - Storage cylinders are filled with 100% SF_6
  - Liquified gas when full
  - GIE filled using either regulator & cylinder or recovery system
  - Some freezing will occur, but does not affect mixture
  - Heels remain in inventory for later use

Liquid vs. Vapor Gas Handling

- C4 & C5 Mixtures
  - Different ratios of the mixture & temperature/pressure will determine if gas is in liquid or vapor form
  - Gaseous = minimal amount of gas compressed into cylinder for transport. More Cylinders!
  - Liquid = maximum amount of gas compressed into liquid form for transport. Less Cylinders!

Liquid vs. Vapor Gas Handling

- C4 & C5 Mixtures in gaseous form
  - GIE can be filled onsite using regulator & hose; however, mixture must be gaseous form as a homogenized mixture from the supplier before fill.
  - Must account for the minimal volume of gas that can fit inside of a cylinder & remain in gaseous form.
  - Think about SF_6, what if we were to ship in gaseous form @ ~200 psi. Now a standard 100 lb. cylinder may only hold 5-10 lbs. of gas.

Liquid vs. Vapor Gas Handling

- C4 & C5 Mixtures in gaseous form
  - Due to minimal amount of gas available in a gaseous cylinder, recovery system is required to remove all gas from cylinder & transfer into GIE
  - Consider the number of partial cylinders (heels) in inventory if not completely emptied
  - Different ratios mean they cannot be reused on another breaker unless ratios are the same

Liquid vs. Vapor Gas Handling

- C4 & C5 Mixtures in liquid form
  - Like SF_6, this allows you to transport the most gas possible from point A to B in the least number of cylinders.
  - However, since this is a mixture of gases, that constitute different molecular structures, once compressed into a liquid, the gases separate.

Liquid vs. Vapor Gas Handling

- C4 & C5 Mixtures in liquid form
  - Filling must be conducted using a Recovery system
  - Before you can begin filling, the liquified gas must become a homogenized mixture

