LOW GWP CHILLER DEVELOPMENT

Honeywell
Agenda

- Introduction
- Refrigerant Roadmap
- Chiller Fluids
- Compressor Technologies
- Medium Pressure Chillers
- Low Pressure Chillers
- Conclusions
F-Gas Implications On Chillers

- Phase down controlled by a quota allocation system
- Declining supply of HFC
- Increasing refrigerant prices weighted on GWP value
Eco-Design Implications On Chillers

Large number of chillers will not meet MEPS targets
# Review Of The Solstice® Family

## Solstice® HFO molecules

### Low and medium pressure applications

<table>
<thead>
<tr>
<th></th>
<th>Nonflammable (ASHRAE A1)</th>
<th>Mildly flammable (ASHRAE A2L)</th>
<th>Examples of potential applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R-134a</strong>&lt;br&gt;GWP=1300</td>
<td></td>
<td><strong>Solstice® yf</strong>&lt;br&gt;GWP* &lt; 1</td>
<td>Auto A/C, Vending, Refrigerators</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Solstice® ze</strong>&lt;br&gt;GWP* &lt; 1</td>
<td>Chillers, CO₂ Cascades Refrigerators</td>
</tr>
<tr>
<td><strong>R-123</strong>&lt;br&gt;GWP= 79</td>
<td><strong>Solstice® zd</strong>&lt;br&gt;GWP* = 1</td>
<td></td>
<td>Centrifugal Chillers&lt;br&gt;High temperature heat pump</td>
</tr>
</tbody>
</table>

## Solstice® Blends

<table>
<thead>
<tr>
<th></th>
<th>Non Flammable (ASHRAE A1)</th>
<th>Mildly Flammable (ASHRAE A2L)</th>
<th>Examples of potential app.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R-134a</strong>&lt;br&gt;GWP=1300</td>
<td><strong>Solstice® N13 (R-450A)</strong>&lt;br&gt;GWP* = 547</td>
<td><strong>Solstice® N13az (R-515A)</strong>&lt;br&gt;GWP* = 390</td>
<td>Chillers, Med-temp Refrigeration</td>
</tr>
<tr>
<td><strong>R-404A</strong>&lt;br&gt;GWP=3943</td>
<td><strong>Solstice® N40 (R-448A)</strong>&lt;br&gt;GWP* = 1273</td>
<td><strong>Solstice® L40X (R-455A)</strong>&lt;br&gt;GWP* = 146</td>
<td>Low-Temp Refrigeration</td>
</tr>
<tr>
<td><strong>R-22</strong>&lt;br&gt;GWP=1760</td>
<td></td>
<td><strong>Solstice® L20 (R-444B)</strong>&lt;br&gt;GWP* = 295</td>
<td>Stationary A/C, Refrigeration</td>
</tr>
<tr>
<td><strong>R-410A</strong>&lt;br&gt;GWP=1923</td>
<td></td>
<td><strong>Solstice® L41 (R-447A)</strong>&lt;br&gt;GWP* = 572</td>
<td>Stationary A/C Applications</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Solstice® L41y (R-452B)</strong>&lt;br&gt;GWP* = 698</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Solstice® L41z (R-447B)</strong>&lt;br&gt;GWP* = 740</td>
<td></td>
</tr>
</tbody>
</table>

* IPCC, AR5
** Provisional ASHRAE number
Chiller Fluids

<table>
<thead>
<tr>
<th></th>
<th>Molar Mass</th>
<th>Critical Temperature °C</th>
<th>Normal Boiling Point °C</th>
<th>GWP</th>
<th>ODP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R11</td>
<td>137</td>
<td>197.6</td>
<td>23.71</td>
<td>4750</td>
<td>1.000</td>
</tr>
<tr>
<td>R123</td>
<td>153</td>
<td>183.68</td>
<td>27.82</td>
<td>77</td>
<td>0.020</td>
</tr>
<tr>
<td>Solstice® zd</td>
<td>131</td>
<td>165.5</td>
<td>19</td>
<td>1</td>
<td>0.000</td>
</tr>
<tr>
<td>R12</td>
<td>121</td>
<td>111.97</td>
<td>-29.75</td>
<td>10900</td>
<td>1.000</td>
</tr>
<tr>
<td>R134a</td>
<td>102</td>
<td>101.06</td>
<td>-26.07</td>
<td>1300</td>
<td>0.000</td>
</tr>
<tr>
<td>Solstice® yf</td>
<td>114</td>
<td>94.7</td>
<td>-29.45</td>
<td>1</td>
<td>0.000</td>
</tr>
<tr>
<td>Solstice® ze</td>
<td>114</td>
<td>109.37</td>
<td>-18.95</td>
<td>1</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Some working fluids properties

