Understanding Applications for Alternative Refrigerants

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Goals for Today’s Discussion

• Brief discussion on industry drivers
• Communicate differences in applying lower-GWP A1 refrigerants
  – Reliability and performance
• Discuss which challenges face the different channels
  – OEMs, wholesalers, contractors, end users
• Update on A2L/A3 refrigerants
  – Industry activity
  – Emerson’s readiness and facility investment

Is it reliable?
Lower-GWP Synthetic Refrigerants, Blends and Natural Refrigerants Are Available Options in Various Applications.
## Summary of EPA’s Refrigerant SNAP Approval and Delistings by Application

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>GWP</th>
<th>Supermarket (New**)</th>
<th>Supermarket (Retrofit***)</th>
<th>Remote condensing unit (New)</th>
<th>Remote condensing unit (Retrofit***)</th>
<th>Stand-Alone</th>
<th>Refrigerated food processing and dispensing equipment (New)</th>
<th>Cold storage warehouses (New)</th>
<th>Ice machines (New)</th>
<th>Very low-temp refrigeration (New)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-452A</td>
<td>2,140</td>
<td>-</td>
<td>-</td>
<td>OK</td>
<td>OK</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>1,300</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>Jan. 1, 2019</td>
<td>Jan. 1, 2020</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>R-448A</td>
<td>1,282</td>
<td>1,296</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>Neither SNAP-approved, nor banned</td>
<td>Neither SNAP-approved, nor banned</td>
<td>OK</td>
<td>OK for LT only</td>
<td>-</td>
</tr>
<tr>
<td>R-513A</td>
<td>573</td>
<td>547</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>R-450A</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>R-744</td>
<td>1</td>
<td>OK</td>
<td>-</td>
<td>OK</td>
<td>-</td>
<td>OK</td>
<td>OK</td>
<td>-</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>R-717</td>
<td>0</td>
<td>OK (in primary loop of secondary system)</td>
<td>-</td>
<td>OK (in primary loop of secondary system)</td>
<td>-</td>
<td>OK (in primary loop of secondary system)</td>
<td>OK (in primary loop of secondary system)</td>
<td>OK (in primary loop of secondary system)</td>
<td>OK (in primary loop of secondary system)</td>
<td>OK</td>
</tr>
</tbody>
</table>

** Includes ice machines connected to a supermarket rack refrigeration system.

*** EPA uses term “retrofit” to indicate the use of a refrigerant in an appliance that was designed for and originally operated using a different refrigerant. Term does not apply to upgrades to existing equipment where the refrigerant is not changed.

*Abbreviated; for complete listing, see EPA website.
## Refrigeration Application Alternatives

### Emerson’s Approvals in Progress or Complete

<table>
<thead>
<tr>
<th>Volumetric Capacity / Pressure</th>
<th>Naturals</th>
<th>Mildly Flammable (A2L) HFO and Blends</th>
<th>Lowest GWP Non-Flammable (A1) HFC/HFO blends</th>
<th>Today’s Non-flammable (A1) HFCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevated</td>
<td>R-744 (CO₂) 1</td>
<td>R-455A (HDR-110) 146 R-454C (XL20) 146 R-457A (ARM-20a) 139</td>
<td>R-449A (XP40) 1,282 R-448A (N40) 1,273 R-449B (ARM-32) 1,296</td>
<td>R-407A 1,923 R-407C 1,624 R-407F 1,674</td>
</tr>
<tr>
<td>Medium “R-404A like”</td>
<td>R-290 (Propane) 3</td>
<td>R-455A (HDR-110) 146 R-454C (XL20) 146 R-457A (ARM-20a) 139</td>
<td>R-449A (XP40) 1,282 R-448A (N40) 1,273 R-449B (ARM-32) 1,296</td>
<td>R-507A 3,985 R-404A 3,943</td>
</tr>
<tr>
<td>R-717 (Ammonia) 0</td>
<td>R-455A (HDR-110) 146 R-454C (XL20) 146 R-457A (ARM-20a) 139</td>
<td>R-449A (XP40) 1,282 R-448A (N40) 1,273 R-449B (ARM-32) 1,296</td>
<td>R-507A 3,985 R-404A 3,943</td>
<td></td>
</tr>
<tr>
<td>Low “R-134a like”</td>
<td>HFO-1234yf &lt;1</td>
<td>HFO-1234ze &lt;1 ARM-42 131</td>
<td>R-513A (XP10) 573 R-450A (N13) 547 R-515A 392</td>
<td>R-134a 1,300</td>
</tr>
<tr>
<td>GWP</td>
<td>0–5</td>
<td>0–150</td>
<td>350–1,300</td>
<td>1,300–4,000</td>
</tr>
</tbody>
</table>

