A) Convergence to a common evaporative fluid for the SCT and Pixels

[Greg Hallewell & Vic Vacek]

and

B) Compressor Studies for fluorocarbon vapors.

[Pierre Bonneau & Vic Vacek]

Presented by

Vic Vacek
### Basic properties of the candidates → fluorinerts for Atlas Pixel and SCT Cooling System

<table>
<thead>
<tr>
<th>Fluorinert</th>
<th>C3F8</th>
<th>C4F10</th>
<th>CF3I</th>
<th>Custom Mix 3_7</th>
<th>Custom Mix 5_5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name</strong></td>
<td>octafluoropropane</td>
<td>decafluorobutane</td>
<td>trifluoriodomethane</td>
<td>C3F8[30%mass]</td>
<td>C4F10[70%mass]</td>
</tr>
<tr>
<td><strong>Molar mass</strong></td>
<td>188.2</td>
<td>238.03</td>
<td>195.91</td>
<td>220.4</td>
<td>210.1</td>
</tr>
<tr>
<td><strong>Triple point temperature [°C]</strong></td>
<td>-160.15</td>
<td>-84.15</td>
<td>-153.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Boiling point temperature [°C]</strong></td>
<td>-36.6</td>
<td>-2.09</td>
<td>-22</td>
<td>Pseudo-critical Properties:</td>
<td>Pseudo-critical Properties:</td>
</tr>
<tr>
<td><strong>Critical temperature [°C]</strong></td>
<td>71.87</td>
<td>113.18</td>
<td>122.22</td>
<td>98.65</td>
<td>90.1</td>
</tr>
<tr>
<td><strong>Critical pressure [bar]</strong></td>
<td>26.8</td>
<td>23.23</td>
<td>38.82</td>
<td>25.24</td>
<td>25.92</td>
</tr>
<tr>
<td><strong>Critical density [kg/m³]</strong></td>
<td>628</td>
<td>599.8</td>
<td>874</td>
<td>608</td>
<td>613.6</td>
</tr>
<tr>
<td><strong>Accentric factor [-]</strong></td>
<td>0.325</td>
<td>0.374</td>
<td>0.1796</td>
<td>-</td>
<td>Custom Mix 7_3</td>
</tr>
<tr>
<td><strong>Dipole at NBP [debye]</strong></td>
<td>0.014</td>
<td>0.0</td>
<td>0.92</td>
<td>-</td>
<td>C3F8[70%mass] C4F10[30%mass]</td>
</tr>
<tr>
<td><strong>Range of applicability</strong></td>
<td>Molar mass = 200.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Minimal temperature [°C]</strong></td>
<td>-160.2</td>
<td>-84.2</td>
<td>-93.2</td>
<td>Tc = 82.32</td>
<td></td>
</tr>
<tr>
<td><strong>Maximal temperature [°C]</strong></td>
<td>226.9</td>
<td>226.9</td>
<td>146.9</td>
<td>Pc = 26.18</td>
<td></td>
</tr>
<tr>
<td><strong>Maximal pressure [bar]</strong></td>
<td>300</td>
<td>300</td>
<td>200</td>
<td>$\rho_c = 619.3$</td>
<td></td>
</tr>
<tr>
<td><strong>Maximal density [kg/m³]</strong></td>
<td>2049</td>
<td>1823</td>
<td>2614</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Prediction of the thermophysical properties and their verification

- We are able to generate for the requested fluorinerts:
  - Saturation tables
  - Iso-property tables
  - Single property at any state point
  - Generate appropriate diagrams
  - Predict composition of the mixtures and their property
Three different compositions of the C3F8/C4F10 custom mixtures were prepared and tested:

**Mass fractions:**

<table>
<thead>
<tr>
<th>Target composition</th>
<th>Verified composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 0.3/0.7</td>
<td>[0.30/0.70]</td>
</tr>
<tr>
<td>(b) 0.5/0.5</td>
<td>[0.44/0.56]</td>
</tr>
<tr>
<td>(c) 0.7/0.3</td>
<td>[0.80/0.20]</td>
</tr>
</tbody>
</table>

⇒ Target composition was verified by gas chromatography analysis and via measurement of the velocity of sound using the Sonar tube developed by G. Hallewell
Performed measurements

- Temperature profiles along the SCT and Pixel structures were measured

- HTC were measured for all fluids & various technological parameters
  - Different geometries [I.D. or I.Dₜₜ.]
  - Different heat fluxes
  - Different mass flows
  - Different sub-cooling

- Needle valve, ruby injectors and capillaries were tested in the evaporative circuits
Summary results from HTC coefficient measurements

