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Project: Use of Novec 649 in the ATLAS Thermosiphon cooling system

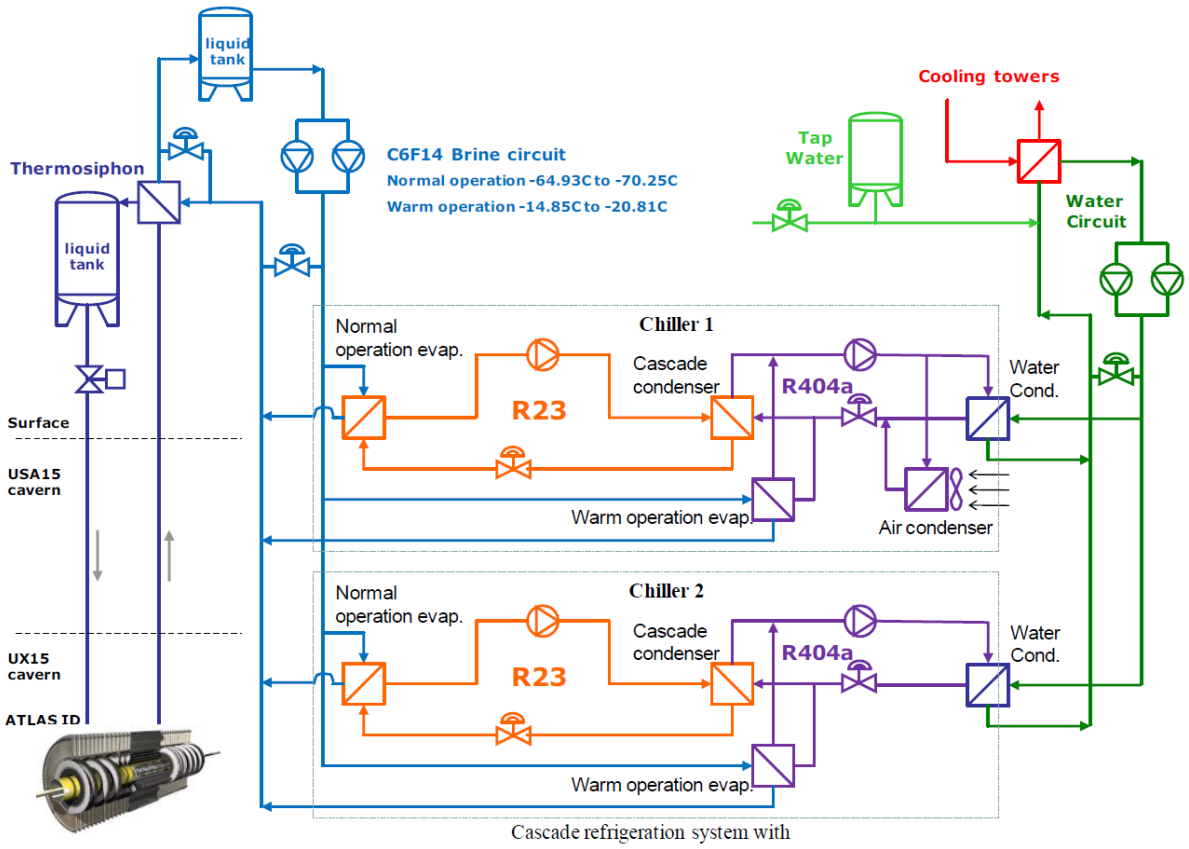
Abstract

Novec 649 is a fluid with thermo-physical properties similar to C_6F_{14} and very low global warming potential. This memo presents information about the potential use of Novec 649 instead of C_6F_{14} in ATLAS detector cooling applications like TRT cooling, cable cooling and Thermosiphon.

