LOW GWP REFRIGERANTS FOR HEAT PUMP SYSTEMS

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AGENDA

- Introduction
  - Overall view of refrigerant options for heat pump applications
  - Update on ASHRAE registration of CF3I and other blends
- Performance of refrigerants R410A replacements in heat pumps
- Solubility and miscibility with POE oil
- Material compatibility
- Concluding Remarks
## Overview of Refrigerant Options

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>R-123</strong>&lt;br&gt;GWP=79</td>
<td><img src="image" alt="Solstice® zd" /> (R-123zd(E))&lt;br&gt;GWP=1</td>
<td><img src="image" alt="High Temperature Heat Pump" /> <img src="image" alt="LP Chillers" /></td>
</tr>
<tr>
<td><strong>R-134a</strong>&lt;br&gt;GWP=1430</td>
<td><img src="image" alt="HDR137" /> (R-515B*)&lt;br&gt;GWP=292</td>
<td><img src="image" alt="Solstice® yf" /> (R-1234yf)&lt;br&gt;GWP=1</td>
</tr>
<tr>
<td><strong>R-22</strong>&lt;br&gt;GWP=1810</td>
<td><img src="image" alt="Solstice® N20" /> (R-446A)&lt;br&gt;GWP=988</td>
<td><img src="image" alt="Commercial Refrigeration" /> <img src="image" alt="MP Chillers" /></td>
</tr>
<tr>
<td><strong>R-404A</strong>&lt;br&gt;GWP=3922</td>
<td><img src="image" alt="Solstice® N40" /> (R-446A)&lt;br&gt;GWP=1387</td>
<td><img src="image" alt="HDR126" /></td>
</tr>
<tr>
<td><strong>R-410A</strong>&lt;br&gt;GWP=2068</td>
<td><img src="image" alt="R466A*" /> (R-515B*)&lt;br&gt;GWP=733</td>
<td><img src="image" alt="Heat Pump Water Heater" /> <img src="image" alt="Stationary A/C Heat Pump" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="HDR-147" /> GWP=399</td>
<td><img src="image" alt="HDR-147" /> GWP=399</td>
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</tbody>
</table>

Note: All GWP values from the IPCC, “AR4”

*Provisional ASHRAE number

**Solstice® HFO Blends for Low, Medium & High Pressure Applications**
OVERVIEW OF R410A REPLACEMENTS

- **Non-flammable option with GWP<750**: System design similar to R410A allows swift transition for the industry due to reduced development time.
- **Non-flammable option with GWP<400 or GWP<300**: They can potentially provide the lowest overall environmental impact. Still some trade-off in system design will be needed.
- **Non-flammable option with GWP<150**: They have higher indirect emissions due to worse system performance. Significant system design changes are needed to improve efficiency.

### LCCP Evaluation 3 Ton Heat Pump for 15-year lifetime

- **GWP~400**: Lowest Environmental Impact

### Assumptions:
- Increase compressor displacement volume
- Heat exchanger sizes are kept the same. Only circuitry is changed
- Suction and discharge lines diameter are slightly increased

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- **R-466A**: System design similar to R410A
CF3I and R-466A Characteristics

- **Official WEEL OEL** for CF3I received at 500 (Class “A”, low toxicity)
  - In 2017, WEEL committee assigned OEL of 500 based on toxicity test results

