Recent Developments in Low GWP Refrigerants for Air Conditioning & Refrigeration Applications

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Agenda

- Introduction – Honeywell’s Solstice™ Refrigerants
- Evaluation Results of Low GWP Alternatives to R-410A
  - Performance
  - Lubricant Evaluations
- Evaluation of Low GWP Alternatives to R-22 at high ambient application
  - Simulation Results
  - Learnings for High Ambient Applications
- Summary
Introduction and Product Overview
Decision-Making Criteria vs. Alternatives

Environmental
- Low Global Warming Potential
- Zero Ozone Depletion
- Good Life Cycle Climate Performance in All Climates
- Recycling / Reclamation

Safety
- In Use, Storage, Transport
- Comprehensive Toxicology Testing
- Acceptable Flammability

Performance
- High Energy Efficiency Over Complete Operating Range
- Long-term Durability

Cost-To-Serve
- Low Capital Cost
- Low Operating Cost
- Better Cost vs. Alternatives
- Low System Maintenance

Must Meet All Criteria to Allow Rapid Adoption
### Solstice™ HFO’s for Low and Medium Pressure Applications

<table>
<thead>
<tr>
<th>Current Product</th>
<th>Non Flammable</th>
<th>Mildly Flammable (ASHRAE A2L)</th>
<th>Examples of Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC-134a</td>
<td></td>
<td>Solstice yf GWP = 4</td>
<td>Auto A/C, Vending, Refrigerators</td>
</tr>
<tr>
<td>GWP=1430</td>
<td></td>
<td>Solstice ze GWP = 6</td>
<td>Chillers, CO₂ Cascades Refrigerators</td>
</tr>
<tr>
<td>R-123</td>
<td>Solstice zd GWP &lt;5</td>
<td></td>
<td>Centrifugal Chillers</td>
</tr>
</tbody>
</table>
# Honeywell’s Solstice™ Low GWP Refrigerant Blends

## Solstice™ HFO Blends

<table>
<thead>
<tr>
<th>Current Product</th>
<th>Solstice™ N Series</th>
<th>Solstice™ L Series</th>
<th>Examples of Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reduced GWP Option</td>
<td>Lowest GWP Option</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non Flammable (ASHRAE A1)</td>
<td>Mildly Flammable (ASHRAE A2L)</td>
<td></td>
</tr>
<tr>
<td>HFC-134a</td>
<td>N-13 – GWP ~600</td>
<td></td>
<td>Chillers, Med-temp Refrigeration</td>
</tr>
<tr>
<td>GWP=1430</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCFC-22</td>
<td>N-20 – GWP ~1000</td>
<td>L-20 – GWP &lt;300</td>
<td>Stationary A/C, Refrigeration</td>
</tr>
<tr>
<td>GWP=1810</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-404A</td>
<td>N-40 – GWP ~1300</td>
<td>L-40 – GWP &lt;300</td>
<td>Low-Temp Refrigeration</td>
</tr>
<tr>
<td>GWP=3922</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-410A</td>
<td></td>
<td>L-41 – GWP &lt;500</td>
<td>Stationary A/C Applications</td>
</tr>
<tr>
<td>GWP=2088</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Solstice™ HFO Blends for Medium & High Pressure Applications**
Commercial Status of Solstice™ Products

**Solstice™ yf**
- In commercial use by auto industry now
- Sample quantities available today for stationary applications

**Solstice™ ze**
- Commercially available today
- Announced world scale plant for 2013

**Solstice™ Blends**
- Contains Solstice ze and/or yf blended with other products
- Recently announced availability of Solstice™ L-41, L-20, N-20, etc.
- Currently sampling to OEM’s and compressor manufacturers
- Currently being evaluated by AHRI’s AREP Program

*Working with Industry to Commercialize Solstice™*
Evaluation of Low GWP Alternatives to R-410A
A ductless split system was evaluated at Honeywell’s test facility in Shanghai

- DC inverter heat pump with nominal cooling capacity of 3.6 kW and nominal heating capacity of 5.0 kW
- Test conditions based on ISO Std. 5151 as shown below:
- For L-41, a compressor with slightly larger displacement (11.3 cc vs. 10.2 cc) was used

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Indoor Ambient</th>
<th>Outdoor Ambient</th>
<th>Compressor speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DB (°C)</td>
<td>WB (°C)</td>
<td>DB (°C)</td>
</tr>
<tr>
<td>cool-01 (T1 rating, moderate climate)</td>
<td>27</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td>cool-02 (T1 Intermediate)</td>
<td>27</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td>cool-03 (T2 rating, cool climate)</td>
<td>21</td>
<td>15</td>
<td>27</td>
</tr>
<tr>
<td>cool-04 (T3 rating, hot climate)</td>
<td>29</td>
<td>19</td>
<td>46</td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td></td>
<td>DB (°C)</td>
<td>WB (°C)</td>
<td>DB (°C)</td>
</tr>
<tr>
<td>Heat-01 (High Temp. rating)</td>
<td>20</td>
<td>&lt;15</td>
<td>7</td>
</tr>
<tr>
<td>Heat-02 (High Temp. intermediate)</td>
<td>20</td>
<td>&lt;15</td>
<td>7</td>
</tr>
<tr>
<td>Heat-03 (Low Temp. rating)</td>
<td>20</td>
<td>&lt;15</td>
<td>2</td>
</tr>
<tr>
<td>Heat-03 (Extra Low Temp. rating)</td>
<td>20</td>
<td>&lt;15</td>
<td>-7</td>
</tr>
</tbody>
</table>
Solstice™ L-41: Performance-Mini-Split System

**Performance Results**

- Higher efficiency achieved for both heating and cooling modes relative to R410A
- Lower capacity with nominal compressor; slightly higher displacement compressor required
- Capacity and Efficiency results match R410A performance with higher displacement compressor
- Discharge temperature was slightly higher with L-41 (~11°C) but well below maximum permissible and below temperatures seen with R-32

*Low GWP solutions for R410A based systems developed*
Tests were recently conducted with our latest L-41 refrigerant in a representative ducted split heat pump.