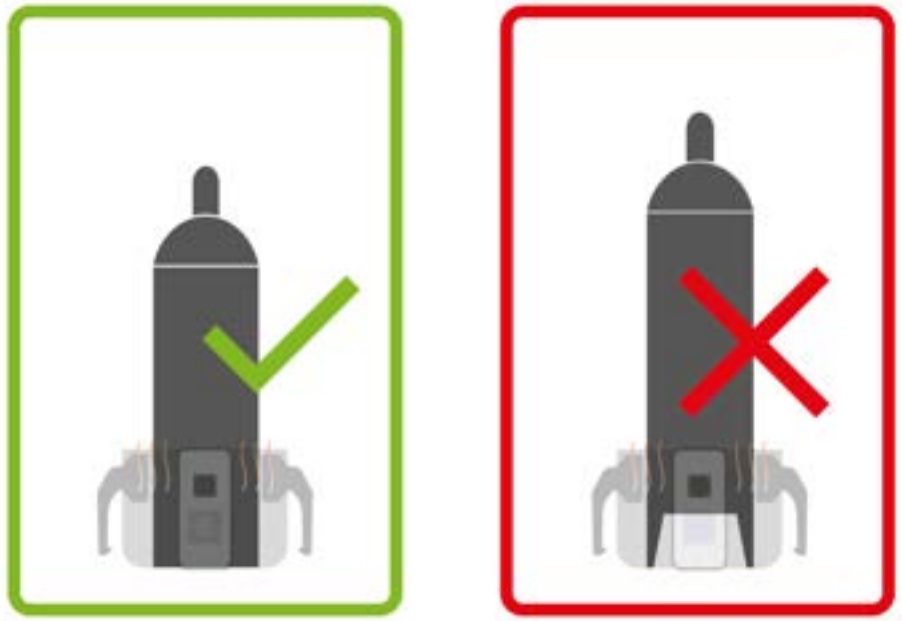
Homogenized Mixture

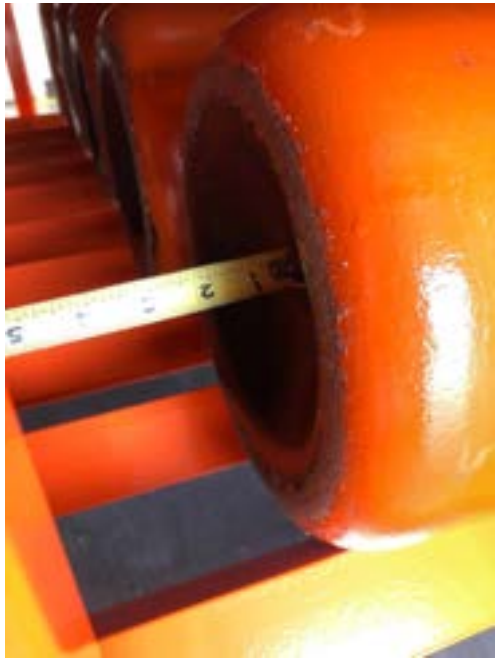
- To start the process of creating the homogeneous mixture, the liquid mixture must be heated up to 50°C. This is to prevent freezing of the liquified gas, like SF_6.

Importance of pre-heating on liquefied gas mixtures
Since single components of the mixture are partially liquefied inside the cylinder, the mixture must first be homogenized before filling the equipment.

Homogenized Mixture

- Special induction heater design
- Only to be used with flat bottom cylinders – Cannot be used on cylinders with concave bottom





Homogenized Mixture

- If the gas freezes & you cannot remove all the mixture from the cylinder, the ratio/mixture will be incorrect. This is mainly due to the fact the C4 – Fluoronitrile & C5 – Fluoroketone are the densest of the gases in their respective mixture.
  Thus, if the mixture is not completely emptied from the cylinder, the Fluoronitrile or the Fluoroketone will be what remains in the cylinder.
- Once gas mixture is heated & cylinder is completed emptied, it must be circulated in a buffer tank to become homogenized

Homogenized Mixture

- Only after this circulation takes place, can you start physically filling the GIE.

- Due to the available buffer tank capacity, filling is limited to one cylinder at a time. Each cylinder will need to go through this same process before moving onto the next.

Conclusion – Gaseous vs. Liquid

Gaseous storage

Advantages	Disadvantages
Certified gas	Relatively small quantities can be stored
Small gas compartments can be filled	Partial liquefaction possible when cooling down
No service cart necessary (only gas refilling device)	Mixing ratio cannot be changed on site

Partially liquefied storage

Advantages	Disadvantages
Large storage quantity	No direct withdrawal possible without service cart
Exact predefined gas mixture	Heating by service cart is time-consuming
Independent of outside temperature	Mixing ratio cannot be changed on site

