The Future of Refrigerants

Charles Allgood, PhD
Refrigerants Technology Leader – Chemours
2017 HVAC Excellence, Orlando FL
“Prediction is very difficult; especially if it’s about the future.”

- Neils Bohr
Agenda

- The Chemours Story
- A Historical View of Refrigerants
- Environmental Concerns and Regulations
- HFO’s – Why and How
- Optimizing for the Future
- Available Resources
- Q & A
The Chemours Story

New company created from DuPont Performance Chemicals
July 2015

Industry Leader
...with over 85 years of experience in refrigeration

Inventors of Freon Refrigerants
What is the Future of Refrigerants?

- Finding the Right Solution
  - Functionality
  - Cost
  - Availability

- Installed Systems & New Equipment

- Evolving Regulatory Landscape
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A Brief History of Refrigerants

1800 – 1920’s

Ammonia (NH3), Methyl Chloride (CH3Cl), and Sulfur Dioxide

1920’s

Fatal Accidents with CH3Cl
People moved refrigerators to their backyards

Collaborative Search for Safer Refrigerants by General Motors, Frigidaire, & DuPont

1928

Thomas Midgley and Charles Kettering invent a “miracle compound” called Freon®
The Freon® Age Begins

CFC's: Freon-12

Cl\[\text{Cl}\] Cl

dichlorodifluoromethane

KINETIC CHEMICALS, INC.
Du Pont Building
Wilmington Delaware

Technical Paper No. 1
March 13, 1931

THE THERMODYNAMIC PROPERTIES OF DICHLORODIFLUOROMETHANE (F-12)

The Equation of State of Superheated Vapor

KINETIC
Safe Refrigerants
KINETIC CHEMICALS, INC.
DuPont Building
Wilmington, Delaware
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Why Do We Need New Refrigerants Now?

Worldwide focus on:

“Ozone Depletion”

“Climate Change”
Regulations Driving Change
The Regulatory Challenge for Refrigeration

R-22 is getting phased out

R-404A/507 will soon be unacceptable for retrofit & new equipment

<table>
<thead>
<tr>
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<tr>
<td>2017</td>
<td>January</td>
<td>February</td>
<td>March</td>
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</tbody>
</table>

Unacceptable for Retrofit:
R-404A & R-507A

Unacceptable for New Equipment:
R-404A & R-507A

Please consult local country-specific regulations. HFC unacceptability described is based on US EPA SNAP Program change of status for refrigerants, issued July 20, 2015, and applies to refrigeration racks. For complete overview of SNAP program regulations by product and application, please consult [www.epa.gov/significant-new-alternatives-policy-snap](http://www.epa.gov/significant-new-alternatives-policy-snap)
US Regulations: EPA Section 608

Overview of Current Requirements

- **Service Practice Requirements**: Technicians servicing air-conditioning and refrigeration equipment must meet EPA certification criteria by passing an EPA-approved examination.
- **Refrigerant Recovery and Recycling Equipment**: Equipment must be certified by an EPA-approved testing organization to meet specific EPA requirements for refrigerant recovery efficiency.
- **Refrigerant Leaks**: Industrial and commercial refrigeration equipment and comfort cooling equipment are subject to specific EPA requirements for leak repair.
- **Refrigerant Sales Restrictions**: Sale of ODS refrigerants is restricted to certified technicians.
- **Safe Disposal Requirements**: When refrigeration and air-conditioning equipment enters the waste stream, the final person in the disposal chain must remove (or make certain that their customers have removed) refrigerants prior to appliance disposal.
- **Major Recordkeeping Requirements**: Service technicians, owners, and operators of large refrigeration and air-conditioning equipment, refrigerant wholesalers, and EPA-certified refrigerant reclaimers are required to maintain records documenting dates, refrigerant charge amounts, and related information for equipment servicing and disposal.
- **Reclamation**: Before recovered refrigerant can change ownership, it must be reclaimed to virgin specifications by a reclamer that meets EPA certification requirements.

