Natural Refrigerants: Future-proof Solutions for Today
eurammon End-Users
Design and Construction of a Small Ammonia Heat Pump

by

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Introduction (1/2)

- Water-to-water heat pump (ground source)
- Low charge of ammonia
- 7 kW heating capacity at -5 °C and +40 °C evaporation and condensation temperatures
- Both tap water heating and space heating
- Enough for a single-family house in central Sweden
- Compact design
Introduction (2/2)

• Between 1994 and 2008, more than 800000 heat pumps were sold in Sweden

• Share of small heat pumps installed in single-family houses is much larger than other types of heat pumps

• In Swedish market, commercially built heat pumps for single-family houses have 5 kW to 10 kW heating capacity

• About 90% of annual required heating and 60% of required heating power in the coldest days of heating season are covered

• Common refrigerants for ground source heat pumps in Sweden are R407C, R404A, R134a, and R290 (propane)
Environmental Impacts (1/2)

- Total Equivalent Warming Impact (TEWI) is even more important

- TEWI depends on GWP, running hours, leakage rate, refrigerant charge, energy consumption, (kg CO₂/kWh), (kgCO₂/kg ref), etc.

- (kg CO₂/kg ref) of production of ammonia is lower than that of synthetic refrigerants

- An important factor is the efficiency of the system

<table>
<thead>
<tr>
<th></th>
<th>R407C</th>
<th>R404A</th>
<th>R134a</th>
<th>R290</th>
<th>R717</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODP</td>
<td>&lt;0.0003</td>
<td>&lt;0.0003</td>
<td>&lt;0.0005</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GWP (100-yr)</td>
<td>1700</td>
<td>3800</td>
<td>1300</td>
<td>≈20</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
Environmental Impacts (2/2)

- Engineering Equation Solver (EES) model
- \(t_1=40\,^\circ\text{C},\; t_2=-5\,^\circ\text{C},\; \text{SH}=5\,\text{K},\; \text{SC}=5\,\text{K},\; \eta_{\text{motor}}=80\%\)

- Volumetric efficiency
  \[ \eta_s = k_1 \cdot \left(1 + k_s \frac{t_{2k} - 18}{100}\right) \cdot e^{\frac{k_s \frac{p_1}{p_2}}}{e} \]

- Volumetric to isentropic efficiency
  \[ \frac{\eta_s}{\eta_k} = (1 + k_e \frac{t_{2k} - 18}{100}) \cdot e^{\left(\frac{a \frac{t_1 + 273.15}{t_2 + 273.15} + b}{100}\right)} \]

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<tbody>
<tr>
<td>COP(_1)</td>
<td>3.73</td>
<td>3.68</td>
<td>3.52</td>
<td>3.96</td>
<td>3.91</td>
</tr>
<tr>
<td>(P_1) (bar)</td>
<td>16.3</td>
<td>18.3</td>
<td>10.2</td>
<td>13.7</td>
<td>15.6</td>
</tr>
<tr>
<td>(P_2) (bar)</td>
<td>4.31</td>
<td>5.19</td>
<td>2.44</td>
<td>4.06</td>
<td>3.55</td>
</tr>
<tr>
<td>(t_{1k}) (°C)</td>
<td>65.4</td>
<td>54.4</td>
<td>63.1</td>
<td>55.9</td>
<td>134.2</td>
</tr>
</tbody>
</table>

- To produce sanitary hot water, higher condensation pressure is needed for the refrigerants other than ammonia, which leads to lower COP\(_1\) values than the values in the above table for them.
Setup installed in a house

- Hydronic system
- Sanitary hot water
- Surge tank
- Borehole
- Ball valve
- Filter
- Sight glass
- Oil separator
- Expansion valve
- Pump
- Flow meter
- Electrical heater

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refrigerants delivered by mother nature
Setup tested in the laboratory
**EES software model**

- **Basis for choosing the components (needed capacity)**
  - Pipes on refrigerant side
  - Heat exchangers and needed flow rate through them
  - The pump, flow meters, and 3-way valves on water side