1. *ATLAS cooling overview*

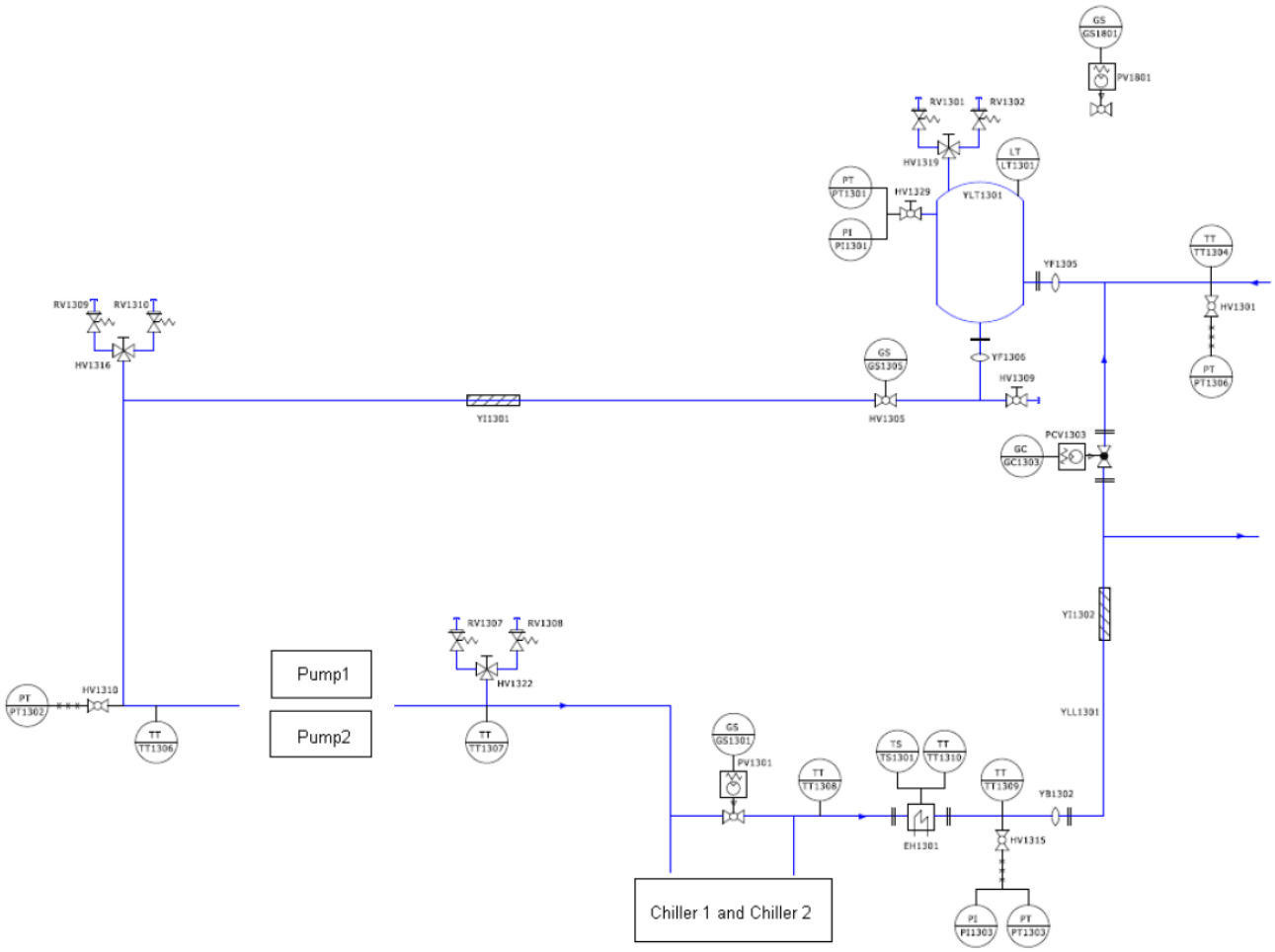
In the current cooling system of ATLAS, C_6F_{14} (Brine) is used in a closed loop in order to cool down the condenser of the Thermosiphon Circuit. It is composed of set of two redundant pumps which circulate C_6F_{14} between Chiller units and Thermosiphon condenser with automatic swap procedure based on priority level. The C_6F_{14} liquid is stored in the tank placed in the roof of SH1 building. The tank liquid level monitoring provides basic leak detection.