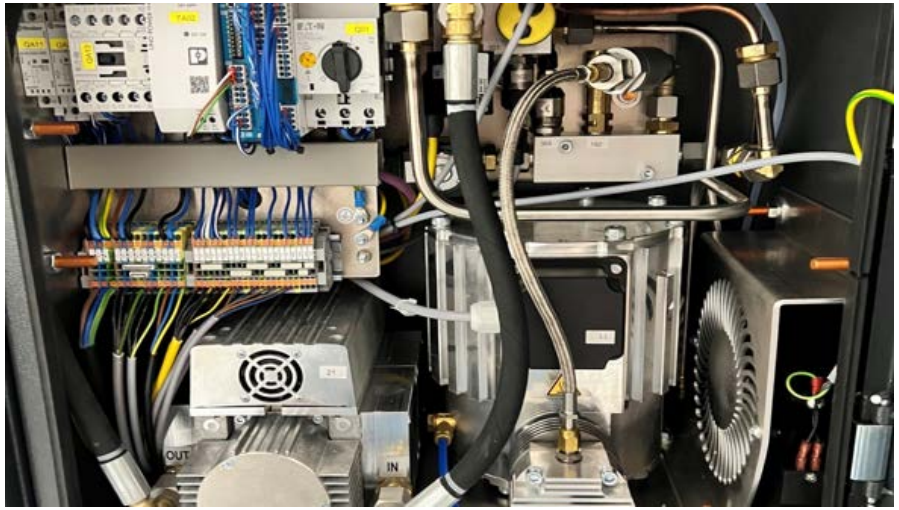
Homogenized Mixture

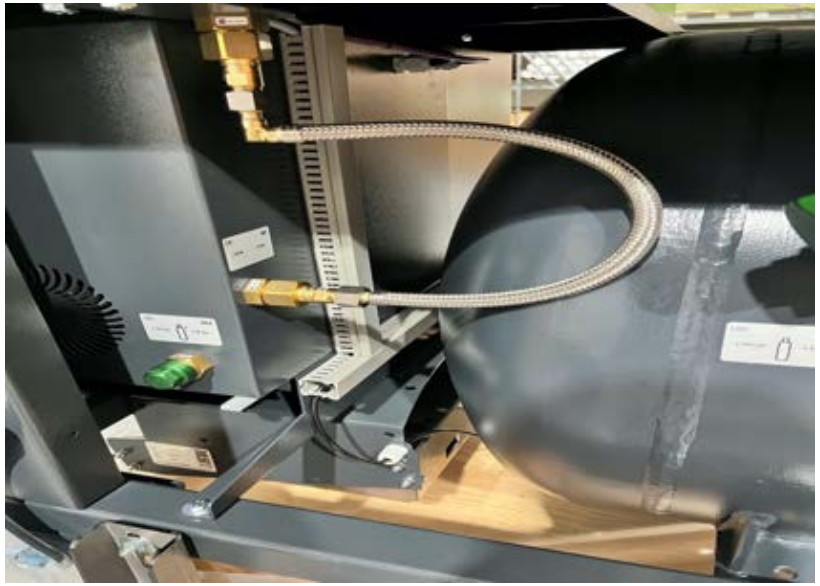
- Once the GIE has been filled to operating pressure, any remaining gas can be sent off site for disposal/destruction or reconditioning
- Service cart will need to be evacuated to prevent contaminating mixture on the next breaker with a different ratio

