Heat flux to the helium cryogenic system elements in the case of incidental vacuum vessel ventilation with atmospheric air

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Cryogenic Safety- HSE seminar
Outline

• Problem’s background
• WUST test setup description
• Experiment methodology discussion
• Conclusions
Problem’s background

The cryogenic vessels or fluid distribution circuits need to be protected by safety equipments against excessive pressure caused by intensive heat inflow to this elements.

ESS Cryogenic Distribution System - process lines safety equipment
Problem’s background

One of the heat inflow source to be considered in the safety equipments sizing is the incidental ventilation of the vacuum vessel with atmospheric air.
Problem’s background

The heat flux with atmospheric air inflow to helium temperature elements has been already experimentally determined as $3.7 - 5.0 \text{ kW/m}^2$ [1,2,3], but no heat flux to thermal shields were investigated.
Problem’s background

The thermal shields are covered from external side with 30-40 layers of MLI. The heat flux through the MLI side can be expected as 0.25 kW/m² [4], but ...
Problem’s background

... the heat flux to the bare side of thermals shield is unknown.

\[ Q_{\text{Air-TS MLI}} = 0.25 \text{ kW/m}^2 \]

\[ Q_{\text{Air-He}} = 3.7 - 5 \text{ kW/m}^2 \]

\[ Q_{\text{Air-TS Bare}} = ??? \]
Problem’s background

- Air
- Air_Liq
- Condensation
- Gas convection
- Cryosorption
Problem’s background

The heat flux to the bare side of thermals shield:

- for $T_{TS} > T_{Air\_Liq}$ - gas convection, but it is not clear if convection is forced, natural or „mix” type

Model tuning by adjusting a natural convection heat transfer coefficient [5]
Problem’s background

The heat flux to the bare side of thermals shield for $T_{Air\_Liq} > T_{TS} > T_{Air\_III}$ can be estimated with Nusselt model.

Modelling results of ambient air condensation on a cryogenic horizontal tube. Variation of mean heat transfer coefficient for superheating $\Delta T_1 = 0, 100, 200$ and $300$ K [6]
Problem’s background

The heat flux to the bare side of thermals shield for $T_{TS} < T_{Air_{III}}$ can be estimated with cryopumping effect.

Gas velocity
$$v = \frac{\dot{V}}{A} = \sqrt{\frac{kT}{2\pi M}}$$

For nitrogen
$$v_{N_2} = 11.9 \text{ l/s per cm}^2$$

Mass stream
$$\dot{m} = \rho \cdot \dot{V}$$

For nitrogen
$$\dot{m}_{N_2} / A = 1.25 \cdot 11.9 \cdot 10^{-3} \cdot 1/10^{-4} = 148 \text{ kg/s per m}^2$$

Enthalpy difference
$$h_{N_2}(300K \rightarrow 50K) \approx 480 \text{ kJ/kg}$$

Heat load with nitrogen
$$\dot{q}_{N_2} = \dot{m}_{N_2} / A \cdot h_{N_2} = 148 \cdot 480 = 71 \text{ MJ/m}^2$$
WUST cryostat

3.8m long
2.5m high
50l cold vessel volume
13l \( \text{N}_2 \) tank volume
529l vac. tank volume
4.0 bar a He vessel SV set pressure
1.9m\(^2\) helium tank heat transfer area
2.94m\(^2\) thermal shield inside heat transfer area
3.02m\(^2\) thermal shield outside heat transfer area
WUST cryostat Thermal Shield
## Physical properties of air components

<table>
<thead>
<tr>
<th>Gas</th>
<th>Normal boiling temperature, K</th>
<th>Triple point temperature, K</th>
<th>Heat of evaporation, kJ/kg</th>
<th>Heat of melting, kJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>78.8</td>
<td>58</td>
<td>205.1</td>
<td>23</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>77.36</td>
<td>63.2</td>
<td>199</td>
<td>25.6</td>
</tr>
<tr>
<td>Argon</td>
<td>87.29</td>
<td>83.85</td>
<td>163</td>
<td>29.6</td>
</tr>
</tbody>
</table>
Experiment methodology

- Safety Valve
- Vacuum Tank
- 30 Layers of MLI
- Thermal Shield
- 10 Layers of MLI
- Cold Vessel
- Cold Vessel
- Nitrogen Tank
- Argon Tank
- Flow Meters
Experiment methodology

WUST set-up allowing:

• Measurement of the heat flux to He vessel – measurement of p, T or evaporation mass stream for SV open

• Measurement of the heat flux to the Thermal Shield bare side – measurement of the Shield temperature

• Measurement of the heat flux to LN2 vessel - evaporation mass stream
Conclusions

- Heat flux to Thermal Shield of large cryogenic helium distribution systems is less interested in both, theoretical and experimental investigations, but is of high importance in TS SV sizing.
- WUST has designed a dedicated cryostat that allowing measurements of the heat flux to different elements of the helium distribution systems in case of the vacuum vessel ventilation with atmospheric air as well as with process gas (cold helium).

2. Will Francis, Mike Tupper, Stephen Harrison, Conformable tile method of applying CRYOCoAT™ UL79 insulation to cryogenic tanks.


4. G.F. Xie, X.D. Li, R.S. Wang, Study on the heat transfer of high-vacuum-multilayer-insulation tank after sudden, catastrophic loss of insulating vacuum, Cryogenics 50 (2010) 682-687


6. Z. Zhao, Y. Li, L. Wang, Z. Liu, J. Zheng, Flow and heat transfer characteristics of ambient air condensation on a horizontal cryogenic tube, Cryogenics 62 (2014) 110-117
Thank you for the attention!