R-22 Alternatives

75th Annual RSES Conference
November 16, 2012

Stephen V. Spletzer
Sr. Technical Sales Engineer
(610) 878-6980
Learning Outcomes / “Takeaways”

- Legislative / Regulatory Issues
- Status of the R-22 Phase-out
- Overview of Retrofit Issues
- Ability to Make an Informed Retrofit Selection
Legislative / Regulatory Issues

Status of the R-22 Phase-out
NA HFC Submission to the MP

The graph shows the cap (% baseline) for Non-Article 5 Parties and Article 5 Parties over the years from 2015 to 2050. The cap starts at 100% in 2015 and decreases progressively each year, with Non-Article 5 Parties reducing more rapidly than Article 5 Parties.
2012 Proposed Allocation Rule

HCFC-22 PHASE-OUT

- 2010 Allocation Rule
- Levels From Previous 2010 EPA Allocation Rule
- 2012 Proposed Rule - High Level
- 2012 Proposed Rule - Low Level
- Montreal Protocol HCFC Consumption Cap (Historical EPA Allowances Below This)
Regulatory Update

Illegal R-22 Importation

- DOJ Activity
  - HCFC-22 smuggling cases prosecuted

- Catch-22 Compliance Website / Number
  - http://www.klexserve.com/catch22
  - (866) 506-6134

- EPA Website
  - www.epa.gov/compliance/complaints/index.html
R-22 Transition Strategy

- Service as usual
  - Refrigerant price / availability
  - Leaks

- Replacement
  - Initial equipment costs
  - Energy savings
  - Refrigerant recovery

- Retrofit
  - Refrigerant / equipment / labor costs
  - Refrigerant recovery
  - Energy costs
Refrigerant Terminology

Replacement Refrigerant: intended for long term use in new equipment

Retrofit Refrigerant: used for servicing existing systems
  - Equipment changes
  - Oil changes

Replacements that are very similar to the original product may be used as retrofits
R-22 Replacement Refrigerants

Air Conditioning

- Forane 134a
- Forane 407C
- Forane 410A

Refrigeration

- Forane 22
- Forane 404A
- Forane 407A
- Forane 507A
The Truth About R-22 Retrofits

- None work as well as R-22 OVERALL
- None are as efficient as R-22 OVERALL
- None are “Drop-Ins”
- None are miscible with MO or AB
- None will work in every R-22 system
Overview of Retrofit Issues
Elastomer Changes

- **R-22 vs. HFCs with elastomers**
- **May need to change seals during retrofit**
  - Schrader valves / caps
  - Ball valves
  - Solenoid valves
  - EPRs
  - Filter-driers
  - Sight glasses
  - Receiver level gages
  - Etc

- **Leak check after retrofit**
Working with Blends

**Blend Identification**
- 400 or 500 series refrigerants
- Azeotropes, Zeotropes, & Near-azeotropes
- Charge all blends as liquid

**Fractionation:** preferential separation of a refrigerant blend’s components that occurs during phase change due to differences in component volatilities, which may affect performance / safety

**Glide:** a temperature gradient resulting from fractionation (evaporator / condenser) during the phase change process
Blends – Understanding Glide

INLET

OUTLET

= High Volatility

= Low Volatility

Refrigerant Temperature

Evaporator Position

FORANE® REFRIGERANTS

ARKEMA
Blends – Handling Leaks

Blend types
- Azeotropes / Near-azeotropes
- Zeotropes

Leak types
- Liquid vs. Vapor
- Running vs. Dormant System

Top–offs

Flooded evaporators
Discharge Temperature Effects

- R-22 suffers from high discharge temps
  - May exceed 300°F,
    @ high ambients / low temp

- Discharge temps of R-22 retrofits lower
  - Most typically < 250°F,
    even @ high ambients / low temp

- Need for liquid injection, desuperheaters, & oil coolers reduced / eliminated

- Improved capacity / efficiency for low temp
Ability to Make an Informed Retrofit Selection
R-22 Retrofit Blends

R-404A  R-407A  R-407C
R-407F  R-417A  R-417B
R-421A  R-421B  R-422A
R-422B  R-422C  R-422D
R-424A  R-427A  R-428A
R-434A  R-438A  R-507A
Etc.
## Blend Compositions (weight %)

