Jason Prenger
Refrigeration Engineering Director
Emerson

Jason Prenger has more than 17 years of professional experience in the HVACR industry. During this time, he’s worked at Emerson in various roles, including engineering, operations and marketing. He currently serves as engineering director in refrigeration, where he is responsible for new product development for hermetic, semi-hermetic and scroll technologies.

Jason earned both a bachelor’s degree in mechanical engineering and a master’s degree in business administration from the University of Dayton.
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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
  – OEM, wholesalers, contractors, end users
• Update on A2L/A3 refrigerants
  – Industry activity
  – Emerson’s readiness and facility investment
Lower-GWP Synthetic Refrigerants, Blends and Natural Refrigerants Are Available Options in Various Applications.

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<thead>
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<tbody>
<tr>
<td>HFC-134a</td>
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<td>OK</td>
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<td>OK</td>
<td>Jan. 1, 2019</td>
<td>Jan. 1, 2020</td>
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<td>Likely alternatives (Emerson perspective)</td>
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<td></td>
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<tr>
<td>R-448A/449A</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK for LT only</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>R-450A/513A</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
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<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>R-290</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</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-744</td>
<td>OK</td>
<td>-</td>
<td>OK</td>
<td>-</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-717</td>
<td>OK</td>
<td>(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 (in primary loop of secondary system)</td>
<td>OK (in primary loop of secondary system)</td>
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</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.

See proposed rule; go to: https://www.gpo.gov/fdsys/pkg/FR-2016-04-18/pdf/2016-08163.pdf
### 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-290 (Propane) 3</td>
<td>R-449A (XP40) 1,282</td>
<td>R-407A 1,923</td>
</tr>
<tr>
<td></td>
<td>R-717 (Ammonia) 0</td>
<td>R-455A (HDR-110) 146</td>
<td>R-448A (N40) 1,273</td>
<td>R-407C 1,624</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-454C (XL20) 146</td>
<td>R-449B (ARM-32) 1,296</td>
<td>R-407F 1,674</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-457A (ARM-20a) 139</td>
<td></td>
<td>R-507A 3,985</td>
</tr>
<tr>
<td>Medium “R-404A like”</td>
<td></td>
<td></td>
<td>R-450A (N13) 547</td>
<td>R-404A 3,943</td>
</tr>
<tr>
<td>Low “R-134a like”</td>
<td></td>
<td></td>
<td>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>

*This List Is Subject to Change. Please Check Publication, Form 93-11 or With Emerson Representatives for the Most Current Approvals in Progress.*
Poll Question

Are you currently using or working with A1 replacement refrigerants for R-404A or R-134a?

Yes?
No?
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
  – OEM, 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?

OEMs Should Verify the Compressor Manufacturer Has Done Due Diligence Before Applying New Refrigerants to the Product.
R-404A A1 Low-GWP Alternatives Have Higher Heat of Compression

R-448A and R-449A have similar temperature profiles.

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 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.
R-134a A1 Alternatives Have Very Similar Heat of Compression Characteristics

![Graph showing operating envelopes for R-450A and R-513A]

Example of extended medium-temperature operating envelope

- R-134a: 160 °F
- R-450A: 155 °F
- R-513A: 144 °F

Operating Envelopes for R-450A and R-513A Equivalent to R-134a Maps
Drivers of System Capacity: Refrigerant Density

- Evaluate R-448A density relative to R-404A/R-407A

![Saturated Vapor Density Comparison Graph]

- R404A has significantly greater vapor density than R448A resulting in higher R404A mass flows
- R448A-R404A vapor density delta drops as temperature increases
- R407A & R448A have relatively similar vapor densities. Mass flows will be similar

<table>
<thead>
<tr>
<th>Evap Condition</th>
<th>Saturated Vapor Density In Evaporator (lbm/ft³)</th>
<th>Δ, Saturated Vapor Density %</th>
<th>Vapor Density @ 20°F Superheat (lbm/ft³)</th>
<th>Δ, 20°F Superheat Vapor Density %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-25 °F</td>
<td>R404A: 0.616  R407A: 0.416  R448A: 0.420</td>
<td>R404A Vs R448A: +32%</td>
<td>R404A: 0.582  R407A: 0.394  R448A: 0.398</td>
<td>R404A Vs R448A: +32%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R407A Vs R448A: -1%</td>
<td></td>
<td>R407A Vs R448A: -1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R407A Vs R448A: +1%</td>
<td></td>
<td>R407A Vs R448A: +2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R407A Vs R448A: +2%</td>
<td></td>
<td>R407A Vs R448A: +2%</td>
</tr>
</tbody>
</table>

Capacity Driven by Refrigerant Density and Enthalpy
Drivers of System Capacity: Refrigerant Enthalpy

