HFO-1234yf Low GWP Refrigerant – Information for Manufacturing and Service Facilities

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Agenda

- HFO-1234yf Properties
- Flammability of HFO-1234yf
- Flammability Property Comparisons
- CFD Modeling Potential Service Scenarios
- Service and Use
- Availability
HFO-1234yf Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>HFO-1234yf</th>
<th>HFC-134a</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_vap, MPa (25°C)</td>
<td>0.677</td>
<td>0.665</td>
</tr>
<tr>
<td>P_vap, MPa (80°C)</td>
<td>2.44</td>
<td>2.63</td>
</tr>
<tr>
<td>GWP (100 ITH)</td>
<td>4</td>
<td>1430 (AR4)</td>
</tr>
<tr>
<td>Toxicity</td>
<td>A-Low</td>
<td>A-Low</td>
</tr>
<tr>
<td>Flammability</td>
<td>Mild</td>
<td>None</td>
</tr>
</tbody>
</table>

- Same operating conditions as 134a (similar P/T curve)
- Thermally stable under extreme use conditions in a MAC system
- Cooling capacity equivalent to 134a
- Energy efficiency better or equivalent to 134a
- Only modest design changes required in MAC

HFO-1234yf has vapor pressure, toxicity class A, similar to R-134a, but has mild flammability.
HFO-1234yf Flammability Properties - Minimum Ignition Energy

Flammability evaluated by ‘Chance of Flame ‘ and ‘Effect of Flame”
- Chance of Flame occurring -> Lower Flame Limit, Minimum Ignition Energy

![Graph showing flammability comparison between HFO-1234yf and other gases.]

Difficult to ignite HFO-1234yf due to high Minimum Ignition Energy

Ref-Minor, Spatz, Purdue 2008
Even if ignited, HFO-1234yf burns weakly, would have limited effect.
**Flammability Comparison**

<table>
<thead>
<tr>
<th>Flame Limits- ASTM E681-01 at 21C</th>
<th>HFC-134a</th>
<th>HFO-1234yf</th>
<th>HFC-152a</th>
<th>Propane</th>
<th>Gasoline</th>
<th>Hydrogen</th>
<th>Ethanol**</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFL (vol% in Air)</td>
<td>N/A</td>
<td>6.2</td>
<td>3.9</td>
<td>2.2</td>
<td>1.4</td>
<td>4</td>
<td>3.3</td>
</tr>
<tr>
<td>UFL (vol% in Air)</td>
<td>N/A</td>
<td>12.3</td>
<td>16.9</td>
<td>10</td>
<td>7.6</td>
<td>75</td>
<td>19.0</td>
</tr>
<tr>
<td>Minimum Ignition Energy -MIE (mJ)</td>
<td>N/A</td>
<td>&gt;5000</td>
<td>0.38</td>
<td>0.25</td>
<td>0.29</td>
<td>0.016</td>
<td>0.65</td>
</tr>
<tr>
<td>Heat of Combustion (kJ/g)</td>
<td>4.2</td>
<td>10.7</td>
<td>16.5</td>
<td>46.3</td>
<td>47</td>
<td>142.9</td>
<td>29.8</td>
</tr>
<tr>
<td>Burning Velocity (cm/s)</td>
<td>N/A</td>
<td>1.5</td>
<td>23</td>
<td>46</td>
<td>34</td>
<td>265-325</td>
<td>58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flammability Index-Low value preferred</th>
<th>R</th>
<th>F</th>
<th>RF</th>
<th>RF2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC-134a</td>
<td>N/A</td>
<td>0.97</td>
<td>1.78</td>
<td>1.99</td>
</tr>
<tr>
<td>HFO-1234yf</td>
<td>N/A</td>
<td>0.27</td>
<td>0.5</td>
<td>0.55</td>
</tr>
<tr>
<td>HFC-152a</td>
<td>N/A</td>
<td>3.6</td>
<td>16.6</td>
<td>56.7</td>
</tr>
<tr>
<td>Propane</td>
<td>N/A</td>
<td>0.6</td>
<td>17.9</td>
<td>37.2</td>
</tr>
</tbody>
</table>

* Severy, et. Al.
** Brandes and Ural

**HFO-1234yf flammability characteristics are “milder than” those of hydrocarbon gases or other commonly used products within the service repair shop.**
CFD Leakage Modeling-Potential Scenarios

- CFD-Computational Fluid Dynamics
- DuPont conducted CFD modeling to understand potential flammable region of a leak from a severed AC line under various leakage scenarios
- Results useful as input for risk assessments
- Three Scenarios evaluated
  1. Leak from a point in open space (simulating vehicle with potential leak sitting outdoors)
  2. Leak from a point in bounded space (simulating potential leak in garage or mfr plant)
  3. Leak from a point under an open car hood and impinging on a surface (in a service garage)
- CFD Model Output
  - Refrigerant concentration at several distances (x, y and z directions) from the leak point during leak event.
  - Size of refrigerant plume above lower flammability limit (LFL)
CFD MODEL DEVELOPMENT

Approach Used

- Several CFD Models Designed
  - 1st CFD Model - Release was initially modeled with no bounding
  - 2nd & 3rd CFD Model - Release modeled as bounded vapor release using methodology in Venetsanos paper
- Information presented at the American Institute of Chemical Engineers 2010 Spring National Meeting 6th Global Congress on Process Safety 44th Annual Loss Prevention Symposium, San Antonio, Texas

Ref-Koban, Herrmann-Al ChE
Loss Prevention 2010
CFD MODEL DEVELOPMENT-

• Assumptions for all three scenarios
  • 600 g total refrigerant leaked
  • 12.4 g/s of HFO-1234yf
  • total time of leak 48.4 secs
  • Air exchange rate was zero, or low wind field (<0.5 m/sec) for unbounded leak

• Release Details
  • HFO-1234yf will create a two phase leak when released under a severed line situation.
  • The release plume was modeled as vapor phase, since initial modeling did not show large differences in shape of jet plume
HFO-1234yf Plume Release Diagrams

- Liquid and vapor combined release will have the shape above.
- HFO-1234yf will create a two phase release under a severed line situation.

