Thermodynamic Analysis On a Novel Gas-gas Ejector Enhanced Autocascade Refrigeration Cycle

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Outline

Introduction  Cycle description  Simulation results  Summary
Introduction

Background
- Increasing demands for the low temperature environments

Alternatives
- Cascade system
  - High cost
  - Complex
- Autocascade system
  - Simple
  - Low cost
  - Inefficiency

Other Researches
- Proposed a novel gas-gas ejector enhanced ARC
- Conduct a study on the cycle characteristics

Our work
- Choice of the mixtures
- System optimization
A Novel Gas-gas Ejector Enhanced Autocascade Refrigeration Cycle (NARC)

The ejector and phase separator can help to conduct a secondary composition separation and improve the performance.
Cycle description

**Ejector**: one-dimensional constant pressure mixing model

**Cycle**: common thermodynamic analysis method

\[
w_{p2} = \sqrt{2\eta_n (h_{p,i} - h_{p,s,0})} \times 1000
\]

\[
w_{m2} = \frac{w_{p2}}{1 + \mu} \sqrt{\eta_m}
\]

\[
h_{m2} = \frac{h_{p1} + \mu h_{s1}}{1 + \mu} - \left( \frac{w_{m2}^2}{2} \right)/1000
\]

\[
h_{d2} = h_{m2} + \frac{h_{d2s} - h_{m2}}{\eta_d}
\]

**Nozzle**
Based on the energy conservation law

\[
\mu = \frac{\dot{m}_s}{\dot{m}_p}, \quad r_{pj} = \frac{P_d}{P_s}
\]

**Mixing chamber**
Based on the momentum and energy conservation law

\[
W_{com} = m \frac{h_{2s} - h_1}{\eta_{com}}
\]

\[
\dot{Q}_c = m \left[ \chi_{con} + \chi_{exp1} (1 - \chi_{con}) \right] (h_{i0} - h_s)
\]

\[
q_{vc} = \left[ \chi_{con} + \chi_{exp1} (1 - \chi_{con}) \right] (h_{i0} - h_s) / v_i
\]

**Diffuser**
Based on the energy conservation law

\[
\text{COP} = \frac{\dot{Q}_c}{W_{com}}
\]
Simulation results

**Refrigerant:** R134a/R23

**The isentropic efficiencies of the ejector:**
- $\eta_n = 0.8$  
- $\eta_m = 0.95$  
- $\eta_d = 0.8$

The compression ratio can be lowered by an average of 9.2%.

**Figure 3:** The performance variations of two cycles versus $t_e$

<table>
<thead>
<tr>
<th>Evaporating Temperature</th>
<th>COP ↑</th>
<th>Volumetric Cooling Capacity ↑</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60°C</td>
<td>29.2%</td>
<td>36.0%</td>
</tr>
<tr>
<td>-40°C</td>
<td>23.9%</td>
<td>29.3%</td>
</tr>
</tbody>
</table>
Simulation results

Figure 4: The performance variations of two cycles versus the intermediate pressure ratio $\Phi_m$

Figure 5: The performance variations of the ejector versus the intermediate pressure ratio $\Phi_m$

<table>
<thead>
<tr>
<th>Intermediate pressure ratio</th>
<th>COP↑</th>
<th>Volumetric cooling capacity↑</th>
<th>rpj↑</th>
<th>μ↑</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>7.8%</td>
<td>9.6%</td>
<td>0.6</td>
<td>37.4%</td>
</tr>
</tbody>
</table>
Simulation results

Figure 6: The performance variations of two cycles versus the vapor quality at the condenser outlet $x_{\text{con}}$

- $\phi_m = 0.7$
- Vapor quality: 0.3 - 0.45
- Cooling capacity $\uparrow$
- Evaporating pressure $\downarrow$
- ARC COP $\uparrow$, $q_{vc} \uparrow$
- NARC COP, $q_{vc}$ have the maximum values; the fluctuation is minor
- $x_{\text{con}}$ always near the optimal value

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There exist \( z_{\text{opt}} \) for maximum COP

Optimum mass fractions are very close

The ejector improve the performance without affecting the \( z_{\text{opt}} \)

The \( q_{vc} \) decreases with increasing \( z \)
Summary

1. NARC can significantly improve the performance 26.9% of COP, 32.7% of $q_{vc}$ (-60~-40°C)

2. Lowering the intermediate pressure benefits the performance of the NARC

3. There exist optimal vapor qualities for the NARC
   But the fluctuation is minor

4. There exists $z_{opt}$ for maximum COP

5. Can be a guide for the design and operation of the NARC cycle
Thank you!