Section 608 Regulatory Requirements
“Predicting rain doesn’t count. Building arks does.”

- Warren Buffet
Selection of Refrigerants for the Future Will Need to Balance Performance (Capacity and Efficiency), Safety and Sustainability, and Total Cost of System Ownership.
Industrial Gases as Refrigerants – Food for Thought

• Not new, some of the earliest refrigerants

• Used currently where they make sense (safety and efficiency concerns)

• Rebranding as “natural” products, but:
  − The so-called “natural” refrigerants are actually industrial gases produced in large chemical processing facilities
  − These facilities use energy to create or isolate, purify CO$_2$, hydrocarbons and ammonia
  − They also use feedstocks and generate wastes similar to other chemical manufacturing processes
Hydrocarbons are produced in an oil refinery or natural gas processing plant.

There are several process steps to produce high purity refrigerants such as propane:

Example Processing steps:
- Condensate and water removal
- Acid gas removal
- Dehydration
- Mercury removal
- Nitrogen removal
- Natural gas liquid recovery
- Fractionation
- Sweetening purification units

Source: https://en.wikipedia.org/wiki/Natural-gas_processing
Ammonia Manufacture

- Ammonia is primarily produced by reaction of nitrogen with hydrogen
- However, there are several steps preceding this, starting with natural gas feedstock:

1. Sulfur removal from natural gas feedstock:
   \[ \text{H}_2 + \text{RSH} \rightarrow \text{RH} + \text{H}_2\text{S} \text{ (gas)} \]

2. Hydrogen sulfide absorption through beds of zinc oxide:
   \[ \text{H}_2\text{S} + \text{ZnO} \rightarrow \text{ZnS} + \text{H}_2\text{O} \]

3. Catalytic steam reforming to form hydrogen plus carbon monoxide:
   \[ \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2 \]

4. Catalytic shift conversion to carbon dioxide and more hydrogen:
   \[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \]

5. Carbon dioxide is then removed by absorption.

6. Catalytic methanation to remove small amounts of CO and CO2
   \[ \text{CO} + 3\text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O} \]
   \[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]

7. Hydrogen is then catalytically reacted with nitrogen to form anhydrous liquid ammonia, and purified
   \[ 3\text{H}_2 + \text{N}_2 \rightarrow 2\text{NH}_3 \]

Source: https://en.wikipedia.org/wiki/Ammonia_production
CO₂ Manufacture

CO₂ is primarily produced by:
- Combustion of fossil fuel (e.g. coal, oil, gas)
- Separation of the CO₂ from the combustion product stream (e.g. flue gas)
- Several purification steps

**CO₂ separation and purification from power plant flue gas**

**CO₂ Production Options**

What is “Natural”?  

**Natural**  
*adjective* nat·u·ral 
ˈna-chə-rəl, ˈnach-rəl*

**ADJECTIVE**
1. existing in or caused by nature; not made or caused by humankind:
   "carrots contain a natural antiseptic that fights bacteria"

2. of or in agreement with the character or makeup of, or circumstances surrounding, someone or something:
   "sharks have no natural enemies"

3. (of a parent or child) related by blood:
   "such adopted children always knew who their natural parents were"
What is “Natural”? 

“Natural” – *Not a scientific or engineering term*

- Not something that can be measured, tested
  - i.e. US FDA – no real definition
- Controversial usage in advertising/marketing hype
  - “All-natural”, “Natural”
    - Foods, supplements, cosmetics, cleaners, disinfectants, etc.