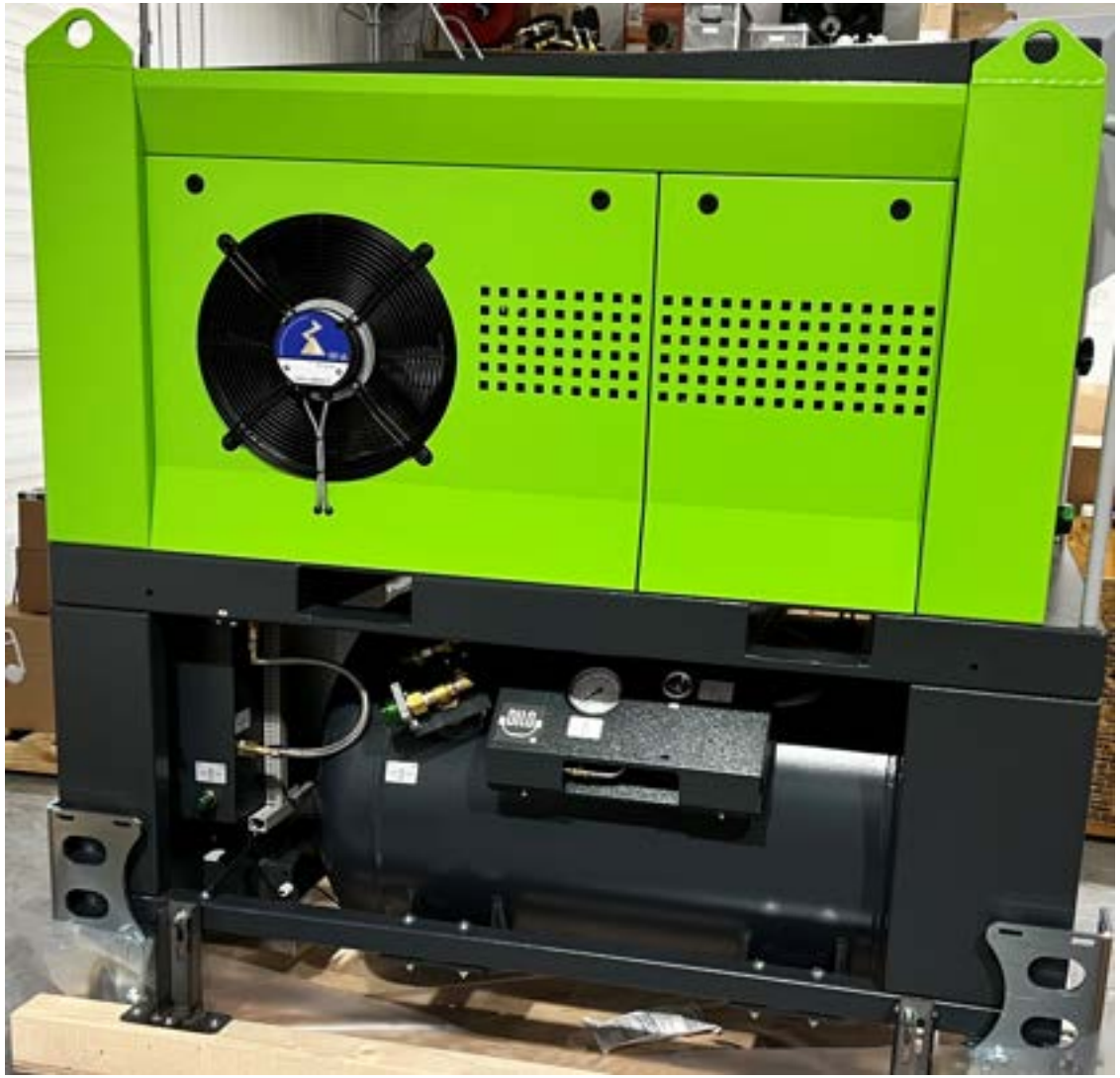
Homogenized Mixture

- Emptying Service Cart & Accessories to prevent contaminating mixtures
  - Automated functions to empty system similar to SF6
- Must carry external evacuated cylinders on hand to completely evacuate gas from lines after system empty
- External Recovery System
- Onboard mini compressor to remove remaining gas from left over lines