***Figure 1**: ATLAS Thermosiphon Circuit simplified P&ID*



Cascade refrigeration system with
R23 as low temperature refrigerant and
R404a as high temperature refrigerant

***Figure 2**: Brine Circuit simplified P&ID*



C_6F_{14} parameters in the current system

- Mass flow 39.8 kg/s
- Volumetric flow 0.0238 m^3/s
- Maximum C_6F_{14} velocity inside the pipes 2m/s
- Cooling Power during nominal operation 180 kW
- Pipe DN125
- Turbulent flow

	Supply	Return
Temperature (°C)	-70.5	-64.5
Density (kg/m^3)	1924	1909
Viscosity (kg/m-s)	$5.79E^{-3}$	$4.63E^{-3}$
C_p (kJ/kg -°C)	0.905	0.983

2. Novec 649 overview

An essential requirement of the fluids used in irradiated environments is the low content of hydrogen. When hydrogen is irradiated, it forms the hydrofluoric acid that might be a cause of corrosion [1]. Fluorocetones have low hydrogen and there is one* commercial fluid available, Novec 649, manufactured by 3M. As shown in Table 1, the thermo-physical properties of Novec 649 and C_6F_{14} are quite similar. As shown in Figure 3, below -10 °C, Novec 649 has a bit better characteristics as a coolant, lower viscosity, higher and more stable specific heat, higher thermal conductivity. This means that with Novec 649 one can expect lower temperature drops along and across the cooling pipe and the turbulent flow will be achieved in smaller fluid velocities than with C_6F_{14}.

<u>Estimation of Thermodynamic potential for Novec 649</u>

According to the following preliminary calculations, Novec 649 seems capable to operate with the current design parameters. Therefore from a thermodynamic point of view it is interchangeable with $C_6F_{14,}$ however other aspects have to be investigated further, such as radiation harness, material compatibility etc.

$Cp_{Novec649}=1091+0.3419*T+0.0039*T^2$

$Cp_{Novec649}$ (-70.5) = 1,137 kJ/kg-C

$Cp_{Novec649}$ (-64.5) = 1.129 kJ/kg-C

For a rough estimation of the heat that Novec 649 needs to remove from the Thermosiphon condenser, the average Cp is used: Cp= (1.137+1.129)/2= 1.113 kJ/kg-C, therefore

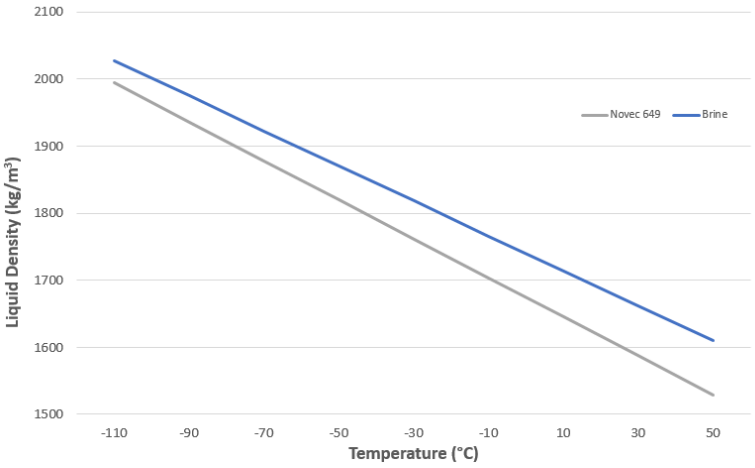
$Q_{Novec649}= m*C_p* dT =39.8*1.133*5=225$ kW during normal operation.

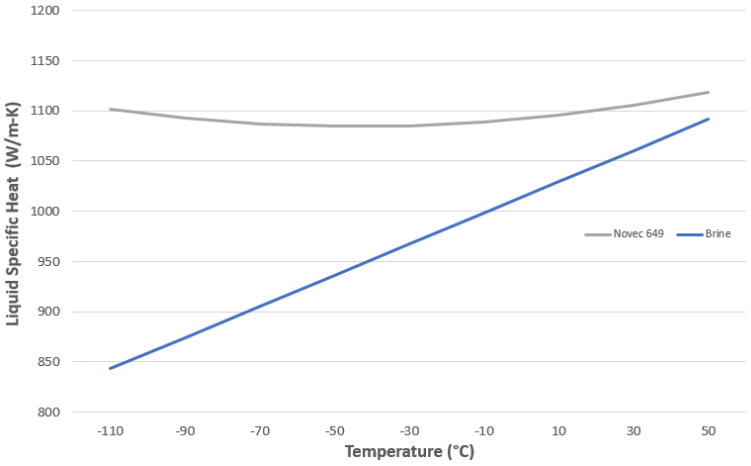
*It is under investigation to find additional producers of this fluid.