<table>
<thead>
<tr>
<th>Blend</th>
<th>R-32</th>
<th>R-125</th>
<th>R-143a</th>
<th>R-134a</th>
<th>R-290</th>
<th>R-600a</th>
<th>R-600</th>
<th>R-601a</th>
<th>Lubricant</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-404A</td>
<td>-----</td>
<td>44.0</td>
<td>52.0</td>
<td>4.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-407A</td>
<td>20.0</td>
<td>40.0</td>
<td>-----</td>
<td>40.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-407C</td>
<td>23.0</td>
<td>25.0</td>
<td>-----</td>
<td>52.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-407F</td>
<td>30.0</td>
<td>30.0</td>
<td>-----</td>
<td>40.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-417A</td>
<td>-----</td>
<td>46.6</td>
<td>-----</td>
<td>50.0</td>
<td>-----</td>
<td>-----</td>
<td>3.4</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-417B</td>
<td>-----</td>
<td>79.0</td>
<td>-----</td>
<td>18.3</td>
<td>-----</td>
<td>-----</td>
<td>2.7</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-421A</td>
<td>-----</td>
<td>58.0</td>
<td>-----</td>
<td>42.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>Added</td>
</tr>
<tr>
<td>R-421B</td>
<td>-----</td>
<td>85.0</td>
<td>-----</td>
<td>15.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>Added</td>
</tr>
<tr>
<td>R-422A</td>
<td>-----</td>
<td>85.1</td>
<td>-----</td>
<td>11.5</td>
<td>-----</td>
<td>3.4</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-422B</td>
<td>-----</td>
<td>55.0</td>
<td>-----</td>
<td>42.0</td>
<td>-----</td>
<td>3.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-422C</td>
<td>-----</td>
<td>82.0</td>
<td>-----</td>
<td>15.0</td>
<td>-----</td>
<td>3.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-422D</td>
<td>-----</td>
<td>65.1</td>
<td>-----</td>
<td>31.5</td>
<td>-----</td>
<td>3.4</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-424A</td>
<td>-----</td>
<td>50.5</td>
<td>-----</td>
<td>47.0</td>
<td>-----</td>
<td>0.9</td>
<td>1.0</td>
<td>0.6</td>
<td>-----</td>
</tr>
<tr>
<td>R-427A</td>
<td>15.0</td>
<td>25.0</td>
<td>10.0</td>
<td>50.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-428A</td>
<td>-----</td>
<td>77.5</td>
<td>20.0</td>
<td>-----</td>
<td>0.6</td>
<td>1.9</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-434A</td>
<td>-----</td>
<td>63.2</td>
<td>18.0</td>
<td>16.0</td>
<td>-----</td>
<td>2.8</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>R-438A</td>
<td>8.5</td>
<td>45.0</td>
<td>-----</td>
<td>44.2</td>
<td>-----</td>
<td>-----</td>
<td>1.7</td>
<td>0.6</td>
<td>-----</td>
</tr>
<tr>
<td>R-507A</td>
<td>-----</td>
<td>50.0</td>
<td>50.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td>R-32</td>
<td>R-125</td>
<td>R-143a</td>
<td>R-134a</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>
</tr>
<tr>
<td>Cond. Pressures (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 62</td>
<td>+ 31</td>
<td>+ 19</td>
<td>- 34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V. R. Capacity (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 60</td>
<td>+ 7</td>
<td>+ 5</td>
<td>- 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COP (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 5</td>
<td>- 11</td>
<td>- 7</td>
<td>+ 0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass Flow Rate (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 36</td>
<td>+ 84</td>
<td>+ 25</td>
<td>+ 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge Temps (°F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 34</td>
<td>- 51</td>
<td>- 46</td>
<td>- 36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GWP (100 year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>675</td>
<td>3500</td>
<td>4470</td>
<td>1430</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flammability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2L</td>
<td>A1</td>
<td>A2L</td>
<td>A1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MO / AB Solubility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Poor</td>
<td>Very Poor</td>
<td>Poor</td>
<td>Very Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 – Relative to R-22, Standard Cycle @ 105°F Condenser, 25°F Evaporator, 10°F of Superheat & Subcooling
2 – From the IPCC AR4
GWP Comparison

- **R-22**: GWP = 1,810
- **R-125 / R-143a Based Blends**
  - R-404A
  - R-407A
  - R-407C
  - R-407F
  - R-427A
  - R-438A
- **R-125 / R-134a Based Blends**
  - R-417A
  - R-417B
  - R-421A
  - R-421B
  - R-422A
  - R-422B
  - R-422C
  - R-422D
- **R-125 / R-143a Based Blends**
  - R-404A
  - R-428A
  - R-434A
  - R-507A
High Side Pressure Comparison

Based on Standard Cycle 105°F Condenser, 25°F Evaporator, 10°F Subcooling & 10°F Superheat

Condenser Pressure Change Relative to R-22 (psig)

-60 to +60

-24 to +24

0

-10 to +10

R-438A
R-427A
R-422D
R-407C
R-407A
R-404A
R-428A
R-421B
R-434A
R-422A
R-407F
R-422C
R-507A
R-417B

Colors indicate:
- Much lower pressure
- Lower pressure
- Similar pressure
- Higher pressure
- Much higher pressure
Refrigerant Capacities

Based on Standard Cycle
25°F Evaporator,
10°F Subcooling
& 10°F Superheat
Refrigerant Flow Rate Issues

Most R-22 retrofits require significantly higher refrigerant flow rates than R-22.