- An all vapor release will have the shape above
- Plume is fully formed within 1/2 second of the start of the release.
- Modeled in both horizontal and parallel directions of the air flow

Outcome - similarities in plume shape/length
Diagram of Scenario - Unbounded leak

Leak source point-
severed A/C line

Refrigerant plume formed when refrigerant escapes from leakpoint

Assumptions:
• Leak is not bounded by room/structure. (imagine severed line AC line outside, not bound/hitting any object)
• Leak assumed to be in low wind field, so no dissipation of refrigerant by wind.
Plume Concentration Profile – Unbounded Leak

Results can vary based on hole size/shape and release direction versus air currents.

Length of plume above LFL is very small (about 15 cm)
Diagram of Scenario - Bounded leak

Dimensions of a single bay garage (7 x 4 x 3 m).

- Leak source point - severed A/C line
- Refrigerant plume
- Small holes at bottom of box keep pressure from building up

- Assumed 600 g charge released in 48 seconds and zero air flow
Plume Profile – Bounded Leak

Plume above LFL is very small (10 cm in x direction, 2 cm in z)

HFO-1234yf Conc.
- >10 vol%
- 10 vol%
- 6.3 vol%
- 4.0 vol%
- 2.5 vol%
- 1.6 vol%

Air Velocity
- >100 m/sec
- 100 m/sec
- 10 m/sec
- 1.0 m/sec
- Below 0.1 m/sec
Diagram of Surface Impinging Scenario

Dimensions of a single bay garage (7 x 4 x 3 m)

Surface that leak impinges upon

Leak source severed A/C line

Small holes at bottom of box keep pressure from building up

Modeled three different distances of leak to impinging surface (0.1 m, 0.22 m and 0.85 m)
Plume Profile – Bounded Leak Impinged on a Surface (0.1m)

Distance to surface = 0.1m

HFO-1234yf Concentration

- 10 vol%
- 6.3 vol%
- 4.0 vol%
- 2.5 vol%
- 1.6 vol%
- Below 1.0 vol%

Plume is continually dispersed by surface, almost no flammable zone available
Plume is continually dispersed by surface with almost no flammable zone formed (~2-4 cm around impact point)
CFD Modeling Summary

• Three leakage scenarios were evaluated
  • In unbounded space (simulating potential leak vehicle sitting outdoors)
  • In bounded space (simulating potential leak in garage or mfr plant)
  • In bounded space, under an open car hood and impinging on a surface (in a garage)

• In all cases, the size of the refrigerant plume above the LFL was very small (on order of few centimeters to 15 centimeters)

• Results indicate low risk of HFO-1234yf ignition due to small flammable envelope
Service and Use

Some Pertinent Regulations

Regulation (EC) No 842/2006

• F-gases (also in mobile equipment) shall, to the extent that it is technically feasible and does not entail disproportionate cost, be recovered by appropriately qualified personnel, to ensure their recycling, reclamation or destruction

Rules on appropriate qualification of personnel recovering F-gases from MACs established by Commission Regulation (EC) No 307/2008 of 2 April 2008

• Minimum requirements for training personnel programs
• Conditions for mutual recognition

There are various additional service regulations in different EU member states
Service and Use

Some potential service differences for HFO-1234yf are:

Service shops and technicians may need to purchase/use new equipment (flammability/product differences)

- Recovery/recycle/recharge equipment (meet J2843, J2851, VDA requirements)
- Refrigerant identifiers
- Leak detection equipment

HFO-1234yf refrigerant system components should not be replaced with ones removed from a system that uses another type of refrigerant, or from a salvaged vehicle

- Replacement evaporators should meet new proposed ISO Std 13043 and/or SAE J2842 when they publish

HFO-1234yf is mildly flammable

- Precautions used with other flammables (gasoline, oil) are applicable to HFO-1234yf
Service and Use

Best Practices

In general, low lying areas, (such as workshop pits, shafts or cellar exits), may cause released refrigerant to pool as it is heavier than air.

• Regulations require work areas to be adequately ventilated and extraction units switched on if available.
• Refer to rules and regulations regarding ventilation.

Care should be taken to avoid over-charging of the refrigerant system.

Service technicians should not smoke or have any open flame present while working on refrigerant containing systems.
Product Availability

• Construction of Commercial Plant Started
• Project on track for initial product shipments 4Q11.
• Currently working on supply plans for OEM and aftermarket requirements.
Summary

- HFO-1234yf is very similar to HFC-134a, except for mild flammability.
- HFO-1234yf has low burning velocity, high minimum ignition energy and is difficult to ignite. HFO-1234yf is less flammable than other commonly used substances.
- Several service scenarios were modeled using CFD analysis and found to have small refrigerant plume above the LFL (only a few centimeters). Results indicating low risk of HFO-1234yf ignition due to small flammable envelope.
- As with any substance, HFO-1234yf service will need to follow appropriate regulations and best practices.
- Construction of the commercial plant has started and on track for initial product shipments 4Q11.
More Information

www.SmartAutoAC.com
Thank You!