

# Material compatibility of Dynamitron equipments with Novec 4710

## **Experimental setup**

The listed materials have been loaded in specific vessels under the following conditions:

- Novec 4710 pure gas
- Pressure: 2.4 bar
- Temperature: 50 °C
- Duration: 2000h (84 days), with intermediate gas sampling after 500h and 1000h.



Cylindric vessels made with Aluminium specifically designed and used for the compatibility tests

It should be noted that the temperature of one of the heat chambers increased accidentally to almost 100°C during 48 hours because of an electrical supply issue. Six high pressure vessels are concerned by the temperature rise. The concerned items (vessels) are indicated with an asterisk in the table.

Indeed, the interpretation of the results hereby takes this incident into account and the influence of temperature is underlined when necessary.

## **Tests and analyses**

The following measurements have been performed on the materials and parts initially (or on specimen samples) and finally, after immersion and aging in the vessels under Novec 4710.

- Gas Chromatography coupled with Mass Spectrometer GC-MS
- Tensile Tests
- Differential Scanning Calorimetry
- Resistivity Measurements
- Contact Resistance Measurements

- Electrical insulation of cables rubber sheath
- Resistance Measurement of Resistor
- Mechanical Withstand of adhesives
- Hardness measurement
- Verification of pressure diaphragm actuator

### **Overview of compatibility tests results on materials and parts in Novec 4710 and SF<sub>6</sub>**

Items	RAW MATERIALS	Observations (after 2000 hours compatibility tests)	
		Novec 4710	SF <sub>6</sub>
82	Stainless Steel Type 304	Compatible	Compatible
83	Brass (30%Zn)	Compatible	Compatible
84	Copper	Compatible	Reddish surface color
85	Bronze [Cu88Sn12 (UE12)]	Compatible	Compatible
89	Acrylic Plexiglas® G = Lucite® (Perspex®) = PMMA	Compatible	Compatible
90	Delrin®	Compatible	Compatible
91	Polyamide - Nylon (PA6.6)	Compatible	Compatible
92	Polycarbonate =LEXAN®	Compatible	Compatible
	<b>ADHESIVES, GLUES AND GREASES</b>		
2	Adhesive Sealant Threadlocker	Tightening torque F=10.7 N <b>Compatible</b>	Tightening torque F=10.9 N <b>Compatible</b>
3*	Adhesive, Epoxy, Two Part	<b>Compatible</b>	Not tested
4*	Adhesive, Silicone, RTV, White	<b>Compatible</b>	Not tested
26*	High Vacuum Grease 5.3 Oz Tubes	No weight loss No major degradation <i>Spreads because of T=100°C</i> <b>Compatible</b>	No weight loss No major degradation <b>Compatible</b>
13*	Compound Sealant Rtv Wht W/Catalyst S	Assembly is loose after test (do not withstand T=100°C) <i>Should be repeated and compared to SF<sub>6</sub></i>	Not tested
	<b>WIRES</b>		
76*	Wire 600vac Yel/Grn 16 Awg Ce	Resistivity of rubber sheath decreased by 10 times	Slight change of rubber sheath color <b>Compatible</b>

Items	RAW MATERIALS	Observations (after 2000 hours compatibility tests)	
		Novec 4710	SF <sub>6</sub>
		Compatibility to be confirmed or alternative material to be used	
77*	Wire Litz Hi Temp 4 Strand 5 X 5 C 26/40	Compatible	Compatible
78*	Wire, Shielded, 14 Awg	Resistivity of rubber sheath decreased by 20 times Compatibility to be confirmed or alternative material to be used	Compatible
79*	Wire, UL1007, 20 Awg, 300v, Grn	Resistivity of rubber sheath decreased by 10 times Compatibility to be confirmed or alternative material to be used	Compatible
	WRAPS AND TUBINGS		
11*	Clamp Cable 3/8 Dia	No change of thermochemical behavior Compatible	Slight yellowing No change of thermochemical behavior Compatible
72*	Tubing Shrink 1/2 Id X .02 Clr	Shrinking (due to T=100°C) Compatible	Slight shrinking Compatible
80*	Wrap Spiral 3/8 Id X 1/2 Od Poly.Natural	Slight yellowing Compatible	Slight yellowing Compatible
81*	Wrap, Spiral, Polyethylene, 1/4" O.D.	Slight yellowing Compatible	Slight yellowing Compatible
59*	Sleeving Plastic Size 10		
	VALVES		
73*	Valve Ball 1 In Npt Bronze	Functionality OK Compatible	Functionality OK Compatible
74	Valve, Relief 1"Npt Viton Seat Ce 100psig	Compatible	Compatible
	MECHANICAL PARTS		
7*	Bearing, Rubber Mounted Pillow Block, For 1" Dia. Shaft	Qualitative test OK Compatible	Slight bright appearance. Partial loss of plasticizer. Qualitative test OK Compatible