“Occurring in Nature” is a *low and not very useful criteria:*

- Water, Helium, Air, Carbon Dioxide
- Sulfur Dioxide, Ammonia, Natural Gas, Methylene Chloride
- Lead, Arsenic, Mercury
- Strychnine, Anthrax, Botulinum
...should be based on:

- **Measurable data and objective chemical, physical, thermodynamic and environmental properties**

- **Standard and reproducible engineering principles, measurements and testing**

**For Example:**
- Boiling Point
- Vapor Pressure
- Heat Capacity
- Ozone Depletion Potential
- Atmospheric Lifetime
- Global Warming Potential
- Toxicity (Acute, Chronic, etc.)
- Flammability (LFL, UFL, Burning Velocity)
- Heat of Combustion
- Energy Efficiency

**Not on ill or undefined, marketing hype or political buzz words, i.e. **Natural**
Selection of Refrigerants for the Future Will Need to Balance Performance (Capacity and Efficiency), Safety and Sustainability, and Total Cost of System Ownership.
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What Exactly is a Global Warming Potential (GWP)?

\[ GWP = \text{Atmospheric Lifetime} \times \text{Infrared Absorbance} \]

Atmospheric Life \[\rightarrow\] rates of destruction reactions (hydroxyl radical)

\[
\text{HFC} \quad \xrightarrow{k} \quad \cdot[\text{OH-}] 
\]

Huge Variation between different molecules
# Designing a Low GWP Molecule

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Structure</th>
<th>Atmospheric Lifetime</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PFC-116</strong></td>
<td>CF3-CF3</td>
<td>10,000 years</td>
<td>11,100</td>
</tr>
<tr>
<td><strong>HFC-134a</strong></td>
<td>CH2F-CF3</td>
<td>13 years</td>
<td>1300</td>
</tr>
<tr>
<td><strong>HFO-1234yf</strong></td>
<td>CH2=CF-CF3</td>
<td>10 days</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>
How HFOs Work

HFC
Hydro fluorocarbon

HFO
Hydro fluoro olefin

Double bond in HFOs
Quicker breakdown in the atmosphere,
yet stable in systems
HFO-1234yf Similar to HFC-134a

- Same operating conditions as 134a (similar P/T curve)
- Capacity and efficiency similar to HFC-134a

### Chemical Formulas

- **R-134a**: \( \text{CH}_2\text{CF}_3 \)
- **HFO-1234yf**: \( \text{CF}_3\text{CF} = \text{CH}_2 \)

### Molecular Properties

<table>
<thead>
<tr>
<th></th>
<th>R-134a</th>
<th>HFO-1234yf</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formula</strong></td>
<td>( \text{CH}_2\text{CF}_3 )</td>
<td>( \text{CF}_3\text{CF} = \text{CH}_2 )</td>
</tr>
<tr>
<td><strong>Molecular Weight</strong></td>
<td>102</td>
<td>114</td>
</tr>
<tr>
<td><strong>ODP</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>GWP(_{100}) (AR5)</strong></td>
<td>1300</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>T Critical Point</strong></td>
<td>102 °C</td>
<td>95 °C</td>
</tr>
<tr>
<td><strong>Boiling Point</strong></td>
<td>-26 °C</td>
<td>-29 °C</td>
</tr>
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</table>

**Very low GWP but Mildly Flammable**
A Brief Introduction to Flammable Refrigerants
Refrigerant Flammability Classifications

<table>
<thead>
<tr>
<th>Flammability Classification</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly Flammable</td>
<td>Propane, Isobutane</td>
</tr>
<tr>
<td>Moderately Flammable</td>
<td>R-152a</td>
</tr>
<tr>
<td>Mildly Flammable</td>
<td>R-1234yf, R-452B</td>
</tr>
<tr>
<td>Non-Flammable</td>
<td>R-134a, R-410A</td>
</tr>
</tbody>
</table>

To meet 2L flammability, burning velocity must be ≤ 10 cm/s
Primary Flammability Parameters

• **Lower / Upper Flammability Limits (LFL / UFL)**
  – Minimum / Maximum concentrations of a substance in air that exhibit flame propagation (usually shown as volume % in air).

• **Minimum Ignition Energy (MIE)**
  – Minimum energy required to ignite a flammable gas / air mixture. Sources with energy levels below this value will not result in an ignition.

• **Burning Velocity (BV)**
  – The velocity of a laminar flame under given values of composition, temperature and pressure.

