Experimental Study of R-134a Alternative in a Supermarket Refrigeration System

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Topics

- Supermarkets and Hybrid Systems
- XP10 Properties
- Thermodynamic Cycle Performance
- Calorimeter Testing
- Supermarket Testing
- TEWI analysis
- Summary
Supermarkets

- Climate change regulations driving emissions reduction in Europe and US

- New technologies:
  - Many retailers testing variations on \( \text{CO}_2 \) systems for new stores.
  - Growing trend toward 134a Med Temp/\( \text{CO}_2 \) Low Temp cascade hybrid systems
    - lower direct GWP, higher COP, lower leaks
  - XP10 developed as low GWP alternative to R-134a MT in cascade systems with \( \text{CO}_2 \)
  - 85-90% direct GWP reduction versus all R-404A system and energy efficiency improvement
## XP10 Properties

<table>
<thead>
<tr>
<th></th>
<th>R-134a</th>
<th>XP10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical Formula</strong></td>
<td>CF₃CH₂F</td>
<td>Azeotrope</td>
</tr>
<tr>
<td><strong>100 yr GWP (AR4)</strong></td>
<td>1430</td>
<td>near 600</td>
</tr>
<tr>
<td><strong>Toxicity/Flammability</strong></td>
<td>A1</td>
<td>A1 expected</td>
</tr>
<tr>
<td><strong>Boiling Point °C (°F)</strong></td>
<td>-26 (-15)</td>
<td>-29 (-20)</td>
</tr>
<tr>
<td><strong>Critical Point °C (°F)</strong></td>
<td>101 (214)</td>
<td>98 (208)</td>
</tr>
<tr>
<td><strong>Temperature Glide °C (F)</strong></td>
<td>0</td>
<td>Negligible (Azeotrope)</td>
</tr>
</tbody>
</table>
Thermodynamic Cycle Performance

Conditions:
Evaporator Temp = -10°C (14°F)
Condenser Temp = 40°C (104°F)
Subcool amount = 6K (11R)
Suction Temp = 18°C (64°F)
Comp Isentropic Eff. = 70%

<table>
<thead>
<tr>
<th></th>
<th>Temp Glide C (F)</th>
<th>Suction Pressure kPa (Psia)</th>
<th>Disch Pressure kPa (Psia)</th>
<th>Comp Disch Temp C (F)</th>
<th>Capacity kJ/m3 (Btu/ft3)</th>
<th>Cap Rel to 134a</th>
<th>COP</th>
<th>COP Rel to 134a</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-134a</td>
<td>0 (0)</td>
<td>201 (29)</td>
<td>1017 (148)</td>
<td>90 (194)</td>
<td>1497 (40.2)</td>
<td>100%</td>
<td>3.06</td>
<td>100%</td>
</tr>
<tr>
<td>XP10</td>
<td>0 (0)</td>
<td>223 (32)</td>
<td>1070 (155)</td>
<td>82 (180)</td>
<td>1575 (42.3)</td>
<td>105%</td>
<td>3.04</td>
<td>99%</td>
</tr>
</tbody>
</table>

XP10 has about 5% higher capacity, equivalent energy efficiency, lower discharge temperature
Calorimeter Testing in a Recip Compressor
- EER 2% higher, Capacity 5% higher on average

XP 10 Versus R-134a Calorimeter Test
65F Return Gas Temperature

Evaporator/Condenser Condition

Rel EER
Rel Cap
Calorimeter Testing in a Scroll Compressor
- EER 1% lower, Capacity 5% higher on average

XP10 Versus R-134a Calorimeter Test
65F Return Gas Temperature

Evaporator/Condenser Condition

Rel EER
Rel Cap
German Discount Supermarket Field Test
- System retrofitted with XP10, no other changes made
Superheat Temperatures

XP10 superheat is about 2K higher than R-134a
Energy Consumption Versus Ambient Temperature
- range of ambient conditions

Graph showing energy consumption in kWh with R-134a and XP10, minimum and maximum ambient temperature, and average ambient temperature.
Specific Date Selected with Similar Ambient Temperature to Make Energy Comparison
XP10 energy consumption is 3.3% lower than R-134a
System Operating Temperatures

Operating temperatures are similar
COP based on system operating conditions is 4.5% higher for XP10
TEWI Analysis

Objective: To compare both direct impacts from refrigerant emissions and indirect impacts from energy usage for different supermarket refrigeration technologies

Assumptions

- Supermarket equipment life – 15 years
- Supermarket operating power – 75 kW for medium temp and 20 kW for low temp
- Fractional run time – 55% for medium temp and 85% for low temp
- Refrigerant charge size – 200 kg in medium temp, 100 kg in low temp
- Average refrigerant leak rate – 15% per year
- Refrigerant recovered at end of life – 80% of charge
- CO2 emitted from electricity generation (Brouwers, 2007) – 0.616 kg CO2/kw-hr
Systems Evaluated in TEWI Analysis:

• Uncoupled standard DX system using R-404A in both medium (MT) and low temp (LT) circuits,

• Cascade system with CO$_2$ in both MT and LT circuits
  - evaluated in both northern and southern European climates due to differences in CO$_2$ performance sub- and trans-critical*

• R-134a MT - CO$_2$ LT cascade system

• XP10 MT - CO$_2$ LT cascade system

* CO2-CO2 cascade systems were specified to match published data on energy consumption relative to an R-404A DX system (Seinel and Finckh, 2007)
TEWI Results – XP10-CO$_2$ cascade has lowest environmental impact

**MT - LT**

404A - 404A DX

CO2 - CO2 CCD S EU

CO2 - CO2 CCD N EU

134a - CO2 CCD

XP10 - CO2 CCD

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0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0

**INDIRECT-MT**

**INDIRECT-LT**

**RFR LEAK-MT**

**RFR LEAK -LT**

million Kg CO2 Equivalent over 15 year life
Summary

- Supermarkets retailers are investigating several alternative options to reduce refrigerant GWP and increase energy efficiency.
- Growing trend is to use R-134a in medium temp cascaded to CO₂ low temp – “hybrid system”
- XP10/CO₂ has potential to reduce direct GWP 85-90% versus an all R-404A system
- XP10/CO₂ hybrid cascade system has lowest environmental impact based on TEWI analysis
Thank you!

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