Items	RAW MATERIALS	Observations (after 2000 hours compatibility tests)	
		Novec 4710	SF <sub>6</sub>
17*	Coupling, Flexible, 1" X 7/8"	Slightly shiny appearance (Partial loss of plasticizer?) Brown spots on metallic part Flexibility (OK)  <b>Compatible</b>	Slightly shiny appearance (Partial loss of plasticizer?) Brown spots on metallic part (less than Novec 4710) Flexibility (OK)  <b>Compatible</b>
23*	Gasket, 2" Asa X 1/8"	<b>Compatible</b>	<b>Compatible</b>
25*	Grommet Rubber 9/16 Id	shiny appearance (Partial loss of plasticizer?) Density increase 0.2% (<5%) Qualitative flexibility OK <b>Compatible</b>	Density decrease 1.4% (<5%) Qualitative flexibility OK <b>Compatible</b>
34*	O-Ring, Buna N, .312 Dia., 78-3/4" I.D., O.A.L. 248.381"	Density increase 0.03% (<5%) Hardness decrease 3.9% (<5%) Qualitative flexibility OK <b>Compatible</b>	Density increase 0.03% (<5%) Hardness increase 2.9% (<5%) Qualitative flexibility OK <b>Compatible</b>
62*	SPACER RING, GLASS, 203mm (8") BEAM TUBE	<b>Compatible</b>	<b>Compatible</b>
	<b>ELECTRICAL PARTS AND ACTUATORS</b>		
9*	Choke	<b>Compatible</b>	<b>Compatible</b>
10*	Choke Rf	<b>Compatible</b>	Not tested
24*	Generator 115v/1ph 400cyc 3428 Rpm	Slight whitening of external surface of the generator. No change of the other motor and generator parts. <b>Compatible</b>	Not tested
35*	Overload Thermal-3 Amp Trip		
42*	Resistor 10 Megohm 2w Comp +/- 5%	<b>Compatible</b>	<b>Compatible</b>
63*	Spark Plug, Screw Off Top Style	Slight yellowing of metallic part <b>Spark voltage to be tested to confirm compatibility</b>	<b>Compatible</b>
68*	Switch, Pressure, Diaphragm Actuator, 30-300 Psi	Behaves as expected <b>Compatible</b>	Slight shift with original calibration. TBC** <b>Compatible</b>
69*	Term Bd 30 Amp 3 Terminal	<b>Compatible</b>	<b>Compatible</b>
67*	Switch, Interlock, Door, Thermoplastic Actuator	Functionality OK <b>Compatible</b>	Functionality OK <b>Compatible</b>

*\*Materials and parts that have seen the temperature rise to 100°C for 48 hours*

*\*\*To be confirmed*

### **Gas quality and by-products analysis by chromatography and mass spectrometer**

Gas analysis have been performed initially before the compatibility test and after 500 hours and 2000 hours (end of the compatibility test). The gas purity is above the criteria for Novec 4710 purity ( $\geq 99.5\%$ ) for all the gas samples after 500 hours compatibility tests. After 2000 hours, 5 vessels have their gas purity slightly lower than the criteria yet still higher than 99%. Therefore the impact on the dielectric characteristics is not significant. The main assumption to be considered is the following: the fact that the temperature has risen up to 100°C for some vessels for 48 hours could have contributed to the partial degradation of the gas. The vessel with pure Novec has also seen the temperature rise to 100°C and has shown a decrease of the purity by 0.3%. Therefore, the high temperature emphasized the degradation of the gas.

Besides the linear  $\text{CF}_3\text{-(CF}_2)_2\text{-CN}$  by-product (originally available in pure Novec 4710), the main by-products are:

- $\text{CF}_3\text{-CN}$  typical Novec 4710 by-product: stable traces ( $< 6$  ppm) over the different vessels and over time.
- $\text{CF}_3\text{-(CF}_2)_2\text{-CO-NH}_2$  (amide by-product) ( $< 400$  ppmv) the result of a partial hydrolysis of Novec 4710 in presence of humidity. It is independent of the surrounding material.
- Other by-products ( $\leq 0.1\%$ ) such as  $(\text{N}=\text{C}(\text{CF}_3\text{-CF}_2\text{-F}))_3$  result of the polymerization reaction of Novec 4710 molecules as a further hydrolysis step in presence of humidity.

Regarding the by-products toxicity, considering the very low amounts of by-products, the ATE (Acute Toxicity Estimate) is very close to 12000 which is the ATE of pure Novec 4710. Based on the acute toxicity hazard categories of gases by inhalation, all the mixtures before and after tests, belong to the toxicity class 4 ( $2500 \leq \text{ATE} \leq 20\,000$ ) which is the lowest toxicity category.

### **Conclusions**

The compatibility test campaign in Novec 4710 and  $\text{SF}_6$  at 50°C involving parts and materials used in Dynamitron® shows that besides slight changes in copper surface or some polymers, the materials are compatible to Novec 4710. Tests do not show major degradation of the materials properties.

However, item 13 Sealant RTV lost the mechanical withstand probably due to polymerization. It may be tested again in Novec 4710 at 50°C to rule out the hypothesis that  $T=100^\circ\text{C}$  might affect the sealant electrical withstand. Furthermore, the electrical wires (items 76, 78 and 79) show lower resistivity of rubber sheath. If needed, wires compatibility tests will be carried-out again at 50°C. Polymer (item 17) shows slight loss of plasticizers after compatibility tests in Novec 4710 (and in  $\text{SF}_6$  at a lower scale). Item 42 resistor 10 M $\Omega$  shows also a decrease of the

resistance by 1%. The impact on the resistance should be checked by IBA. Delrin material (item 90) shows a slight decrease of surface and volume resistivity by a factor  $< 4$ ).

Besides, there is no major change in electrical properties of conducting or insulating materials after compatibility tests. Hardness and density measurements on materials do not show major change due to compatibility tests in gas.

Regarding gas quality, there is no major degradation of the gas due to temperature or due to the material and parts. Few by-products are formed during compatibility tests. Besides  $\text{CF}_3\text{-(CF}_2)_2\text{-CN}$  originally available in pure Novec 4710, by-products did not exceed 0.5%. Novec 4710 purity is equal or higher than 99.5% unless in few vessels that have undergone  $T=100^\circ\text{C}$  for 48 hours. The toxicity of all the gas samples after tests are classified in ATE category 4 and the partial degradation of Novec 4710 do not increase the acute toxicity estimation of the gas.