Performance Analysis of Joule-Thomson Cooler Supplied with Gas Mixtures

Agnieszka Piotrowska, Maciej Chorowski, Pawel Dorosz

Wrocław University of Technology
Faculty of Mechanical and Power Engineering

ICEC25-ICMC 2014, July 8th
Outlines

1. Introduction - motivation of J-T coolers development
2. Hybrid systems
3. J-T technology key points
4. J-T test stand and tests
5. Conclusions
Motivation of J-T cooler development
Motivation of J-T cooler development
# On-site system for liquid O\textsubscript{2} production

## AIR SEPARATION SYSTEM

### PRESSURE SWING ADSORPTION

- up to 95% for single stage system
- up to 99.5% for multi-stage system

Product at 6 bar

Commercially available

## COOLER

## POLYMER MEMBRANE

- up to 45%

Product at 1 bar

Commercially available

Courtesy of GRASYS
## On-site system for liquid $O_2$ production

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<thead>
<tr>
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**POLYMER MEMBRANE**

- up to 45% product at 1 bar
- Commercially available

Courtesy of GRASYS
**On-site system for liquid O\(_2\) production**

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<tr>
<td>up to 95% for single stage system</td>
<td>To produce 0.5 dm(^3)/h of LO2 @ 1bar, 85W of cooling power produced at 90-105 K is required</td>
</tr>
<tr>
<td>up to 99.5% for multi-stage system product @ 6 bar</td>
<td></td>
</tr>
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On-site system for liquid O$_2$ production

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<td>PRESSURE SWING ADSORPTION</td>
<td>JOULE-THOMSON</td>
</tr>
<tr>
<td>up to 95% for single stage system</td>
<td>- simple construction</td>
</tr>
<tr>
<td>up to 99.5% for multi-stage system</td>
<td>- no moving parts working at low temperatures</td>
</tr>
<tr>
<td>product @ 6 bar</td>
<td>- high reliability</td>
</tr>
<tr>
<td>Commercially available</td>
<td>- short start-up time</td>
</tr>
</tbody>
</table>

![Air Separation System](image1)

![Cooler](image2)
Joule-Thomson cooler

<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>10 – 20 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>
Joule-Thomson cooler supplied with gas mixtures

Key points of the J-T cooler supplied with gas mixtures technology:

1. Investment costs - compressor
2. Working parameters - mixture composition
3. Commercialization of the system - repeatability of the working parameters
Compressors

COMPRESSORS OF J-T COOLERS

NITROGEN
- High pressure
- Oil free
- Expensive

GAS MIXTURE
- Low pressure
- Oil compressor
- Comercially available = low price
Compressors

COMPRESSORS OF J-T COOLERS

- NITROGEN
  - High pressure
  - Oil free
  - Expensive

- GAS MIXTURE

REFRIGERATION TECHNOLOGY
## 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 isobutene)</td>
</tr>
<tr>
<td></td>
<td>Pure hydrocarbons R290, R600a</td>
<td></td>
</tr>
<tr>
<td>Temperature limit of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>outlet medium (discharge side)</td>
<td><strong>150°C</strong> (to avoid thermal decomposition of the oil)</td>
<td></td>
</tr>
<tr>
<td>Pressure ratio limit</td>
<td>6</td>
<td><strong>25</strong></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>
<tr>
<td>Lubrication</td>
<td>Oil (mineral or synthetic)</td>
<td>Oil (mineral or synthetic) - oil change not needed</td>
</tr>
<tr>
<td>Oil removal</td>
<td>either oil trap in the installation or oil separator required</td>
<td>Oil separator required</td>
</tr>
</tbody>
</table>
Compressor cooling systems

Outside cooling system - air cooling

Inside cooling system

Small capacity systems

TO BE SOLVED
Desired properties of the mixture

1. High isothermal throttling effect of the isenthalpic expansion $\Delta h_T$, even for a relatively low compression pressure, to allow the use of commercially available compressors.

2. The lowest evaporation temperature should not exceed the value resulting from the refrigerator application field, e.g. to guarantee the oxygen liquefaction it should be of about 90-100 K.

3. The compression temperature should not exceed 150°C. In the case of closed systems this enables the use of standard refrigeration compressors.

4. No solid phase in any point of the system
Mixture composition

Aspen HYSYS simulation:

Mixture composition:
- Nitrogen 10%, methane 20%, ethane 20%, propane 20%, i-butane 40%
- Working pressure: 20 bar

Mixture composition:
- Nitrogen 20%, methane 20%, ethane 40%, propane 10%, i-butane 10%
- Working pressure: 20 bar
J-T coolers designed, manufactured and tested at WUT
Test results

Mixture composition: Nitrogen 20%, Methane 30%, Ethane 11%, Propane 20%, I-butane 20%

![Diagram of the system](image)

![Graphs showing temperature and pressure over time and cooling power](image)
Repeatability of the working parameters

Mixture composition: Nitrogen 20%, Methane 30%, Ethane 11%, Propane 20%, I-butane 20%
Conclusions

1. Hermetic piston compressor can be used for Joule-Thomson cooler supplied with gas mixtures.

2. Joule-Thomson cooler supplied with 5-components mixture of nitrogen, methane, ethane, propane and i-butane:
   - The lowest temperature achieved 98 K
   - Cooling power of 3-9 W at 100-108 K has been produced.

3. The repeatability of the cooler parameters has been observed.
Acknowledgments

This work has been supported by the National Centre for Research and Development, as Strategic Project PS/E/2/66420/10 “Advanced Technologies for Energy Generation: Oxy-combustion technology for PC and FBC boilers with CO₂ capture” and statutory funds from Ministry for Science and Higher Education (S-10057/I-2201)