• **Heat Of Combustion (HOC)**
  – Heat per unit mass (or mole) released by the combustion of a substance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Risk Trend</th>
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</thead>
<tbody>
<tr>
<td>Lower LFL</td>
<td>↑</td>
</tr>
<tr>
<td>Larger (UFL – LFL)</td>
<td>↑</td>
</tr>
<tr>
<td>Lower MIE</td>
<td>↑</td>
</tr>
<tr>
<td>Higher UFL</td>
<td>↑</td>
</tr>
<tr>
<td>Higher HOC</td>
<td>↑</td>
</tr>
</tbody>
</table>
# Flammable Property Comparison

<table>
<thead>
<tr>
<th></th>
<th>R-290 (Propane)</th>
<th>R-152a</th>
<th>R-717 (Ammonia)</th>
<th>R-1234yf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Rating</td>
<td>A3</td>
<td>A2</td>
<td>B2L</td>
<td>A2L</td>
</tr>
<tr>
<td>LFL (vol. %)</td>
<td>2.2</td>
<td>3.9</td>
<td><strong>15.0</strong></td>
<td>6.2</td>
</tr>
<tr>
<td>UFL (vol. %)</td>
<td>10.0</td>
<td>16.9</td>
<td>28.0</td>
<td>12.3</td>
</tr>
<tr>
<td>UFL – LFL (vol. %)</td>
<td>7.8</td>
<td>13.0</td>
<td>13.0</td>
<td><strong>6.1</strong></td>
</tr>
<tr>
<td>MIE (mJ)</td>
<td>0.25</td>
<td>0.38</td>
<td>100 - 300</td>
<td>&gt; 5,000</td>
</tr>
<tr>
<td>BV (cm/s)</td>
<td>46</td>
<td>23</td>
<td>7.2</td>
<td><strong>1.5</strong></td>
</tr>
<tr>
<td>HOC (kJ/g)</td>
<td>46.3</td>
<td>16.5</td>
<td>18.6</td>
<td><strong>10.7</strong></td>
</tr>
</tbody>
</table>
# Understanding Pressure Rise on Ignition

**Watch the ping pong balls for pressure rise**

<table>
<thead>
<tr>
<th></th>
<th>t = 63 ms</th>
<th>125 msec</th>
<th>250 msec</th>
<th>500 msec</th>
<th>750 msec</th>
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</thead>
<tbody>
<tr>
<td><strong>Isobutane</strong></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>Elect. Arc</td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td>4 vol%</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>R-152a</strong></td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
<td><img src="image19.png" alt="Image" /></td>
<td><img src="image20.png" alt="Image" /></td>
</tr>
<tr>
<td>Elect. Arc</td>
<td><img src="image21.png" alt="Image" /></td>
<td><img src="image22.png" alt="Image" /></td>
<td><img src="image23.png" alt="Image" /></td>
<td><img src="image24.png" alt="Image" /></td>
<td><img src="image25.png" alt="Image" /></td>
</tr>
<tr>
<td>8 vol%</td>
<td><img src="image26.png" alt="Image" /></td>
<td><img src="image27.png" alt="Image" /></td>
<td><img src="image28.png" alt="Image" /></td>
<td><img src="image29.png" alt="Image" /></td>
<td><img src="image30.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>HFO-1234yf</strong></td>
<td><img src="image31.png" alt="Image" /></td>
<td><img src="image32.png" alt="Image" /></td>
<td><img src="image33.png" alt="Image" /></td>
<td><img src="image34.png" alt="Image" /></td>
<td><img src="image35.png" alt="Image" /></td>
</tr>
<tr>
<td>Elect. Arc – no ign</td>
<td><img src="image36.png" alt="Image" /></td>
<td><img src="image37.png" alt="Image" /></td>
<td><img src="image38.png" alt="Image" /></td>
<td><img src="image39.png" alt="Image" /></td>
<td><img src="image40.png" alt="Image" /></td>
</tr>
<tr>
<td>Lighter – above 4 vol%, no ign</td>
<td><img src="image41.png" alt="Image" /></td>
<td><img src="image42.png" alt="Image" /></td>
<td><img src="image43.png" alt="Image" /></td>
<td><img src="image44.png" alt="Image" /></td>
<td><img src="image45.png" alt="Image" /></td>
</tr>
<tr>
<td>Elect. Arc + butane → ign</td>
<td><img src="image46.png" alt="Image" /></td>
<td><img src="image47.png" alt="Image" /></td>
<td><img src="image48.png" alt="Image" /></td>
<td><img src="image49.png" alt="Image" /></td>
<td><img src="image50.png" alt="Image" /></td>
</tr>
<tr>
<td>8 vol%, orange flame is butane</td>
<td><img src="image51.png" alt="Image" /></td>
<td><img src="image52.png" alt="Image" /></td>
<td><img src="image53.png" alt="Image" /></td>
<td><img src="image54.png" alt="Image" /></td>
<td><img src="image55.png" alt="Image" /></td>
</tr>
</tbody>
</table>

