Adaptation of refrigeration compressors for Joule-Thomson cryocoolers fed with gas mixtures

Agnieszka Piotrowska, Maciej Chorowski, Pawel Dorosz

Wroclaw University of Technology, Poland
CEC-ICMC 2015, June 29th, 2015
Outlines

1. Joule-Thomson coolers - open system
2. Joule-Thomson coolers supplied with gas mixture - closed system
3. Refrigeration compressors
4. The possibility of the compressor cooling
5. Conclusions
Joule-Thomson coolers - open system

1. Simple construction
2. No moving parts working at low temperatures
3. Short start-up time

1. High working pressure, min. 80 bar for N2, up to inversion pressure
2. Low thermodynamic efficiency
3. Limited working time (need of pressure tank replacement)
Joule-Thomson coolers

- **Micro capacity**: Cooling power: below 1 W
- **Low capacity**: up to 10 W
- **Medium capacity**: up to 50 W

**CLOSED SYSTEM REQUIRED** (reduction of working pressure)

University of Twente, Netherlands

Wroclaw University of Technology, Poland
### Joule-Thomson cooler - closed system

<table>
<thead>
<tr>
<th>Working fluid</th>
<th>Nitrogen</th>
<th>Gas mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working pressure</td>
<td>100 – 200 bar</td>
<td>15 – 25 bar</td>
</tr>
<tr>
<td>Temperature at 1 bar</td>
<td>77.8 K</td>
<td>80 – 120 K</td>
</tr>
<tr>
<td>Phase change inside the heat exchanger</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Temperature difference at the cold end of HE</td>
<td>70 – 90 K</td>
<td>5 – 15 K</td>
</tr>
</tbody>
</table>
**J-T cooler with hermetic piston compressor**

<table>
<thead>
<tr>
<th></th>
<th>Refrigeration technology</th>
<th>Cryogenics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working medium</td>
<td>Refrigerants (both one component or mixtures) R 134a, R404a</td>
<td>3, 4 and 5-component mixtures of nitrogen and hydrocarbons (methane, ethane, propane and i-buthane)</td>
</tr>
<tr>
<td></td>
<td>Pure hydrocarbons R290, R600a</td>
<td></td>
</tr>
<tr>
<td>Pressure ratio limit</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>Temperature limit of outlet medium (discharge side)</td>
<td>150°C</td>
<td>(to avoid thermal decomposition of oil)</td>
</tr>
<tr>
<td>Inlet medium (cooling of the electric motor winding)</td>
<td>Low temperature vapor of the refrigerant</td>
<td>Gas mixture vapor at ambient temperature</td>
</tr>
</tbody>
</table>
Compression process

Poisson equation

\[ \frac{T_2}{T_1} = \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \]

Nitrogen \( k = 1.40 \)
Methane \( k = 1.31 \)
Ethane \( k = 1.19 \)
Propane \( k = 1.13 \)
I-butane \( k = 1.10 \)
Mixture \( k = (1.10 - 1.40) \)
Compressor test stand

- aftercooler
- throttling valve
- compressor
Test results

Nitrogen

Methane

Ethane

Propane

I-butane

5-components mixture
Solutions of the compressor cooling

Compressor located in the stream of the after-cooler air
- refrigeration technology
Hermetic compressors

Calculation results of the required compressor surface
Compressors: Danfoss VTZ serie

- nitrogen
- mixture
Solutions of the compressor cooling

Process modification

To decrease inlet temperature of the working mixture:
Process modification

Test results:

\[ \Delta T_{\text{expected}} = 22 \text{K} \]

\[ \Delta T_{\text{measured}} = 6 \text{ K} \]
Solutions of the compressor cooling

Modification of the construction

Additional cooling of the oil

Graph showing temperature changes over time:
- Purple line: Outlet temperature of gas – no additional cooling
- Green line: Outlet temperature of gas – additional cooling
- Red line: Temperature of the compressor shell – no additional cooling
- Blue line: Temperature of the compressor shell – additional cooling

Diagram of the cooling system:
- Compressor
- Oil pump
- Water filter
- Heat exchanger
- Oil filter
- Water flow path
J-T coolers designed, manufactured and tested at WUT
Test results - min. temp. 84 K

Nitrogen 20%, Methane 30%, Ethane 10%, Propane 20%, I-butane 20%
Summary

1. Laboratory tests confirm the possibility of using refrigeration compressors for Joule-Thomson coolers supplied with gas mixtures.

2. Temperature of oil (directly depending on the final temperature of compression process) is main limit factor.

3. Depending on the volumetric efficiency, the hermetic refrigeration compressors can be used without any modifications (for low efficiencies), for high efficiencies the modifications are the must.