Homogenized Mixture

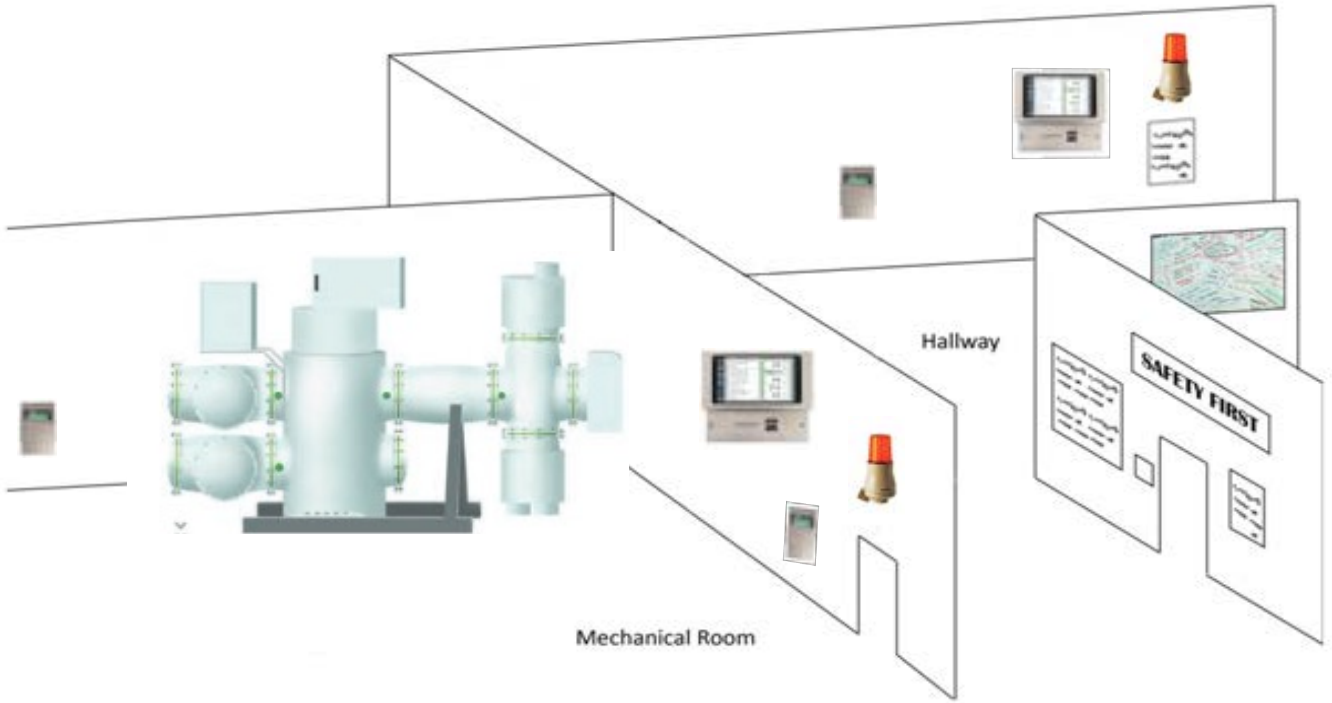






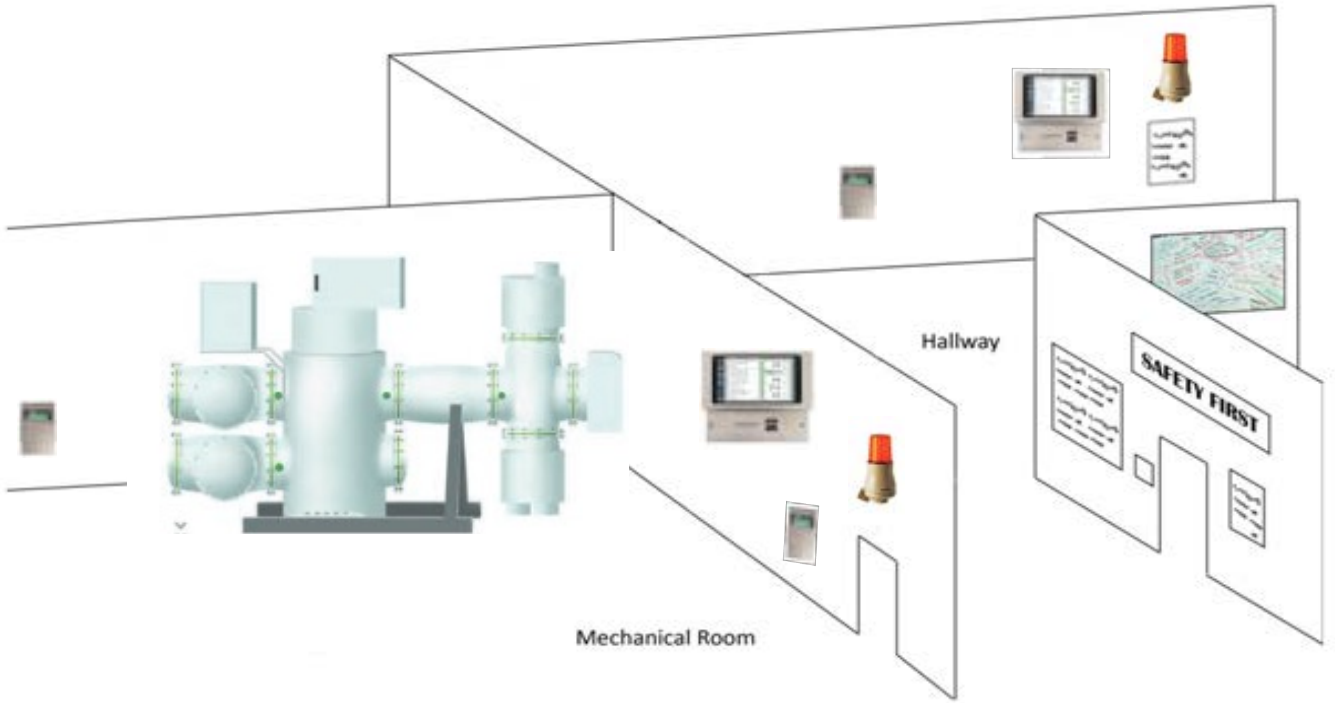
Leak Detection

- Zero Emissions!
- Prevent leaks to extend breaker lifetime & minimize faults
- Similar process to SF_6



Leak Detection

- Sensing technology virtually eliminates false alarms
- Low detection limit ability enables leaks to be found quickly to reduce gas loss & equipment failure – extend GIE lifetime
- No annual calibration required
  - Minor periodic maintenance
  - Filters & diagnostics to ensure proper operation