HFO-1234yf flames can best be characterized as “lazy and unstable” with low energy release.

Reference: B. Hill, MACS January 21, 2010
Codes & Standards Activities

• Standards updates required to address flammable refrigerant needs

• Code updates also required
  – UMC, IMC, IRC, NFPA

• EPA activities
  – SNAP

• Industry activities supporting flammable refrigerants
  – Joint ASHRAE-AHRI-DOE research
Working Safely with Flammables

- Identification
- Controlling charge size / room area
- Eliminating ignition sources
- Leak detection
- Mitigation strategies
- Best work practices
- Education & training
# Changes to Service Equipment for A2Ls

<table>
<thead>
<tr>
<th>Service Item</th>
<th>R-404A</th>
<th>R-410A</th>
<th>Opteon™ XL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guage manifold</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Charging hose</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Torque wrench</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Flare tool</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Pipe cutter</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Pipe bender</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Hex wrench</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Ventilation Fan, if low ventilation</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Scales</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Vacuum pump</td>
<td>Routine</td>
<td>Routine</td>
<td>Routine</td>
</tr>
<tr>
<td>Dry Powder/CO₂, Fire Extinguisher</td>
<td>Not necessary</td>
<td>Not necessary</td>
<td>Chemical compatible</td>
</tr>
<tr>
<td>Gas Detector</td>
<td>Routine</td>
<td>Routine</td>
<td>2L certified</td>
</tr>
<tr>
<td>Electronic leak detector</td>
<td>Routine</td>
<td>Routine</td>
<td>2L certified</td>
</tr>
<tr>
<td>Refrigerant recovery cylinder</td>
<td>Routine</td>
<td>Routine</td>
<td>Flammable (GHS label, left hand thread)</td>
</tr>
<tr>
<td>Recovery machines</td>
<td>Routine</td>
<td>Routine</td>
<td>2L certified</td>
</tr>
</tbody>
</table>
“When you arrive at a fork in the road, take it.”

- Yogi Berra
Global Adoption of HFO-1234yf by Automotive Ind.

- SAE International – HFO-1234yf accepted
  - Safe for use; low environmental impact
- HFO-1234yf selected by Auto OEMs globally to meet EU MAC Directive

Million’s of 1234yf cars on the road, but:
What about Stationary Refrigeration?
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- The Chemours Story
- A Historical View of Refrigerants
- Environmental Concerns and Regulations
- HFO’s – Why and How
- Optimizing for the Future
- Available Resources
- Q & A
Opteon™ Offers the Optimal Balance of Properties

- Efficiency + Capacity
- Performance

- Safety & Sustainability
  - Zero ODP
  - Low GWP
  - No or low flammability

- Total Cost of Ownership
  - Capital Costs + Operation Costs
  - Total Cost of Ownership

- Commercially Available
Opteon™ Low GWP HFO Products for Refrigeration

- **R-22** (HCFC)  
  - **GWP: 1760**
  - **XP40** (R-449A)  
    - **GWP: 1282**
  - **XL20** (R-454C)  
    - **GWP: 146**