- Evaluate R-448A theoretical enthalpy relative to R-404A/R-407A

<table>
<thead>
<tr>
<th>Condition (°F)</th>
<th>SH (°F)</th>
<th>SC (°F)</th>
<th>Subcooled Liquid Enthalpy (h4) @ Evap In (Btu/lbm)</th>
<th>Superheated Vapor Enthalpy (h1) @ Compressor In (Btu/lbm)</th>
<th>Change in Enthalpy [h4-h1] (Btu/lbm)</th>
<th>Percent Δ in Enthalpy Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>-25/105</td>
<td>20</td>
<td>10</td>
<td>R404A 108.32 R407A 108.26 R448A 108.76</td>
<td>R404A 153.93 R407A 167.07 R448A 169.04</td>
<td>R404A 45.61 R407A 58.81 R448A 60.28</td>
<td>R448A vs R404A 32.2% R448A vs R407A 2.5%</td>
</tr>
<tr>
<td>20/120</td>
<td>20</td>
<td>10</td>
<td>R404A 114.19 R407A 114.04 R448A 114.67</td>
<td>R404A 160.46 R407A 173.33 R448A 175.43</td>
<td>R404A 46.27 R407A 59.29 R448A 60.76</td>
<td>R448A vs R404A 31.3% R448A vs R407A 2.5%</td>
</tr>
<tr>
<td>20/70</td>
<td>20</td>
<td>10</td>
<td>R404A 95.57 R407A 95.59 R448A 97.223</td>
<td>R404A 160.46 R407A 173.33 R448A 175.43</td>
<td>R404A 64.89 R407A 77.74 R448A 78.21</td>
<td>R448A vs R404A 20.5% R448A vs R407A 0.6%</td>
</tr>
<tr>
<td>45/130</td>
<td>20</td>
<td>10</td>
<td>R404A 118.28 R407A 118.04 R448A 118.78</td>
<td>R404A 163.80 R407A 176.50 R448A 178.67</td>
<td>R404A 45.52 R407A 58.46 R448A 59.89</td>
<td>R448A vs R404A 31.6% R448A vs R407A 2.4%</td>
</tr>
</tbody>
</table>

R448A holds a significant advantage in theoretical enthalpy change over R404A across the evap and condensing ranges.

Capacity Driven by Refrigerant Density and Enthalpy
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)

Medium Temperature 20/120 Capacity (Dew Point)

- R404A Baseline
- R407A: -3.9% vs R404A
- R448A: -1.1% vs R404A

Medium Temperature 20/120 Capacity (Mid Point)

- R404A Baseline
- R407A: +0.2% vs R404A
- R448A: +3.0% vs R404A

Why is this delta important?
Mid-Point vs. Dew Point and the Refrigeration Cycle

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.
Mid-Point vs. Dew Point and the Refrigeration Cycle (continued)

But when there is glide …

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

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

Assume negligible pressure drop effects.
Scroll LT — Mid/Dew Point Capacity
R-404A vs. R-407A/R-448A (-25/105)

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

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)

<table>
<thead>
<tr>
<th>R404A Baseline</th>
<th>+0.7% vs R404A</th>
<th>-4.8% vs R404A</th>
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</table>

Low Temperature Weighted EER (Dew Point)

<table>
<thead>
<tr>
<th>R404A Baseline</th>
<th>-0.9% vs R404A</th>
<th>-6.1% vs R404A</th>
</tr>
</thead>
</table>

Compressor: ZFD26KVE-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) +60% (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>
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<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-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
Hermetic LT Capacity — R-134a vs. R-450A/R-513A

R-450A/R-513A vs. R-134a
Capacity 5/95 40 °F RG

- R-134a baseline
-14.1% vs. R-134a
+4.0% vs. R-134a

R-450A/R-513A vs. R-134a
Capacity -10/120 40 °F RG

- R-134a baseline
-14.7% vs. R-134a
+7.0% vs. R-134a

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

R-450A/R-513A vs. R-134a
WEER (65 °F return gas)

R-134a baseline
-0.5% vs. R-134a
-1.2% vs. R-134a

Compressor: ARE51C4

Weighted EER Condition = 20% (20 Evap / 120 Cond) + 80% (20 Evap / 70 Cond)
Poll Question

In terms of refrigerant characteristics, what is your biggest concern with the A1 replacements for R-404A & R-134a?

Reliability
Capacity match
Efficiency
Handling glide
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  - OEMs, wholesalers, contractors, end users
- Update on A2L/A3 refrigerants
  - Industry activity
  - Emerson’s readiness and facility investment
## Alternate Refrigerants — Challenges Through the Channel

<table>
<thead>
<tr>
<th>OEM</th>
<th>Wholesaler</th>
<th>Contractor</th>
<th>End User</th>
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<tbody>
<tr>
<td>Component selection</td>
<td>SKU proliferation</td>
<td>Training</td>
<td>Regulatory compliance</td>
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<tr>
<td>System redesigns</td>
<td>Counter training</td>
<td>Retrofit challenges</td>
<td>Sustainability goals</td>
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<tr>
<td>Engineering resources</td>
<td>Inventory planning</td>
<td></td>
<td>Energy consumption</td>
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<tr>
<td>Testing constraints</td>
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<td>Short-term vs. Long-term change</td>
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</tbody>
</table>
Poll Question

What is your biggest concern with the future transitions to new refrigerants?

• Availability
• Training
• Cost
• Time to prepare
• Inventory planning
Goals for Today’s Meeting

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Other Refrigerant, Standards, Code-Related Activity

| Federal acquisition regulation encouraging low-GWP usage in federal buildings |
| Section 608 revisions to refrigerant management now include HFCs |
| Safety standards under revision to include mildly flammable refrigerant (A2L) accommodations |
| Evaluating revisions on increasing charge limits for flammables |
| Building codes for mildly flammable (A2L) refrigerants being expedited for adoption in 2021 code cycle |
| $5.2M partnership by AHRI, ASHRAE, DOE to study flammable refrigerant behavior in real-world applications |

- **U.S.:** UL 1995, ASHRAE 15
  - Target late 2017
- **International:** ISO 5149, IEC 60335, EN378
  - Target late 2017

- **U.S.** A3 charge limit from 150g to 300g–500g

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**Refrigerant-related Changes Are Global in Scope; We Have to Stay on Top to Remain Competitive.**
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
Poll Question

What is your plan on evaluating A2L refrigerants as they would become SNAP approved?

• Immediately
• 3-9 months
• Longer-term
• Never, I would use A3’s
Questions?

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