- **Assumptions**
  - \( t_1 = 40 \, ^\circ C \), \( t_2 = -5 \, ^\circ C \), \( SH = 5 \, K \), \( SC = 5 \, K \), \( Q_2 = 5.4 \, kW \)

- \( \eta_s = k_1 \cdot (1 + k_s \frac{t_{2k} - 18}{100}) \cdot e^{\frac{P_1}{P_2}} \)

- \( \frac{\eta_s}{\eta_k} = (1 + k_e \frac{t_{2k} - 18}{100}) \cdot e^{(\frac{a(t_1 + 273.15)}{t_2 + 273.15} + b)} \)

- **Results**
  - \( Q_1 = 6.9 \, kW \) (\( Q_{cond} = 5.5 \, kW \), \( Q_{desup} = 1.4 \, kW \)), COP \( _{1k} = 4.6 \)
  - \( m_r = 0.0049 \, kg/s \), \( P_1 = 15.6 \, bar \), \( P_2 = 3.55 \, bar \)
Main components (1/4)

- Open-type reciprocating HKT-GOELDNER compressor, O 12 3 DK100

- For $t_1=40 \, ^\circ\text{C}$, $t_2=-5 \, \text{to} \, 0 \, ^\circ\text{C}$, $n=1450 \, \text{rpm}$ → $Q_2 \approx 6 \, \text{kW}$
Main components (2/4)

- Permanent magnet motor (TG drives)
- The rotation speed is controlled by an inverter (OMRON)
Main components (3/4)

• Desuperheater and condenser
  • Fusion-bonded, 100% stainless steel plate heat exchangers (AlfaNova)

• Evaporator
  • Minichannel aluminum heat exchanger
Main components (4/4)

- Electronic expansion valve (Carel)
- Standalone driver (Carel)
- Brine pump (Grundfos)
  - High efficiency
  - Stepless speed control
  - Circulating the brine, ethanol 25% wt, through the evaporator and borehole
3-D model

- Scaled 3-D drawing in AutoCAD®
- Plan to place the components in a limited space

Constructing the heat pump

- According to 3-D model
- AluFlex® 40mm×40mm bars
- Calibration or verification
- Leakage
- Insulation (ARMAFLEX)
Data acquisition and processing

- Thermocouples & Pressure transducers
- Flow meters
- Power measurements

Agilent 34970A, Data Acquisition/Switch Units

Frequency inverter

Pumps

Agilent VEE program (Computer)
Agilent VEE program
Test conditions

- Compressor speed 1500 rpm and 800 rpm
- Condensation temperature 40 °C
- Evaporation temperature -13 °C to +5 °C
- Water leaving desuperheater 60 °C
- Brine temperature change ≈ 3K
Results ($Q_1$ and $Q_2$)
Results ($E_{elm}$, $E_k$, $E_{pump}$)
Results ($Q_{\text{desup}}/Q_{\text{cond}}$)

![Graph showing $Q_{\text{desup}}/Q_{\text{cond}}$ vs. $T_{\text{evap}}$ (°C). The graph includes data points for $Q_{\text{desup}}/Q_{\text{cond}}$ at 1500 rpm and 800 rpm.](image)
Discharge temperature

![Graph showing discharge temperature vs. evaporation temperature with data points for 1500 rpm and 800 rpm.]
Results (COP)

- COP
- $T_{\text{evap}}$ (°C)

Legend:
- COP1 (1500 rpm)
- COP1_hp (1500 rpm)
- COP1_k (1500 rpm)
- COP1 (800 rpm)
- COP1_hp (800 rpm)
- COP1_k (800 rpm)
Results ($\eta_k$ and $\eta_{tot}$)
Conclusions

- A small ammonia heat pump with desirable performance has been built and tested in a range of evaporation temperatures at two compressor speeds.
- The heating capacity and the compact design of the heat pump make it suitable for space heating and tap water heating of single-family houses.
- For the safety reasons in domestic applications, through compact design and using minichannel heat exchanger as evaporator, the heat pump works with low amount of refrigerant.
Future work

• Redesigning the evaporator
• Measuring power after inverter and motor
• Reducing the charge more
• Installing the heat pump in a house
References (1/2)


Thank you