Flow considerations for retrofit
- TXVs
- Pistons, orifices, cap tubes
- Distributor nozzles
- Line sets
- Compressor valve plates
- Etc.
Mass Flow Rates

Based on Standard Cycles
65 - 125°F Condenser,
25°F Evaporator,
10°F Subcooling,
& 10°F Superheat
GWP vs. Mass Flow Rate

Based on Standard Cycles
65 - 105°F Condenser,
25°F Evaporator,
10°F Subcooling,
& 10°F Superheat

Refrigerant Flow Rates (% Relative to R-22)
## Oil Miscibility-Use Matrix

<table>
<thead>
<tr>
<th></th>
<th>MO (Mineral Oil)</th>
<th>AB (Alkylbenzene)</th>
<th>POE (Polyolester)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFCs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>HCFCs</td>
<td>Yes (Limited)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>HFCs</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- All R-22 retrofits are HFC-based refrigerants
- All R-22 retrofits are immiscible with MO & AB
Immiscibility Issues - Oil Hold-Up

OIL-RICH LAYER
LIQUID REFRIGERANT
Immiscibility Issues - Oil Logging
POE Oil Change Issues

- Labor & expense of oil change
  - Retrofit procedures

- Solvency effects
  - Filter changes
  - Elastomers

- Flushes
  - Multiple flushes often not required
    - Oil separators
    - Dirty installations
    - Oil concentration / purity

- Performance improvement
# Oil Change Trade-Offs

<table>
<thead>
<tr>
<th>“No Oil Change”</th>
<th>Oil Change to POE</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-417A</td>
<td>R-404A</td>
</tr>
<tr>
<td>R-417B</td>
<td>R-407A</td>
</tr>
<tr>
<td>R-421B</td>
<td>R-407C</td>
</tr>
<tr>
<td>R-422C</td>
<td>R-407F</td>
</tr>
<tr>
<td>R-428A</td>
<td>R-427A</td>
</tr>
<tr>
<td>R-434A</td>
<td>R-507A</td>
</tr>
<tr>
<td>R-421A</td>
<td>R-424A</td>
</tr>
<tr>
<td>R-422D</td>
<td>R-438A</td>
</tr>
<tr>
<td>R-422B</td>
<td></td>
</tr>
<tr>
<td>R-424A</td>
<td></td>
</tr>
<tr>
<td>R-422C</td>
<td></td>
</tr>
<tr>
<td>R-438A</td>
<td></td>
</tr>
<tr>
<td>R-428A</td>
<td></td>
</tr>
<tr>
<td>R-434A</td>
<td></td>
</tr>
<tr>
<td>R-424A</td>
<td></td>
</tr>
<tr>
<td>R-438A</td>
<td></td>
</tr>
</tbody>
</table>

**Pros**
- Lower Upfront Cost
- Quicker Retrofit
- No “POE Issues”
- 0 – 20
- % R-32 & R-143a

**Pros**
- Reduced Oil Logging
- Reliable Oil Return
- Best Performance
- 20 – 52
- % R-32 & R-143a
Test Set-Up

- 1-½ HP R-22 condensing unit / evaporator assembly
- Horizontal line-set sloped down from evaporator → compressor
- Optimized refrigerant charge / adjusted TXV superheat setting
- Ran R-422D, R-427A, and R-438A with MO & POE (camera)
- 100°F Ambient / 0, 25, & 50°F Box Temps – “Dry Coil” tests
# Test Data – Oil Return Results

<table>
<thead>
<tr>
<th></th>
<th>MO</th>
<th>POE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R-22</strong></td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td><strong>R-422D</strong></td>
<td>FAIL</td>
<td>PASS</td>
</tr>
<tr>
<td><strong>R-427A</strong></td>
<td>FAIL</td>
<td>PASS</td>
</tr>
<tr>
<td><strong>R-438A</strong></td>
<td>FAIL</td>
<td>PASS</td>
</tr>
</tbody>
</table>
Test Data – MO Runs

Box Temperature (°F) vs. Refrigerating Capacity (Btu/hr)