- Solstice™ zd is best-suited for low pressure chiller applications
- Solstice™ yf and Solstice™ ze are best-suited to medium pressure chiller applications

HFO's possess essential properties required for use in chiller applications
Chiller Fluids

• Operating pressures are function of refrigerant type used.
• Leaks are pressure dependant.
• Low pressure fluids are key to “leak-tight” chillers.
• Solstice™ yf and Solstice™ ze are best-suited to medium pressure chiller applications
• Solstice™ zd is best-suited for low pressure chiller applications
Refrigerant Cycle Efficiency

![Graph showing Refrigerant Cycle Efficiency with COP values and boiling points for different refrigerants. The graph is labeled with relative COP to R11 on the y-axis and normal boiling point (°C) on the x-axis. The refrigerants are categorized into High, Medium, and Low Pressure zones.]
Chiller Compressor Technologies

- **High Pressure**
- **Medium Pressure**
- **Low Pressure**

- 1 kW
- 50 kW
- 500 kW
- 2 MW
- 20+ MW
Danfoss Turbocor TG Series - HFO 1234ze Efficiency

- Energy efficiency improvements up to 3% when compared to similar R134a systems
- HFO-1234ze is the only medium pressure, ultra low-GWP alternative, without an efficiency tradeoff
- High efficiency at full load and extraordinarily high efficiency at part load conditions
- Oil-Free avoids challenges refrigerant/lubricant and heat exchangers fouling
Expanded Series Of TG Compressors

Danfoss Turbocor Compressor Portfolio

Refrigeration Capacity (kW)

TG Series
- TG310 60-90 TR
- TG390 70-120 TR
- TG520 90-150 TR

TT Series
- TT230 40-70 TR
- TT300 60-90 TR
- TT350 70-120 TR
- TT400 90-150 TR
- TT700 130-200 TR

VTT Series
- VTT300 Up to 300 TR
- VTT350 Up to 250 TR
- VTT880 Up to 250 TR
- VTT1000 Up to 300 TR
- VTT1200 Up to 350 TR

Refrigeration Capacity (Tons)
Operating Envelope Same As R134a

TG Series – Air Cooled Capable Range

TG230 TG310
Operating Envelope Same As R134a

TG Series – Water Cooled Capable Range

TG390

TG520
FRASCOLD Screw Compressors
Series CX approved for HFO refrigerants
Frascold CX Compressor – 1234ze Series

Frascold CX Compressor – 1234yf Series
Bitzer Compact Screw Compressors

The "CSH" has been selectively developed with a view to its application in air cooled liquid chillers and heat pumps intended for operation at higher condensing temperatures.

The "CSW" series has been developed for use at lower condensing temperatures, as is usual in countries with cooler climates or when using water-cooled condensers.

Products developed for refrigerants like R1234yf, R1234ze and low GWP.

High efficiency in full and part load
- Efficiency improvements of motor and mechanics
- High system efficiency in part load operation
- Optimized mechanical capacity regulation
- Specially developed frequency inverters
Bitzer Compact Screw Compressors
Bitzer Compact Screw Compressors

Application Limits

R1234yf & R134a standard

R1234ze

© 2016 by Honeywell International Inc. All rights reserved.
Carrier AquaForce Chiller

- 4 years of development work, 320 fluids investigated
- HFO1234ze with Screw compressor technology identified as best choice in terms of Efficiency
- All components and Oil have been qualified for HFO1234ze
- Field trials in progress in various regions. Switzerland (19), France(3), Norway(1), Holland(1)

https://www.youtube.com/watch?v=wVhMGGTK5WQ
https://www.youtube.com/watch?v=k3FgzXxIut4
Carrier AquaForce Chiller