- **R-404A/R-507** (HFC)  
  - **GWP: 3943**
  - **XP40** (R-449A)  
    - **GWP: 1282**
  - **XP44** (R-452A)  
    - **GWP: 1945**
  - **XL40** (R-454A)  
    - **GWP: 237**
  - **XL20** (R-454C)  
    - **GWP: 146**

- **R-134a** (HFC)  
  - **GWP: 1300**
  - **XP10** (R-513A)  
    - **GWP: 573**
  - **YF** (R-1234yf)  
    - **GWP: <1**

- **Incumbent Gas**
- **Mildly Flammable Replacement**
- **Non-Flammable Replacement**
- **Not Yet Commercial for Refrigeration in US**
Meeting Regulatory Goals with an Optimal Balance of Performance and Sustainability

Opteon™ XP40 (R-449A)

- Meets regulatory requirements
  Non-ozone depleting
  SNAP listed; 67% lower GWP vs. R-404A/507

- Non-flammable, Non-toxic (A1)

- Reduces energy consumption
  Up to 12% energy savings

- Extends life of existing equipment
  Replaces R-22, 404A, 507, 408A, HP80
  Major OEM approvals: Emerson, Bitzer, Carlyle

Commercially available
- Emerson (Copeland), Bitzer & Tecumseh Approved
- Thousands of supermarkets & commercial refrigeration systems already using R-449A globally

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Replaces R-22 & R-404A

ASHRAE #: R-449A
Blend Components: R-1234yf/134a/125/32
Blend Composition: 25.3/25.7/24.7/24.3
R-22 Retrofit Success

Conversion from R-22 to Opteon™ XP40 (R-449A)
October 2015

• Average Energy benefit of 8%
  (5-12% range, depending on rack & ambient)

• Changed Lubricant to POE

• No changes to equipment or piping

• Tweaked TXVs for optimized performance

• Met cooling demand

• Stable operation
R-404A/CO₂ Cascade System Retrofit Success

- R-404A/CO₂ hybrid cascade system
- R-404A MT rack with six screw compressors
- System has programmable EEVs
- Covers 73 cabinets and 7 cold store rooms
- Filter drier replaced, EEVs programmed, no other changes

Energy Consumption

![Graph showing energy consumption with a 7% reduction]
Consider 100 stores running on R-22, approx. 1 ton refrigerant charge/store, leaking 10% /yr
• Conversion to R-407A → 1,630 tons higher greenhouse gas emissions each year
• Conversion to Opteon™ XP40 → 4,780 tons lower greenhouse gas emissions each year

Consider 100 stores running on R-404A, approx. 1 ton refrigerant charge/store, leaking 10% /yr
• Conversion to Opteon™ XP40 → 26,610 tons lower greenhouse gas emissions each year
• Added indirect benefit of up to 12% reduced energy consumption
Lot’s of Choices
Agenda

- The Chemours Story
- A Historical View of Refrigerants
- Environmental Concerns and Regulations
- HFO’s – Why and How
- Optimizing for the Future
- Available Resources
- Q & A
Resources from Chemours

www.freon.com
www.opteon.com
# General Replacement Guide

## R-22 Replacements

<table>
<thead>
<tr>
<th>Product Name</th>
<th>ASHRAE#</th>
<th>Applications</th>
<th>Refrigerant Type</th>
<th>Equipment Type</th>
<th>Compatible Oil</th>
<th>GWP</th>
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<tbody>
<tr>
<td>Dryvac™ XP40</td>
<td>R-449A</td>
<td>LT, MT</td>
<td>HFO Blend</td>
<td>New, Retrofit</td>
<td>POE</td>
<td>1282</td>
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<td>Freon® 407A</td>
<td>R-497A</td>
<td>LT, MT</td>
<td>HFO Blend</td>
<td>New, Retrofit</td>
<td>POE</td>
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<td>Freon® M229</td>
<td>R-422D</td>
<td>LT, MT</td>
<td>HFC Blend</td>
<td>Retrofit</td>
<td>MO, AB, POE</td>
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<tr>
<td>Freon® M369</td>
<td>R-438A</td>
<td>AC</td>
<td>HFC Blend</td>
<td>Retrofit</td>
<td>MO, AB, POE</td>
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<td>Freon® 407C</td>
<td>R-407C</td>
<td>AC</td>
<td>HFC Blend</td>
<td>New, Retrofit</td>
<td>POE</td>
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<td>Freon® 410A</td>
<td>R-410A</td>
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<td>HFC Blend</td>
<td>New</td>
<td>POE</td>
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## R-12, M39, M56, R-409A Replacements