### GWP Values

- **A1** – Non-flammable
- **A2L** – Mildly flammable
- **A3** – Flammable
- **B2L** – Toxic, mildly flammable

*This List Is Subject to Change. Please Check Publication, Form 93-11 or With Emerson Representatives for the Most Current Approvals in Progress.*
Goals for Today’s Meeting

• Brief discussion on industry drivers

• Communicate differences in applying lower-GWP A1 refrigerants
  – Reliability and performance

• Discuss which challenges face the different channels
  – OEMs, wholesalers, contractors, end users

• Update on A2L/A3 refrigerants
  – Industry activity
  – Emerson’s readiness and facility investment
What Should a Compressor Manufacturer Do to Qualify a New Refrigerant?

A Great Amount of Due Diligence Needs to Be Done by Compressor Manufacturers When Qualifying New Refrigerants for an Application.
Theoretical Discharge Temperature (Medium-Pressure)

**Low-Temperature** (-25 °F Evaporator)

- R448A/449A
- R407A
- R455A
- R457A
- R454C
- R-452A
- R-404A

**Medium-Temperature** (20 °F Evaporator)

- R448A/449A
- R407A
- R455A
- R457A
- R454C
- R-452A
- R-404A

assumes 100% isentropic efficiency

*Compressor Cooling Will Be Needed for Many R-404A Replacements in Low-Temp Applications.*
R-404A A1 Low-GWP Alternatives Have Higher Heat of Compression

Increase in Discharge Temperature Dependent on Condition
R-404A vs. R-448A Operating Envelopes
ZS*KA Example

Check Application Engineering Bulletin Before Applying the Same Compressor in an Application With Different Refrigerants.
Models With Liquid Injection Can Still Run Full Operating Envelope Capabilities

Compressors Running Higher Heat of Compression Refrigerants Can Run Reliably With Injection; More Power Will Be Consumed.
Theoretical Discharge Temperature (Low-Pressure)

Low-Temperature (-25 °F Evaporator)

Medium-Temperature (20 °F Evaporator)

Discharge Temperature Minimal Concern for Low-Pressure Refrigerants.
**R-134a A1 Alternatives Have Very Similar Heat of Compression Characteristics**

**Operating Envelopes for R-450A and R-513A Equivalent to R-134a Maps**
Theoretical Compressor Capacity (Medium-Pressure)

Low-Temperature (-25 °F Evaporator)

Medium-Temperature (20 °F Evaporator)

R-404A Replacements Do Not Deliver as Much Capacity.

assumes 100% volumetric efficiency, dew point condition
Heat exchangers (condenser and evaporator) operate at mid-point (or bubble/dew) conditions.

Compressors see dew point conditions.

When there is no glide and assuming little/no pressure drop, the temperature at mid-point = temperature at dew point.

Assume negligible pressure drop effects.
But when there is glide …

Per AHRI standards, compressors are rated based on dew point pressure/temperatures.

Assume negligible pressure drop effects.

When there is glide and assuming little/no pressure drop, the temperature at mid-point ≠ temperature at dew point.
Temperature Glide is Significant for A1 R-404A Replacements

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Temperature Glide °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-404A</td>
<td>~1 °F</td>
</tr>
<tr>
<td>R-407A</td>
<td>~8 °F</td>
</tr>
<tr>
<td>R-448A</td>
<td>~7 °F</td>
</tr>
<tr>
<td>R-449A</td>
<td>~7 °F</td>
</tr>
<tr>
<td>R-452A</td>
<td>~5 °F</td>
</tr>
</tbody>
</table>

Significant considerations needed for temperature glide (system component sizing, etc.)
Scroll MT — Dew Point Capacity
R-404A vs. R-407A/R-448A (20/120)

Medium Temperature 20/120
Capacity (Dew Point)

Compressor: ZB45KCE-TF5 (60Hz)
Scroll MT — Mid/Dew Point Capacity
R-404A vs. R-407A/R-448A (20/120)

Why is this delta important?

