Modeling and Experimental Validation of a Multi-Port Vapor Injected Scroll Compressor

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Outline

- Background/Motivation
- Goals and Objectives
- Experimental Test
  - Test Setup
  - Test Results and Model Validation
- System Model and Analysis
- Conclusion
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Background

- Vapor compression cycle performance can be improved through incorporation of economization
- Compressors with ports for refrigerant injection enable economization within a single-stage compressor
  - Number of injection ports can be increased relatively easily and at low cost
  - Injection has been demonstrated with scrolls

102: Vapor Injection Port
104: Vapor Injection Passage (Perevozchikov, 2003)
Background

Schematic of Saturated Vapor Injection Cycle
Outline

- Background/Motivation
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- Modeling of Scroll Compressor with Vapor Injection
  - Sub Models
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Goals and Objectives

- To find out the working process of vapor injected scroll compressor.
  - Developing the vapor injected scroll compressor model
  - Performing the experiments of prototype
  - Validating model predictions

- To evaluate the improvements brought about by the incorporation of vapor injection
  - Developing a simple cycle model employing flash tank
  - Coupling testing results into cycle model

- To investigate the benefits in the cold climate region
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Simplified schematic of hot-gas bypass load stand

P-h Plot
Test Setup
Outline

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## Test Matrix

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Nominal Values Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensing Temperature</td>
<td>°C</td>
<td>43.3</td>
</tr>
<tr>
<td>Evaporating Temperature</td>
<td>°C</td>
<td>-10, -20, -30</td>
</tr>
<tr>
<td>Compressor Suction Superheat</td>
<td>°C</td>
<td>11.1</td>
</tr>
<tr>
<td>Higher/Lower Vapor Injection Pressure</td>
<td>kPa</td>
<td>1100/900, 1300/900, 1300/1100, 1500/1300, 1500/1100, 1500/900, 1700/1500, 1700/1300</td>
</tr>
</tbody>
</table>
Model Validation

Suction Mass Flow Rate [kg/s]

Power Consumption [W]
Model Validation

Discharge Temperature [K]

![Graph showing discharge temperature comparison between modeling and experimental results. The graph includes data points for -30°C, -20°C, and -10°C with annotations for +10K and -10K.]
Model Validation

Lower Injection Mass Flow Rate [kg/s]  

Higher Injection Mass Flow Rate [kg/s]
The experimental data are fit into the correlation of multiple input variables with limitations

$$\Pi = a_0 + a_1 \times \left( \frac{p_{disc}}{p_{suc}} \right)^{a_2} \times \left( \frac{p_{V,I,h}}{p_{suc}} \right)^{a_3} \times \left( \frac{p_{V,I,l}}{p_{suc}} \right)^{a_4}$$

<table>
<thead>
<tr>
<th>$\Pi$</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{V,I,h}$</td>
<td>-0.1262</td>
<td>0.1570</td>
<td>-0.1592</td>
<td>1.097</td>
<td>0.02495</td>
<td>0.998</td>
</tr>
<tr>
<td>$M_{V,I,l}$</td>
<td>-0.4597</td>
<td>0.3204</td>
<td>-0.04321</td>
<td>-0.1482</td>
<td>0.8981</td>
<td>0.999</td>
</tr>
<tr>
<td>$\dot{m}_{suc}$</td>
<td>-11.82</td>
<td>11.99</td>
<td>-0.004295</td>
<td>-0.0009476</td>
<td>-0.0005733</td>
<td>0.991</td>
</tr>
<tr>
<td>$\dot{W}$</td>
<td>-27.51</td>
<td>-41.54</td>
<td>-3.488</td>
<td>32.14</td>
<td>0.05131</td>
<td>0.954</td>
</tr>
<tr>
<td>$T_{disc}$</td>
<td>98.64</td>
<td>0.002351</td>
<td>4.268</td>
<td>0.6079</td>
<td>-0.2864</td>
<td>0.973</td>
</tr>
</tbody>
</table>

$M_{V,I} = \frac{\dot{m}_{VI}}{\dot{m}_{suc}}$
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Cycle Model

Schematic of Saturated Vapor Injection Cycle

P-h plot for Saturated Vapor Injection Cycle
Coupled Analysis
Coupled Analysis

![Graph showing coupled analysis results]
Coupled Analysis

\[ \text{COP}_{\text{rel}} = \frac{\text{COP}_{VI}}{\text{COP}_{\text{baseline}}} \]

\[ \text{COP}_{VI} = \frac{\dot{Q}_{h,VI}}{P_{VI}} \]
Calculation of Loading in Minnesota

Hourly Temperature Distribution of Minneapolis based on TMY data

Heating and Cooling Load at various ambient temperatures for Minneapolis
Heat Demand in Minnesota

Heating Demand

- Annual Heating Requirement [kWhr]
- Load (kW)

Ambient Temperature [°C]

Load [kW]

Annual Heating Requirement [kWhr]

-30 25 20 15 10 5 0 5 10 15 18.33

0 5 10 15 20 25 30 35

0 2000 4000 6000 8000 10000 12000 14000
Coupled Analysis for Cold Climate

Heating Capacity

Assume pinch point of 5°C and subcooling of 5°C
Coupled Analysis for Cold Climate

Heating COP

\[ COP_h = \frac{\dot{Q}_{HP}}{P_{HP}} \]
Coupled Analysis for Cold Climate

System COP

\[ \text{System COP} = \frac{\text{Load}}{\text{HP} + \text{Fan} + \text{Aux}} \]

\[ P_{\text{Fan, condenser}} = 0.38kW \]

\[ P_{\text{Fan, evaporator}} = 0.30kW \]

Ambient Temperature [°C]

System COP

Baseline Cycle
Saturated Vapor Injection Cycle
Coupled Analysis for Cold Climate

Baseline Cycle  Saturated VI cycle

Seasonal Energy Efficiency Ratio [Btu/Wh]

8.048

9.059

12.57% improvements in SEER
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Conclusion

- The vapor injected scroll compressor model is validated with experimental results.
- From modeling results, vapor injection can lower discharge temperature and increase heating capacity.
- Testing results indicate that with the increase of pressure ratio, the improvements in COP increase.
- In cold climate region, the heat pump system employing the compressor prototype in this study can bring about 12.57% improvement in SEER.
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Thank you!