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<th>Product Name</th>
<th>ASHRAE#</th>
<th>Applications</th>
<th>Refrigerant Type</th>
<th>Equipment Type</th>
<th>Compatible Oil</th>
<th>GWP</th>
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<tbody>
<tr>
<td>Dryvac™ XP30</td>
<td>R-513A</td>
<td>MT, AC</td>
<td>HFO Azeotrope</td>
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<td>Freon® 134a</td>
<td>R-134A</td>
<td>MT, AC, Auto</td>
<td>HFC</td>
<td>New, Retrofit</td>
<td>POE, PAG</td>
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<td>Dryvac™ YF</td>
<td>R-5254y</td>
<td>MT, Auto, Ac</td>
<td>HFC (Jal)</td>
<td>New</td>
<td>POE, PAG</td>
<td>&lt;1</td>
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<tr>
<td>Freon® MQ35A</td>
<td>R-437A</td>
<td>LT, MT</td>
<td>HFC Blend</td>
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## R-404A, 507, HP80, HP81, R-408A, 508 Replacements

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<th>Product Name</th>
<th>ASHRAE#</th>
<th>Applications</th>
<th>Refrigerant Type</th>
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<th>GWP</th>
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<td>Dryvac™ XP60</td>
<td>R-449A</td>
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<td>HFO Blend</td>
<td>New, Retrofit</td>
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<td>Dryvac™ XP64</td>
<td>R-452A</td>
<td>LT, Transport</td>
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<td>Freon® M079</td>
<td>R-422A</td>
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<td>HFC Blend</td>
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## R-503, R-13 Replacements

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<th>Applications</th>
<th>Refrigerant Type</th>
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<td>R-505B</td>
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<td>PFOMCt2</td>
<td>New, Retrofit</td>
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<td>HFC</td>
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<td>POE</td>
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For more detailed information on Refrigerants from Chemours and their applications, visit www.chemours.com; www.opteon.com; and consult local country-specific regulations.

1. LT = Very Low Temperature, HT = Low Temperature, MT = Medium Temperature, AC = Air Conditioning, Tran. = Transport Refrigeration, Auto = Automotive Air Conditioning
2. *R* Refrigerants listed have ASHRAE A3 Safety Classification, unless otherwise noted.
4. GWP = Global Warming Potential (IPCC Fifth Assessment Report, AR5)
Retrofit Guidelines

Opteon™ XP40 Retrofit Guidelines to Replace R-404A/R-507

Introduction
Opteon™ XP40 is a low global warming potential (GWP) refrigerant designed for direct replacement for R-404A/R-507 and is suitable for cold room, commercial, and industrial applications.

Opteon™ XP40 (the registered trade name for HC-32HOD)-12F2C1 (esterification of HC-32HOD and HFC-12F2C1) is intentionally designed as a direct replacement for R-404A/R-507. It is available for both R-404A and R-507 and can be used in direct replacement for both refrigerants.

Opteon™ XP40 offers improved energy efficiency, lower environmental impact, and reduced cost compared to R-404A/R-507.

Using these retrofit guidelines, existing systems can be converted to Opteon™ XP40, allowing the equipment to function efficiently with a greatly reduced environmental impact.