Compressor: ZB45KCE-TF5 (60Hz)
Scroll LT — Mid/Dew Point Capacity
R-404A vs. R-407A/R-448A (-25/105)

Compressor sizing should be done off of mid-point.
Scroll MT — Mid/Dew Point Weighted EER
R-404A vs. R-407A/R-448A

Medium Temperature Weighted EER (Mid Point)

<table>
<thead>
<tr>
<th></th>
<th>R-404A Baseline</th>
<th>-2.2% vs R-404A</th>
<th>-0.1% vs R-404A</th>
</tr>
</thead>
</table>

Medium Temperature Weighted EER (Dew Point)

<table>
<thead>
<tr>
<th></th>
<th>R-404A Baseline</th>
<th>-2.1% vs R-404A</th>
<th>-0.3% vs R-404A</th>
</tr>
</thead>
</table>

Compressor: ZB45KCE-TF5 (60Hz)

Low Temp Weighted Condition = 20% (-25 Evap/105 Cond) +80% (-25 Evap/70 Cond)
Med Temp Weighted Condition = 20% (20 Evap/120 Cond) +80% (20 Evap/70 Cond)
Scroll LT — Mid/Dew Point Weighted EER
R-404A vs. R-407A/R-448A

Low Temperature Weighted EER (Mid Point)

- R404A Baseline
- +0.7% vs R404A
- -4.8% vs R404A

Low Temperature Weighted EER (Dew Point)

- R404A Baseline
- -0.9% vs R404A
- -6.1% vs R404A

Compressor: ZFD25KVE-TFD (60Hz)

Low Temp Weighted Condition: 20% (-25 Evap/105 Cond) +80% (-25 Evap/ 70 Cond)
Med Temp Weighted Condition: 20% (20 Evap/120 Cond) +80% (20 Evap/ 70 Cond)
Temperature Glide Is Significant for A1 R-404A Replacements, not so for R-134a

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Temperature Glide °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-404A</td>
<td>~1 °F</td>
</tr>
<tr>
<td>R-407A</td>
<td>~8 °F</td>
</tr>
<tr>
<td>R-448A</td>
<td>~7 °F</td>
</tr>
<tr>
<td>R-449A</td>
<td>~7 °F</td>
</tr>
<tr>
<td>R-452A</td>
<td>~5 °F</td>
</tr>
<tr>
<td>R-134a</td>
<td>0 °F (single component)</td>
</tr>
<tr>
<td>R-450A</td>
<td>~1 °F (near azeotrope)</td>
</tr>
<tr>
<td>R-513A</td>
<td>0 °F (azeotrope)</td>
</tr>
</tbody>
</table>

Significant considerations needed for temperature glide (system component sizing, etc.)

No glide considerations necessary
Theoretical Compressor Capacity (Low-Pressure)

**Low-Temperature** (-25 °F Evaporator)

**Medium-Temperature** (20 °F Evaporator)
Hermetic LT Capacity
R-134a vs. R-450A/R-513A

Compressor: AFE12C4E
Hermetic HT — Weighted EER
R-134a vs. R-450A and R-513A

Weighted EER Condition = 20% (20 Evap / 120 Cond) + 80% (20 Evap / 70 Cond)
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### Alternate Refrigerants — Challenges Through the Channel

<table>
<thead>
<tr>
<th>Challenges</th>
<th>OEMs</th>
<th>Wholesalers</th>
<th>Contractors</th>
<th>End Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component selection</td>
<td>SKU proliferation</td>
<td>Training</td>
<td></td>
<td>Regulatory compliance</td>
</tr>
<tr>
<td>System redesigns</td>
<td>Counter-training</td>
<td>Retrofit challenges</td>
<td></td>
<td>Sustainability goals</td>
</tr>
<tr>
<td>Engineering resources</td>
<td>Inventory planning</td>
<td></td>
<td>Energy consumption</td>
<td></td>
</tr>
<tr>
<td>Testing constraints</td>
<td></td>
<td></td>
<td>Short-term vs.</td>
<td>Long-term change</td>
</tr>
</tbody>
</table>

**Regulation Uncertainty**

*What Challenges Are You Faced With, Given All the Change in the Industry?*
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## Other Refrigerants, Standards, Code-Related Activities

<table>
<thead>
<tr>
<th>Safety standards under revision to include mildly flammable refrigerant (A2L) accommodations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U.S.</strong></td>
</tr>
<tr>
<td><strong>International</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CARB will start rulemaking process this fall that will affect high-GWP HFCs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Federal acquisition regulation encouraging low-GWP usage in federal buildings</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Section 608 revisions to refrigerant management now include HFCs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>EPA plans to revisit rule in response to petitions</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Evaluating revisions on increasing charge limits for flammables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U.S.</strong> A3 charge limit from 150g to 300g–500g</td>
</tr>
<tr>
<td>October meeting in Russia for IEC to make a decision on A3 charge limits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building codes for mildly flammable refrigerants being expedited for adoption in 2021 code cycle</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$5.2M partnership by AHRI, ASHRAE, DOE to study flammable refrigerant behavior in real-world applications</th>
</tr>
</thead>
</table>
Emerson Is Investing in A3/A2L Testing Capability to Be Prepared

- A3/A2L performance stands (10–200K)
- Life test stands
- Ambient chamber (0 °F – 120 °F)

Functionality Coming Online Throughout 2017
Questions?