- R-422D / MO
- R-427A / MO
- R-438A / MO
Test Data – MO vs. POE Runs

Refrigerating Capacity (Btu/hr) vs. Box Temperature (°F)

- R-422D / MO
- R-427A / MO
- R-438A / MO
- R-422D / POE
- R-427A / POE
- R-438A / POE
Testing – Operating Parameters

Average Change Relative to R-22

-25 -20 -15 -10 -5 0 5 10 15 20 25

R-422D / MO
R-422D / POE
R-427A / MO
R-427A / POE
R-438A / MO
R-438A / POE

Suction Pressure (psi)
Discharge Pressure (psi)
Mass Flow Rate (%)

FORANE REFRIGERANTS ARKEMA
### R-22 Retrofit Metrics*

<table>
<thead>
<tr>
<th>Capacity (%)</th>
<th>COP (%)</th>
<th>MFR (%)</th>
<th>Discharge P (psi)</th>
<th>Suction P (psi)</th>
<th>Discharge T (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-25</td>
<td>+25</td>
<td>+15</td>
<td>+75</td>
<td>+75</td>
<td>+75</td>
</tr>
<tr>
<td>+15</td>
<td>+15</td>
<td>+9</td>
<td>+45</td>
<td>+45</td>
<td>+45</td>
</tr>
<tr>
<td>+5</td>
<td>+5</td>
<td>+3</td>
<td>+15</td>
<td>+15</td>
<td>+15</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-5</td>
<td>-5</td>
<td>-3</td>
<td>-15</td>
<td>-15</td>
<td>-15</td>
</tr>
<tr>
<td>-25</td>
<td>-25</td>
<td>-15</td>
<td>-75</td>
<td>-75</td>
<td>-75</td>
</tr>
</tbody>
</table>

*Standard Cycle 105 °F Condenser, 25 °F Evaporator, 10 °F Subcooling & 10 °F Superheat*
# R-22 Retrofit Metrics*

<table>
<thead>
<tr>
<th>Capacity (%)</th>
<th>COP (%)</th>
<th>Mass Flow (%)</th>
<th>Discharge P (psi)</th>
<th>Suction P (psi)</th>
<th>Discharge T (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+25</td>
<td>+25</td>
<td>+15</td>
<td>+75</td>
<td>+75</td>
<td>+25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+15</td>
<td>+15</td>
<td>+9</td>
<td>+45</td>
<td>+45</td>
<td>+15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+5</td>
<td>+5</td>
<td>+3</td>
<td>+15</td>
<td>+15</td>
<td>+15</td>
</tr>
<tr>
<td></td>
<td>R-407A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-3</td>
<td>R-427A</td>
<td>R-407C</td>
<td>R-407A</td>
<td>R-407C</td>
<td>R-407C</td>
</tr>
<tr>
<td></td>
<td>R-407C</td>
<td>R-407C</td>
<td>R-407A</td>
<td>R-407C</td>
<td>R-407C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-25</td>
<td>-25</td>
<td>-15</td>
<td>-75</td>
<td>-75</td>
<td>-25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Standard Cycle 105 °F Condenser, 25 °F Evaporator, 10 °F Subcooling & 10 °F Superheat*
# R-22 Retrofit Recommendations

<table>
<thead>
<tr>
<th></th>
<th>R-407C</th>
<th>R-407A</th>
<th>R-427A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong></td>
<td>AC, MT</td>
<td>MT, LT</td>
<td>AC, MT, LT</td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td>Closest AC Match</td>
<td>Closest MT Match</td>
<td>Close pressures</td>
</tr>
<tr>
<td></td>
<td>No TXV changes</td>
<td>No TXV changes</td>
<td>No TXV changes</td>
</tr>
<tr>
<td></td>
<td>Lowest GWP</td>
<td>Lower GWP</td>
<td>Lower GWP</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>Moderate Head Pressure</td>
<td>Moderate Head Pressure</td>
<td>Slight Capacity</td>
</tr>
<tr>
<td><strong>Oil</strong></td>
<td>POE</td>
<td>POE</td>
<td>POE (MO / AB)*</td>
</tr>
<tr>
<td><strong>Limitations</strong></td>
<td>DX Systems Only</td>
<td>DX Systems Only</td>
<td>DX Systems Only</td>
</tr>
</tbody>
</table>

* Successfully used with MO and AB with an Oil Separator
Conclusions

- Need for R-22 retrofits growing

- Many R-22 retrofits
  - No “drop-ins” / No “1 answer”

- Understanding basic HFC components key to differentiating products / advertising claims

- HCs help with oil – immiscibility issues remain

- R-407C, R-407A, & R-427A are good options