Leak Detection

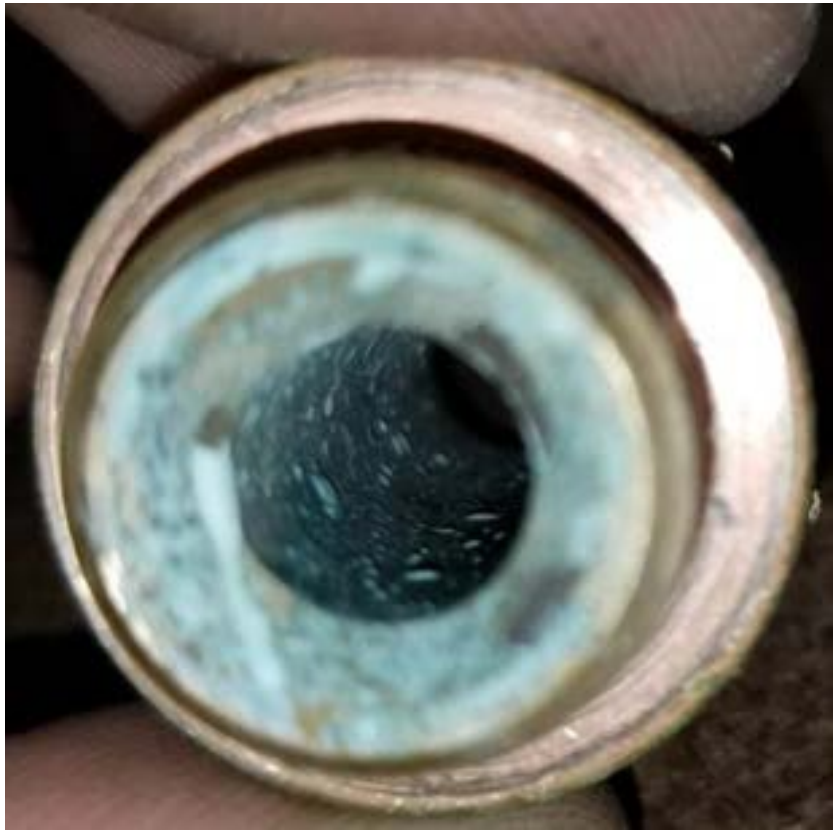
- What are we looking for??
  - SF_6
  - SO_2
  - C4 or C5
  - CO_2
  - O_2
  - CO

Cross Contamination

- Evacuating service cart after each use is a must.
  - With SF_6, this was not a requirement because the next breaker more often than not, utilized the same ratio – 100% SF_6.
  - With exception to mixed gas breakers – SF_6/N_2 or SF_6/CF_4.
- After evacuating Service cart, it is also recommended to flush the system with primary carrier gas – N2/CO2.
- SF_6 hoses & fittings cannot be utilized for C4 or C5 mixtures.
  - Different threads pattern to prevent this from happening in the field.
  - Green Line vs. Orange Line – Differences in fittings.

Cross Contamination

- Learning from Experience

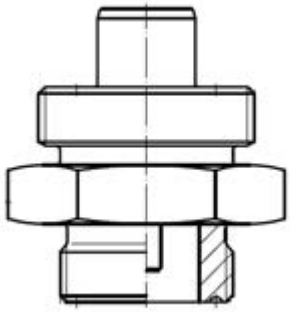


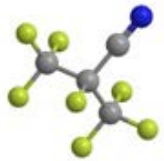
Cross Contamination

Emission-Free connections for SF_6-free gas solutions

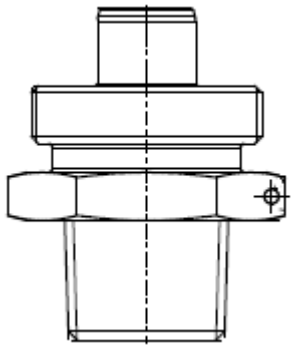
Thread sizes	DN20
SF_6	M45x2
Novec 4710 mixtures C4	M48x2
Novec 5110 mixtures C5	M43x2

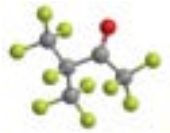
M45X2



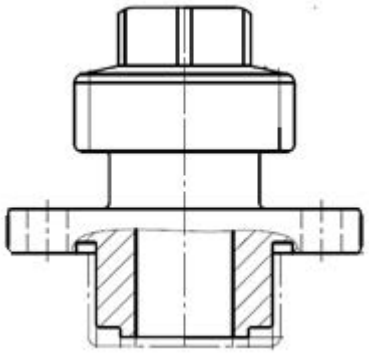


M48X2





M43X2



Cross Contamination

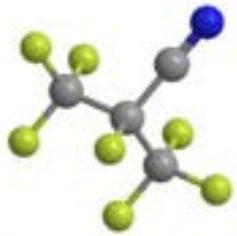
Emission-Free connections for SF_6-free gas solutions