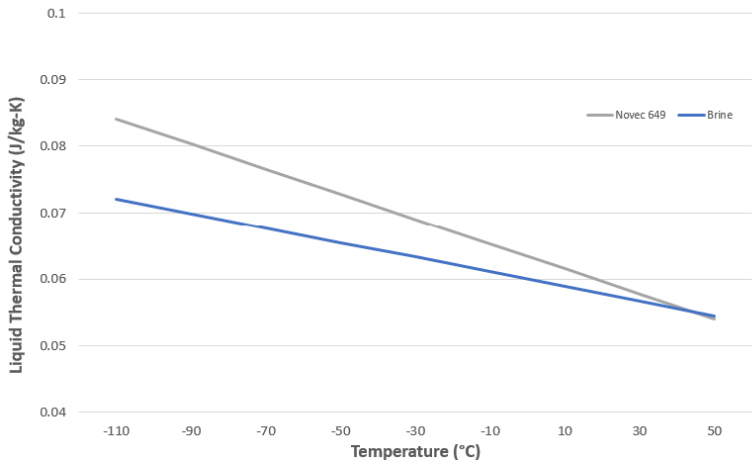
***Table 1**: Physical properties of Novec 649 and C_6F_{14}. All values determined at 25°C unless specified*

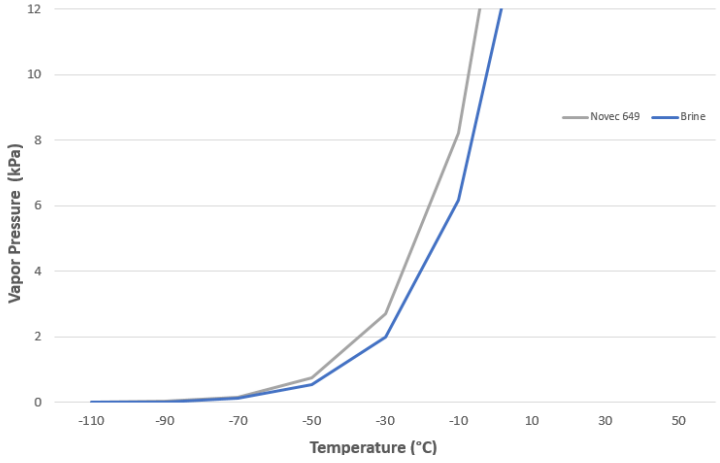
	Novec 649	Brine C_6F_{14}
Chemical formula	C2F5C(O)CF(CF3)2	C_6F_{14}
Fluid type	fluoroketone	perfluorocarbon
Boiling Point (°C) @ 1 atm	49	56
Pour Point (°C)	-108	-90
Molecular Weight g/mol	316	338
Critical Temperature	169	178
Critical Pressure MPa	1.87	1.83
Vapor Pressure kPA	40	30.9
Heat of Vaporization kJ/kg	88	88
Liquid density kg/m^3	1600	1680
Coefficient of Expansion K^{-1}	0.0018	0.0016 °C
Kinematic Viscosity (cP)	0.40	0.38
Absolute Viscosity (cP)	0.64	0.64
Thermal Conductivity (W/m-°C)	0.059	0.057
Surface Tension (mN/m)	10.8	12
Solubility of Water in Fluid (ppm by wt)	20	<12
Global Warming Potential (GWP)	1	9300
Resistivity (Gohm-cm)	10.000	1.000.000
Liquid density (kg/m^3)	1674.4 - 2.904T(°C)	1740 – 2.61 T(°C)
Liquid Thermal Conductivity (Wm-K)	0.063403 - 0.000188 T(°C)	0.060 – 0.00011*T (°C)
Liquid Specific Heat J/kg-K)	1091.9 + 0.3419 T(°C) + $0.0039T^2$	1014 + 1.554*T (°C)
Vapor Pressure (Pa)	ln(P)=22.492-3545.3/T(K)	$\log_{10}$(P)=9.729 – 1562/T(K)