- With reduced R-32 content, a further reduce discharge temperatures and an increase solubility of current lubricants was achieved enabling use of current compressor technology in all climates.
- Capacity was reduced but a slightly larger displacement compressor (~10%) recovered this capacity without negatively impacting efficiency.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Glide Ev (°C)</th>
<th>Capacity (35°C Amb.)</th>
<th>Efficiency (28°C Amb.)</th>
<th>Td (°C) 46°C Ambient</th>
<th>Heating Rating (+8°C Amb.)</th>
<th>Heating Low Temp (-8°C Amb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410A</td>
<td>0.1</td>
<td>100%</td>
<td>100%</td>
<td>96</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>R32</td>
<td>0.0</td>
<td>108%</td>
<td>101%</td>
<td>119</td>
<td>105%</td>
<td>100%</td>
</tr>
<tr>
<td>L-41*</td>
<td>3.8</td>
<td>104%</td>
<td>100%</td>
<td>109</td>
<td>104%</td>
<td>101%</td>
</tr>
</tbody>
</table>

* 11% Larger Displacement Compressor

**Promising Results for Solstice™ L-41**
Most system designs assume that the refrigerant and oil are miscible (one liquid layer).

Immiscibility can lead to oil logging in various parts of the system and can lead to poor oil return to the compressor or an oil slug to enter the compressor.

Unlike R-32, L-41 has no immiscible region for all likely operating temperatures of the a/c or heat pump.

**Solstice™ L-41 Works Well with Existing Lubricant**
Solstice™ L-41 Success Story

Haier Network Smart Appliance Project

- World’s first Solstice L41 A/C
- A cooperative effort between:
  - Honeywell - Shanghai R&D Center
  - Haier - National Laboratory
- Presented in
  - HVAC China  Jul’12, Apr’13
  - Chillventa Europe  Oct’12

- More than 75% reduction in GWP versus R410A
- 30% reduction in GWP versus R32
- Lower discharge pressure than R32
- Lower Discharge temperature than R32
- Lower power consumption than R410A and R32 at high ambient temperature regions
Low GWP Alternatives to R-22
For High Ambient Application
Impact of Critical Temperature at High Ambient Conditions

R22 like

\[ T_{cr} = 96^\circ C \]

More efficient as cycle operates away from critical temperature

R410A like

\[ T_{cr} = 71^\circ C \]

Less efficient as cycle operates close to critical temperature
L20 closely matches R22’s performance (98% at 46°C ambient temperature)
R410A like fluids experience performance degradation at high ambient temperatures
Simulation of 1 Ton Minisplit Designed @ 35°C (T1)

- Systems designed to match capacity and EER (10.2) at 35°C. R22 System has EER of 7.9 at 46°C.
- N20 needs significantly larger compressor (25%) and heat exchangers (10%).
- At 46°C, all alternatives have similar capacity with L20 having the best efficiency.
- Even at 52°C (peak ambient condition), L20 efficiency is very close to R22.

L-20 combines the lowest GWP with the best performance
Learnings for High Ambient Applications

**Systems designed at current Standard conditions of 35°C (T1)**
- R22-like refrigerants have only a minimal performance degradation when working at peak conditions (46°C to 52°C).
- L-20 is the top performer in both direct (lowest GWP) and indirect (energy-efficiency) effect. Differences become more significant in hot climates.
- L-20 enables the use of current R22 technologies (compressors, heat exchangers), minimizing impact for the industry and also end users.

**Systems Designed at 46°C (T3)**
- When designed for high ambient temperatures, performance of all refrigerants are similar. Still some changes are needed.
  - R410A-like refrigerants will need to add more heat exchanger area to minimize performance degradation at high ambient.
  - The cost of these systems increases due to additional material and potential changes in the manufacturing process.
  - R410A-like refrigerants would need 12-25% more heat exchanger area whereas R22-like refrigerants would only need 5-15% (relative to T1 design)
  - The users will still have to deal with issues such as high pressures, high discharge temperatures and potential overload of the compressor.

**L-20 offers superior performance even at peak conditions!**
Honeywell has developed a family of Low GWP Refrigerants to replace today’s most common refrigerants in both unitary and chillers stationary a/c applications.

Latest R-410A replacement, L-41 offers comparable performance to both R-410A and R-32 but avoids the issues of high discharge temperature and poor miscibility with existing lubricants that is associated with R-32 while offering lower GWP.

We are continuing to work closely with industry to evaluate these products in a broad range of stationary air conditioning applications.

HFO’s and HFO blends should be considered as part of the solution to transition away from High GWP refrigerants.
Thank you!!!

Questions?

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