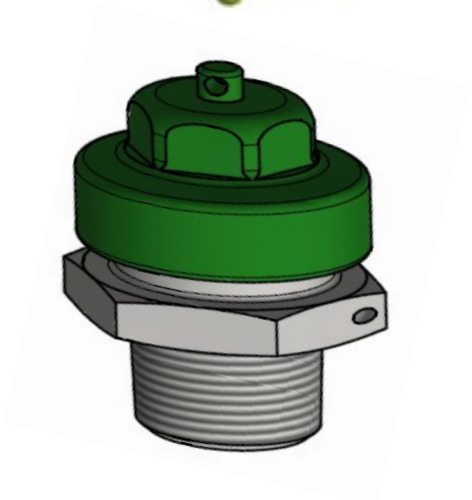
ORANGE Line

SF6

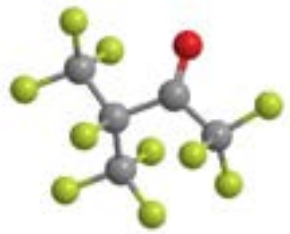
GREEN Line

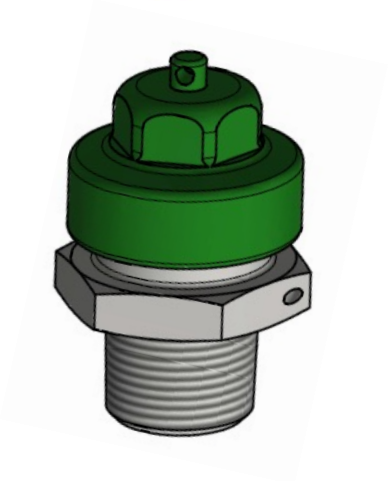
C4





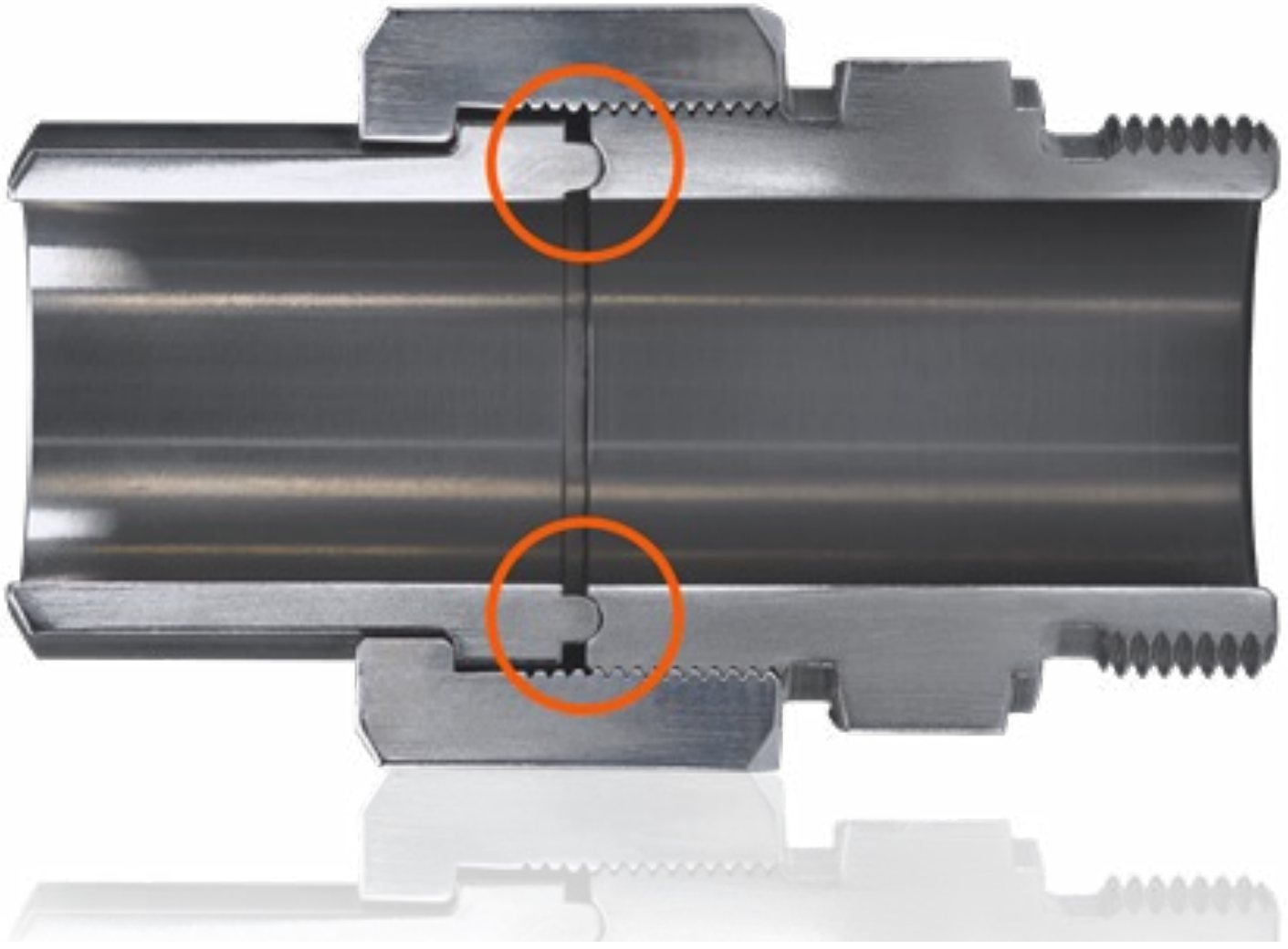
C5





Material Compatibility

- By-Products of C4 & C5 mixtures are still virtually unknown with various possibilities.
  - There is still very much R&D that is taking place.
- What we do know is the C4 & C5 mixture or the main component of the mixture may affect different rubbers & plastics in various ways.
  - For this reason, DILO's metal-to-metal tongue & groove connection is an ideal solution.



Material Compatibility

- The same goes for GIE.
- Much like service cart require a different design with high pressures & material compatibility considerations, the same goes for GIE.
- Breakers will require a new design to accommodate the requirements for SF6 alternatives – C4 & C5 gas Mixtures
- 3M™ **Novec**™ 4710 & 5110

Testing

- Analysis is extremely important!!
  - OSHA – Flammability of O2 is around 22%
- Filling & Maintaining 3M™ **Novec**™ 4710 & 5110 equipment is a bit more involved.
- With extra steps comes more opportunity for human error.
- Most users are experimenting with 5-15% of 3M™ **Novec**™ 4710 & 5110.
  - If just the slightest amount of gas freezes & doesn't get removed from the cylinder, this will greatly impact your ratio & in turn the dielectric strength of your gas.