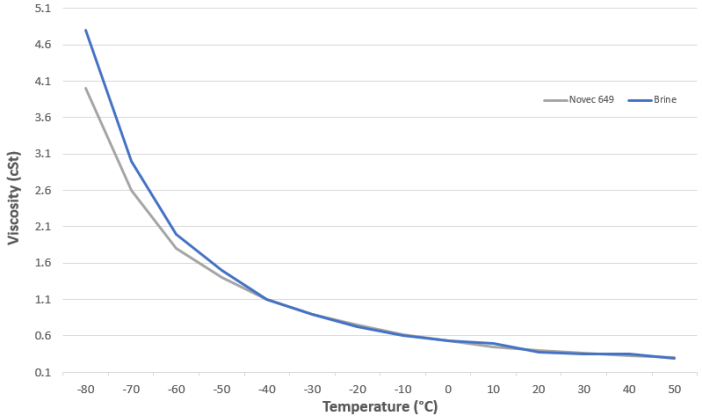
***Figure 3**: A comparison of some thermos-physical properties of C_6F_{14} and Novec 649*











3. *Draft testing plan*

A first brainstorming meeting was organized on 17.02.2015 between Lukasz Zwalinski, Paola Tropea, Olivier Crespo, Claudio Bortolin, Petr Gorbounov and Dina Giakoumi in order to discuss the possibility to replace C_6F_{14} with Novec 649. LHCb has already started studying this issue under a specific work package (WP-C6K-2015) and ATLAS cooling team's perspective is to collaborate in order to have a more efficient research. We have decided to meet every two weeks for knowledge sharing and brainstorming. An initial proposal for topics to be investigated by ATLAS Cooling team with EN/CV and by LHCb is listed below.

ATLAS cooling team with EN/CV

- Identify the dose and neutron flux in the areas to be cooled
- Endurance tests for the refrigerator equipment
- ATLAS cooling proposed the design and construction of a test bench in order to perform endurance tests of the equipment, under the flow of irradiated and non-irradiated fluid. The components of this test (pumps etc) will be identical to the existing in the refrigerator but in scale.
- Investigate the compatibility of Novec 649 with the existing equipment materials. All materials used in ATLAS C_6F_{14} circuit (alloys, polymers, filters) will be exposed to Novec 649. It is proposed to create a list of all the materials used in all LHC systems that circulate C_6F_{14} in order to conduct wider research.
- Identify the radiation products of Novec 649 and how they affect the exposed materials.

LHCb under WP-C6K-2015 ''Alternatives to liquid fluorocarbons for detector cooling applications at CERN''

- Validation of Novec 649 in various temperature conditions and radiation environments.
- Study the hydrolysis properties of Novec
- Investigate how to remove the radiolysis products from the system
- Investigate the reaction between Novec 649 and C_6F_{14}
  In the case where C_6F_{14} is not completely removed from the system before filled with Novec 649, we need to know the reaction between the two fluids

4. References

[1] ''Project: 3M Novec 649 as a replacement of C_6F_{14} in liquid cooling systems'', Version 1.3, P.Gorbounov https://twiki.cern.ch/twiki/pub/LHCb/C6K/EDMS_work_package.pdf

[2] https://twiki.cern.ch/twiki/pub/LHCb/C6K/Coolants_review.pdf

[3] https://twiki.cern.ch/twiki/pub/LHCb/C6K/EDMS_work_package.pdf

[4]http://solutions.3mmagyar.hu/3MContentRetrievalAPI/BlobServlet?lmd=1351678101000&locale=hu_HU&assetType=MMM_Image&assetId=1319241050803&blobAttribute=ImageFile

[5] https://detector-cooling.web.cern.ch/detector-cooling/data/C6F14_Product_Information.pdf