Ammonia and CO$_2$ Combined Package Systems for Commercial and Industrial Applications
Introduction

Natural substances | Cheap refrigerants
Excellent thermodynamic and heat-transfer properties

Ammonia

Limiting Factors for a Wide Implementation

- Investments to the machinery room design for the direct systems
- Charge restrictions

- High Toxicity
- Moderate Flammability
Introduction

Carbon Dioxide

Natural substances | Cheap refrigerants
Excellent thermodynamic and heat-transfer properties

Limiting Factors for a Wide Implementation

- Requires specific design solutions for sub/transcritical operations
- High pressure equipment
- Intelligent control of high pressure in transcritical operation is essential

• Low critical temperature;
• High critical pressure;
• Availability of equipment
CO₂-Glycol Cascade System
Key Design Features

• Standardized pre-engineered Ammonia chiller;
• CO₂ compressor and vessel packages;
• Equipment to provide defrost by warm glycol;
• CO₂ evaporators with interlaced coils for Low Temperature demand;
• Glycol air coolers for Middle Temperature demand interconnected by pre-insulated polymer pipes;
• Secondary circuit with glycol between Ammonia high stage and CO₂ low stage systems;
Case Study

CO₂-Glycol Cascade System

CO₂ Low Stage Unit

Glycol Air Cooler

CO₂ Evaporator

Ammonia High Stage Unit

Heat Recovery

Warm Glycol to Defrost

Cold Glycol Circuit

Cooling Tower

9th IIR Gustav Lorentzen Conference on natural working fluids, 12-14 April 2010
Sydney Convention and Exhibition Centre
Data considered in the case study for a facility consisting of a total of 6 rooms:
3 Freezer Rooms - can also be run as Cool Rooms;
3 Cool Rooms only.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Direct ammonia system</th>
<th>Cascade system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low temp saturated suction temperature, °C</td>
<td>-26 (ammonia)</td>
<td>-26 (CO$_2$)</td>
</tr>
<tr>
<td>Medium temp saturated suction temperature, °C</td>
<td>-10 (ammonia)</td>
<td>Ammonia: -15 glycol supply: -12</td>
</tr>
<tr>
<td>Condensing temperature, °C</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Low temperature system peak load, kW</td>
<td>537</td>
<td>537</td>
</tr>
<tr>
<td>Medium temperature system peak load, kW</td>
<td>675</td>
<td>675</td>
</tr>
</tbody>
</table>
Plant Equipment and Operational Safety

- **Ammonia charge**
  - ammonia charge in the Cascade System is restricted to the chiller and is classified as an indirect system.
  - it makes 10-15% of the charge in the direct ammonia system.

- **Plant room ventilation**
  - Higher the ammonia charge, greater the minimum ventilation rate.

- **Personal Protective Equipment**
  - Very basic PPE for the systems with ammonia charge <900kg is required.
Plant Equipment and Operational Safety

- Refrigerant detecting equipment
  - Very basic ammonia detection system for the Cascade System
  - Sophisticated detection system could be used for direct ammonia system;

- Electrical equipment
  - Additional safety requirements apply to the electrical equipment if LFL can be reached
Mechanical Equipment Supply and Installation

• Cascade System with pre-packaged equipment is higher in equipment cost
  • Costs of the room cooling units can be reduced if electric defrost is implemented;

• Installation and labour costs of Cascade System are significantly reduced
  • CO₂ compressor and vessel units and ammonia chillers are completely supplier-built

• Pipe-work costs
  • Material cost of pipe-work is high for Cascade System
  • On-site installation time and Labour costs are reduced
Mechanical Equipment Supply and Installation

- Electrical and control equipment
  - costs of on-site electrical equipment on the Cascade System are significantly reduced as all these are provided on the supplier-assembled units

- Engineering design and documentation costs
  - Time reduction to produce system design and documentation of the cascade system
## Capital Costs

<table>
<thead>
<tr>
<th></th>
<th>Direct NH₃ (AUD)</th>
<th>Cascade (AUD)</th>
<th>Savings, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Equipment</td>
<td>$1,400,000</td>
<td>$2,100,000</td>
<td>-50%</td>
</tr>
<tr>
<td>Mechanical Installation</td>
<td>$280,000</td>
<td>$125,000</td>
<td>55%</td>
</tr>
<tr>
<td>Electrical/control equipment and labour</td>
<td>$620,000</td>
<td>$550,000</td>
<td>11%</td>
</tr>
<tr>
<td>PPE, plant room ventilation</td>
<td>$30,000</td>
<td>$14,000</td>
<td>53%</td>
</tr>
<tr>
<td>Design and documentation</td>
<td>$170,000</td>
<td>$150,000</td>
<td>12%</td>
</tr>
<tr>
<td>Project Management and Commissioning</td>
<td>$80,000</td>
<td>$65,000</td>
<td>19%</td>
</tr>
<tr>
<td>Spare parts, maintenance</td>
<td>$30,000</td>
<td>$17,000</td>
<td>43%</td>
</tr>
<tr>
<td><strong>Total Project cost</strong></td>
<td><strong>$2,610,000</strong></td>
<td><strong>$3,021,000</strong></td>
<td><strong>-16%</strong></td>
</tr>
</tbody>
</table>
## Running Costs

### Options for the direct ammonia system

<table>
<thead>
<tr>
<th>Option number</th>
<th>Option description</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃ Option 1</td>
<td>1 screw compressor on 100% LT load; 1 screw compressor on 100% MT load; 1 swing compressor on standby at all times</td>
<td>Full standby available at all times.</td>
</tr>
<tr>
<td>NH₃ Option 2</td>
<td>1 screw comp. on 50% LT load; 1 screw comp. on 100% MT load; 1 swing comp. running during periods of high LT load.</td>
<td>Standby not available at high LT load.</td>
</tr>
<tr>
<td>NH₃ Option 3</td>
<td>1 booster compressor on 100% LT load; 1 screw compressor on 50% MT load + heat rejection of low stage compressor; 1 swing compressor running during periods of high MT load</td>
<td>Standby not available at high MT load.</td>
</tr>
</tbody>
</table>
Running Costs

Absorbed power (kW)

- Direct ammonia Option 1: 370 kW
- Direct ammonia Option 2: 381 kW
- Direct ammonia Option 3: 373 kW
- Cascade system: 476 kW

Legend:
- Green: High L.T and M.T load scenario
- Orange: Low L.T load; High M.T load scenario
- Purple: Low L.T and M.T load scenario
- Light blue: Very low L.T and M.T load scenario
Capital and Running Costs

The result of the case study demonstrates

• Total capital cost of the cascade system is about 16% higher than capital cost of the direct ammonia system.

• The cascade system is less efficient than any of the direct ammonia system options at peak load.

• The efficiency of the cascade system approaches close to the efficiency of the direct ammonia system and at very low loads.
## Conclusion

<table>
<thead>
<tr>
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<th>Pros</th>
<th>Cons</th>
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<tr>
<td><strong>Ammonia Direct System</strong></td>
<td>High efficiency; Simple equipment widely available on the market;</td>
<td>High charge of ammonia in a direct system and associated risk; Risk of product spoilage in case of ammonia release;</td>
</tr>
<tr>
<td><strong>CO$_2$-Glycol Cascade System</strong></td>
<td>Easy and quick installation and maintenance; Ammonia is restricted in the machinery room; Risk is substantially lower; Basic safety equipment;</td>
<td>Higher in running and capital costs</td>
</tr>
</tbody>
</table>
Thank You For Attention