- No way of checking liquified mixture until it is homogenized.

Testing – Sensor Capabilities

- C4 Insulating Gas Mixture
  - 3M™ **Novec™ 4710** Insulating Gas – 0-10% (0-30% for R502 version)
  - Moisture - +20°C to -60°C
  - Oxygen (O_2) – 0-25%
  - Carbon Dioxide (CO2) – 0-100%
  - Carbon Monoxide (CO) – 0-500ppm
- C5 Insulating Gas Mixture
  - 3M™ **Novec™ 5110** Insulating Gas NOVEC – 0-15%
  - Moisture - +20°C to -60°C
  - Oxygen (O2) – 0-25%
  - Carbon Dioxide (CO2) – 0-100%
  - Carbon Monoxide (CO) – 0-500ppm

Testing

- What to do with bad gas
  - High Moisture
    - Onsite filtration??
    - Similar to SF_6, there are desiccant filters to remove moisture. However, you would need to be very cautious with this process as to not alter the gas mixture/ratio.
    - Cannot recover gas into a single cylinder with high pressure & potentially liquify mixture.
  - If ratio is incorrect, 5%/95% 3M™ **Novec**™ 4710 /CO2
    - Not removing all liquid gas from cylinder before putting into buffer tank
    - Results in low C4/C5% = Low dielectric strength
    - Gas must be sent offsite for disposal/reconditioning

Thank you!

Questions??

Hands-On Portion

- Recover gas from GIE using recovery system – C4-B095R12 Mini-Series Recovery System
- Fill GIE using regulator – C4-3-393-R004 Filling Device
- Investigate leaks using Leak Detector – 3-033-R400 Leak Spy