On average 5% higher efficiency vs R134a Chiller

https://www.youtube.com/watch?v=k3FgzXxlut4
https://www.youtube.com/watch?v=wVhMGGTK5WQ
Case Study: Plan-les-Ouatres Geneva

Data Centre Cooling and 4.5MW of heating (+Hot Water) to offices, Industry and 3000 homes.

https://www.youtube.com/watch?v=wVhMGGTK5WQ#t=122.4806597
http://www.coolingpost.com/world-news/carrier-latest-to-install-r1234ze-chiller/
TRANE CenTraVac™ Chiller

R-1233zd based chillers are now part of TRANE European product range.

CVHH
- 3-Stage Direct Drive
- Heat Recovery

CDHH
- 3-Stage Direct Drive
- Dual Refrigerant Circuit

© 2016 by Honeywell International Inc. All rights reserved.
TRANE CenTraVac™ Chiller

- The First Low Pressure Centrifugal Chiller using 1233zd, released by TRANE
- Range extended to 14MW (largest HFO Chiller Capacity on the market)
- Up to 13.5% more energy efficiency than the next best chiller available in this tonnage range
- Combining high efficiency benefits associated with low pressure fluids and high capacity due to slightly higher pressure than R123

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVHG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Drive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CVHH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Drive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 or 3-Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDHG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Drive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDHH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Drive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 or 3-Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-123

R-1233zd

Market Leading Efficiency/Capacity achieved with 1233zd
Solstice® zd Cools The Channel Tunnel

the largest HFO chiller installation of its kind in the world, Trane CenTraVac’s using R1233zd(E) will replace the existing R22 chillers serving the Channel Tunnel.*

One of the new Trane chillers during installation in the Sangatte plant*

Solstice® zd Cools the Channel Tunnel

• Solstice zd Chosen for the renovation of the channel tunnel refrigeration system
• 4 New Solstice zd Chillers replaced R22 old system
• Each chiller providing 26MW cooling load, to maintain tunnel temperature below 25°C
• 10% Higher energy efficiency with savings of 200 000 euros/year

The transition to R1233zd has reduced considerably the environmental footprint of the Channel Tunnel:

- No Ozone depletion
- 10% reduction in indirect emissions
- No direct emissions
Recent Solstice® Launches

Solstice zd chillers
• Trane High Efficiency Chillers
• Mitsubishi Heavy Electric

Solstice ze chillers/heat pumps
• Carrier Aqua Force screw chillers
• Danfoss Turbocor compressor for 1234ze
• Friotherm district heating & cooling
• Geoclima screw and centrifugal
• Star Refrigeration high efficiency Turbocor
• Airedale chillers with free cooling
• Cofely Turbocor chiller
• Multistack screw chiller
• Cooltherm chillers
• Smardt chillers
• Blue Box
• RC high efficiency screw chiller, water- and air-cooled chillers
• Climaveneta
• Rhoss
• Aermec
• Viessmann…
Eco-Design Implications On Chillers

Eurovent Chiller Performance Data

- Large number of chiller will not meet MEPS targets
- Solstice® ze chiller with variable speed compressor exceed the MEPS
Summary

• Honeywell Fluorine Products has Established Technical Leadership in Offering Energy Efficient and Environmental Friendly Solutions

• Solstice® Low Global Platform Covering a Broad Spectrum of Applications are Being commercialized Globally

• Solstice® ze successfully replacing R134a in medium pressure chillers

• Solstice® zd matches R123 efficiency with higher capacity in low pressure chillers.

• Solstice® Platform ready to meet F-Gas Cap & Phase Down Needs in Europe and Support High Growth Region’s
Honeywell

Solstice® Refrigerants

http://www.honeywell-refrigerants.com/europe/

nacer.achaichia@Honeywell.com

stefan.schuessler@Honeywell.com

DISCLAIMER

Although all statements and information contained herein are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve the user from the responsibility of carrying out its own tests and experiments, and the user assumes all risks and liability for use of the information and results obtained. Statements or suggestions concerning the use of materials and processes are made without representation or warranty that any such use is free of patent infringement and are not recommendations to infringe on any patents. The user should not assume that all toxicity data and safety measures are indicated herein or that other measures may not be required.