- **A1 ASHRAE classification**
  - CF3I was assigned R-13I1 number and classified as A1
  - R-466A (49% R32, 11.5% R125, 39.5% CF3I). It was classified as A1 by the technical committee of ASHRAE Standard 34. Official publication (addenda) expected by the end of the year.
# PERFORMANCE OF R-410A REPLACEMENTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Class</th>
<th>GWP (AR4)</th>
<th>Cap Cooling</th>
<th>COP Cooling</th>
<th>Cap Heating</th>
<th>COP Heating</th>
<th>Diff. $T_{\text{disch}}$ ($^\circ$C)</th>
<th>$p_{\text{disch}}$</th>
<th>Evap. Glide (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410A</td>
<td>A1</td>
<td>2088</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0</td>
<td>100%</td>
<td>0.1</td>
</tr>
<tr>
<td>R32</td>
<td>A2L</td>
<td>675</td>
<td>105%</td>
<td>100%</td>
<td>105%</td>
<td>100%</td>
<td>+17.2</td>
<td>102%</td>
<td>0.0</td>
</tr>
<tr>
<td>R-466A</td>
<td>A1</td>
<td>733</td>
<td>99%</td>
<td>100%</td>
<td>97%</td>
<td>100%</td>
<td>+8.0</td>
<td>95%</td>
<td>1.2</td>
</tr>
<tr>
<td>HDR-147</td>
<td>A1</td>
<td>GWP&lt;400</td>
<td>95%</td>
<td>103%</td>
<td>93%</td>
<td>101%</td>
<td>+10.8</td>
<td>89%</td>
<td>3.8</td>
</tr>
<tr>
<td>HDR-139</td>
<td>A1</td>
<td>GWP&lt;300</td>
<td>92%</td>
<td>103%</td>
<td>90%</td>
<td>100%</td>
<td>+14.0</td>
<td>86%</td>
<td>5.2</td>
</tr>
</tbody>
</table>

- **R-466A (GWP<750)**
  - Closest match to R410A’s performance. Can be used with same size/design of compressor and heat exchangers
  - Small evaporator glide shows no significant impact on heating mode (frost formation)

- **HDR147 (GWP<400)**
  - Capacity within 5% of R410A with slightly better efficiency. Will need slightly higher compressor displacement.

- **HDR-139 (GWP<300)**
  - Capacity within 8% of R410A with slightly better efficiency. Will need slightly higher compressor displacement.
R-466A/POE shows a close match in viscosity to R410A/POE at typical compressor sump temperatures
MISCIBILITY IN POE LUBRICANT

- R-466A shows better miscibility than R410A with POE lubricant
### ILLUSTRATIVE MATERIALS COMPATIBILITY RESULTS

#### Elastomer and Plastic Compatibility

<table>
<thead>
<tr>
<th>Elastomer</th>
<th>Hardness % change</th>
<th>Volume % change</th>
<th>Weight % change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R410A</td>
<td>R466A</td>
<td>R410A</td>
</tr>
<tr>
<td>NBR*</td>
<td>-19.1%</td>
<td>-20.9%</td>
<td>26.3%</td>
</tr>
<tr>
<td>Neoprene*</td>
<td>0.0%</td>
<td>-5.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>EPDM*</td>
<td>-4.7%</td>
<td>0.0%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Nylon 66*</td>
<td>0.8%</td>
<td>-1.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Nitrile*</td>
<td>-7.4%</td>
<td>-2.4%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Polypropylene*</td>
<td>1.0%</td>
<td>-3.1%</td>
<td>3.1%</td>
</tr>
<tr>
<td>Viton*</td>
<td>-12.9%</td>
<td>-6.8%</td>
<td>21.4%</td>
</tr>
</tbody>
</table>

* 2 weeks at 100°C

- Compatibility generally varies with elastomer formulation
- Results with R-466A generally similar to R-410A
- Testing with various materials in currently ongoing
Testing in systems and compressors

- Currently working with manufacturers to evaluate compressors and systems.
- Testing of typical scroll compressors that use POE oil have complete 5000 hours at high discharge temperature conditions (~140 C).

No change in TAN of lubricant
Fluoride and Iodide are within acceptable limits

Systems testing are ongoing with several manufacturers
All of the above show reliable performance.
CONCLUDING REMARKS

- This work introduced R-466A, a replacement for R410A that fulfills regulations (GWP<750), maintains high level of energy efficiency, and provides the same level of safety (ASHRAE class 1).
- Experimental evaluation in typical residential heat pump system
  - It shows the energy efficiency has a close match to R410A at typical ambient temperatures.
  - It was also found that this refrigerant provide significant higher efficiency at high ambient temperatures (+5% at 55C).
- Solubility and miscibility with POE 32 oil has also been evaluated.
- Initial evaluations of thermal stability and material compatibility was also presented.
- Currently working with the industry to evaluate many types of compressors, heat exchangers and systems.
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