HTC in the tube of ID=3.6mm
Power = 8 W/block; MF ~ 1.5 g/s; t₀ ~ -15 to - 25 C
Summary results from Genova stave measurements

GENOVA STAVE DESIGN (with silicon tiles) measured at CERN, July 1999

C3F8 and Wi&gro Mixture 0,5/0,5

CHANNEL NUMBER

TILE NUMBER

FLOW

Measures in cm
Temperature profiles for C3F8 at 100 W and MIX at 55 W [Genova stave prototype]

Temperature [°C]

Distance along the stave [mm]
HTC COEFFICIENT IN THE GENOVA STAVE PROTOTYPE AT P = 100 W

DISTANCE ALONG THE STAVE [cm]

HTC [W/m²K]

- HTC_c4f10
- HTC_Cf3I
- HTC_mix
- HTC_Vic_C3F8
Temperature profile; C3F8; P=100 W;
ALL Positions of the Genova Stave 07/99 at CERN

DISTANCE ALONG THE STAVE [cm]

Temperature [°C]

-3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13

0 10 20 30 40 50 60 70 80

T[°C] Horizontal
□ Corr.
▲ T[°C] Upsidedown
△ Corr.
◆ T[°C] Vertical
◇ Corr.
Conclusions

• From the point of HTC values [averages]:

  • In the tube of ID = 3.4 mm

<table>
<thead>
<tr>
<th>FLUID</th>
<th>C3F8</th>
<th>C4F10</th>
<th>MIX_ 50/50</th>
<th>CF3I</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVERAGE</td>
<td>4284</td>
<td>3047</td>
<td>2350</td>
<td>3024</td>
</tr>
<tr>
<td>RATIO</td>
<td>1.8</td>
<td>1.3</td>
<td>1.0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

  • In the Genova Stave Prototype

<table>
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<tr>
<th>FLUID</th>
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<th>C4F10</th>
<th>MIX_ 50/50</th>
<th>CF3I</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVERAGE</td>
<td>6759</td>
<td>4881</td>
<td>3232</td>
<td>4892</td>
</tr>
<tr>
<td>RATIO</td>
<td>2.1</td>
<td>1.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
• **Other aspects are to be considered:**

  • Pressure limits for the structure
  • Pressure losses within connecting pipes
  • Temperature ranges [i.e. insulation matters etc.]
  • Availability of the other components of the cooling circuit for certain fluid
  • Compatibility with used materials
  • Safety and environmental aspects
  • Etc.

• **HTC coefficient is not the only priority !!!**
Compressor studies for fluorocarbon vapors.

- Dry scroll compressor Atlas Copco SF4-8-120

Main modifications

- Air intake filter
- Easy access
- Motor
- Pressure switch
- Compressor element
- Compressed air after-cooler
- Belt tension
- Air receiver
Setup for pumping speed measurement
Pumping speed for the fundamental refrigerant vapors

SCROLL - C3F8 and C4F10 - Pumping Speed

- Absolute Outlet Pressure [bar]
- Flow [g/s]

- C3F8-P_in 0.4b
- C3F8-P_in 0.7b
- C3F8-P_in 1b
- C3F8-P_in 1.3b
- C3F8-P_in 1.4b
- C4F10-P_in 0.35b
- C4F10-P_in 0.6b
- C4F10-P_in 0.8b
Performance variation for $\text{C}_3\text{F}_8$ with frequency change

![Graph showing SCROLL_C3F8 - Pumping Speed vs Frequency](image)
Other characteristics

**SCROLL - C3F8 - Heat of Compression**

- Enthalpy (kJ/kg)
- Absolute Pressure (bar)
- Various inlet pressures

**SCROLL - C4F10 - Heat of Compression**

- Enthalpy (kJ/kg)
- Absolute Pressure (bar)
- Various inlet pressures

**SCROLL - C3F8 - Outlet Temperature vs Inlet Pressure**

- Temperature (°C)
- Absolute Inlet Pressure (bar)
- Various outlet pressures
Conclusions

• Successful design changes and modification include:
  • Leak-tightness of the compressor box [Helium was used for the test]
  • Internal cooling loop implementation
  • Frequency regulator device implementation
  • Buffer tank modification

• Performance test have been done with following fluids:
  • Air [initial test]
  • Fluorinert vapors:
    • $C_4F_{10}$
    • $C_3F_8$

  [with an average measured flat pumping speed of ~20 m$^3$hr$^{-1}$ for both $C_4F_{10}$ ($P_{in} = 0.25$, $P_{out} = 4$ bar abs) and $C_3F_8$ ($P_{in} = 1.4$, $P_{out} = 8$ bar abs)].

• Scroll compressor is ready for an installation into the main cooling system circuit and necessary workshop actions are under way.