Important Safety Information
Like all Fluorine refrigerants, Opteon™ XP40 is non-flammable. However, any refrigerant injury can be very painful. Please follow the safety precautions and consult the Material Safety Data Sheet (MSDS) before handling and installing.

Chemours

Opteon™ XP10 Retrofit Guidelines to Replace R-134a

Introduction
Opteon™ XP10 is a low global warming potential (GWP) refrigerant designed for direct replacement for R-134a in medium-temperature refrigeration applications. Opteon™ XP10 is the registered trade name for R-42HOD-1Z6F2C1 (esterification of R-42HOD and HFC-12F2C1) and is intended to be used as a direct replacement for R-134a.

Opteon™ XP10 offers improved energy efficiency, lower environmental impact, and reduced cost compared to R-134a.

Using these retrofit guidelines, existing R-134a systems can be converted to Opteon™ XP10, allowing the equipment to function efficiently with a greatly reduced environmental impact.

Important Safety Information
Like all Fluorine refrigerants, Opteon™ XP10 is non-flammable. However, any refrigerant injury can be very painful. Please follow the safety precautions and consult the Material Safety Data Sheet (MSDS) before handling and installing.

Chemours
R-22 to Freon™ MO99 On-line Training Videos

Retrofit of an R-22 Air Conditioning System to Freon™ MO99 Refrigerant

Case History

Opteon™ XP40 Refrigerant

Raley's Supermarkets Champions the Transition to Non-Ozone Depleting, Reduced Carbon Footprint Refrigerants with Opteon™ XP40 (R-449A)

Background

Raley's, a well-known supermarket chain, places great emphasis on sustainability and its leadership in environmental responsibility. In addition to its sustainability initiatives, such as reducing energy usage, recycling, the installation of solar panels, and generating natural gas from biogas, Raley's is also leading the industry in its transition to refrigerants with a lower global warming potential (GWP) footprint.

When Raley's approached engineers and energy experts about the suitability of commercial refrigeration in light of new regulations and their own sustainability projects, they collaborated with technical experts from long-time refrigerant producer Chemours (formerly DuPont Performance Chemicals) for the latest developments and low GWP options.
Technical Information – P/T Calc App

All the information you need in the field, right on your mobile device!

Chemours PT Calc
The Chemours Company
Technical Information – Refrigerant Expert Tool

Designing or evaluating a system? Our FREE software can help!
Do you have a plan?
Refrigerant Management

Five R’s:

1. Record-keeping
2. Repair Leaks
3. Recover & Reclaim
4. Replace old equipment e.g., R-410A
5. Retrofit to Zero ODP refrigerants
Summary of Low GWP Products for Refrigeration

- **Environmentally sustainable**
- **Infrastructure ready**
  - Trained work-force
  - OEM’s, Components, Tools
  - Decades of experience in system design and optimization
  - Manufacturing and supply chain ready
- **Comparable to Improved Energy Efficiency**
- **Competitive on total cost basis**
- **Commercial products compatible with new, remodel & installed base**
  - R-22
  - R-404A/507
  - R-134a
  - R-407A/407F
Chemours Announces Major Investments in New U.S. HFO-1234yf Plant
Innovative Opteon™ YF Process in Corpus Christi to Triple Chemours’ World-Leading Capacity

WILMINGTON, DE; May 2, 2016 – Chemours will invest $230 million over 3 years to construct the new facility at the Corpus Christi site in Ingleside, Texas, with start-up expected in 3rd quarter of 2018.

This investment will triple the capacity of Opteon™ products, enabling Chemours to capitalize on a cornerstone growth opportunity. This investment will create the world’s largest facility for manufacturing HFOs, and the location will allow Chemours to efficiently service the growing market in North America and Europe, as well as the rest of the world. Today Chemours is the capacity leader for HFO-1234yf based products, a position that will be maintained through this investment.
“I Touch the Future. I Teach.”

- Christa McCauliffe
Thank you!

Chuck Allgood, PhD
Refrigerants Technology Leader

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charles.c.allgood-1@chemours.com
www.opteon.com