Information for HFO-1234yf
Automotive Plant and Service Shop Implementation

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Agenda

• HFO-1234yf Properties
• Flammability Comparison
• OEM Plant Implementation Strategies
• Potential Service Implementation Needs
• CFD AC Leak Modeling
• CFD Results
• Summary
**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

**Vapor Pressure**

- **HFO-1234yf** has vapor pressure, toxicity class A, similar to R-134a, but has mild flammability.
### Flammability Comparison

<table>
<thead>
<tr>
<th></th>
<th>HFC-134a *</th>
<th>HFO-1234yf *</th>
<th>HFC-152a *</th>
<th>Gasoline **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame Limits- ASTM E681-04 at 23C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFL (vol% in Air)</td>
<td>N/A</td>
<td>6.2</td>
<td>3.9</td>
<td>1.4</td>
</tr>
<tr>
<td>UFL (vol% in Air)</td>
<td>N/A</td>
<td>12.3</td>
<td>16.9</td>
<td>7.6</td>
</tr>
<tr>
<td>Minimum Ignition Energy - MIE (mJ)</td>
<td>N/A</td>
<td>&gt;5000</td>
<td>0.38</td>
<td>0.29</td>
</tr>
<tr>
<td>Heat of Combustion (kJ/g)</td>
<td>4.2</td>
<td>10.7</td>
<td>16.5</td>
<td>47</td>
</tr>
<tr>
<td>Burning Velocity (cm/s)</td>
<td>N/A</td>
<td>1.5</td>
<td>23</td>
<td>34</td>
</tr>
</tbody>
</table>

* Reference [15]

** Reference [16]

HFO-1234yf flammability characteristics are “milder than” those of hydrocarbon gases or other commonly used products within the service repair shop.
Strategy employed will depend on location, volume, potential amount of refrigerant in area, potential leak scenarios, etc.
### Potential EU Automotive Plant Implementation Strategies

<table>
<thead>
<tr>
<th>Potential OEM Plant Zones</th>
<th>Amt of Refrigerant</th>
<th>Potential Zone Strategies</th>
<th>Potential Process Duration</th>
<th>Potential Applicable Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside Auto Plant - Refrigerant Filling Stations</td>
<td>Intermediate, limited by line size, high ventilation</td>
<td>No Zone</td>
<td>30 seconds</td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td>Inside Auto Plant - Refrigerant Lines</td>
<td>Minimal &lt; 1 kg per vehicle</td>
<td>No Zone</td>
<td>30 seconds</td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td>Outside Auto Plant - Refrigerant Lines leading into Plant</td>
<td>Semi-bulk tanks 1/2-1 metric tonne per tank, Bulk tanks 20 metric tonnes per tank</td>
<td>No Zone</td>
<td>No release of refrigerant, only during leak situation</td>
<td>Directive 98/24/EC (Chem Agents @ Work), Seveso</td>
</tr>
<tr>
<td>Inside Auto Plant - Refrigerant lines, but multiple stations</td>
<td>Intermediate, limited by line size</td>
<td>Zone 2</td>
<td>30 seconds</td>
<td>ATEX 137 / ATEX 95</td>
</tr>
</tbody>
</table>

Various HFO-1234yf plant implementation strategies can be employed. It is important to consult with appropriate regulatory agencies regarding strategies and limitations.
EU Service Shop Potential Implementation Needs

• Depending on the service shop (size of shop, amount of refrigerant used, regional/country regulations) a risk assessment may need to be performed.
  - While HFO-1234yf is very similar to R-134a, it is mildly flammable and this will need to be considered during usage
  - Local, regional or country regulations may require storage limits, etc, and may also require risk assessments (flammable products routinely used in automotive)

• Therefore, understanding potential service leak scenarios will be valuable for any necessary service risk assessments and subsequent service implementation.

• Methods for automotive plant and service risk assessment are outlined in SAE J1739 and soon to be published ISO 13043.
  - These standards suggest that potential ignition scenario events should be considered in risk assessments.

To successfully develop and understand potential ignition scenarios, it is helpful to determine potential flammable zone if release occurred during service.
HFO-1234yf Automotive Service Implementation - Potential Leakage 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

• 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)

Results useful as input for risk assessments
CFD MODEL DEVELOPMENT- Service Shop

• 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
Diagram of Scenario-Leak in Garage

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

Release modeled as bounded vapor release using referenced paper
Leak in Garage- Leak does not hit surface

**Time of leak**

\( t = 48.0 \text{ sec} \)

**Lower conc**

\( c = 1 \text{ vol}\% \) (light blue)

**ACH rate**

\( r = 0 \)

**Plume extends approximately 1.0 m from release point**
Plume Profile – Bounded Leak

Plume above LFL is very small (10 cm in x direction, 2 cm in z)
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.
Diagram of Scenario – Leak Impinges on Surface (Car Hood)

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
Leak in Garage - Leak **does** hit surface

Distance to surface = 0.1m

*Time of leak*

$t=48$ sec

*ACH rate*

$r=0$

**Plume continually dispersed by surface, almost no flammable zone available**
Leak in Garage - Leak **does** hit surface

Distance to surface = 0.22m

**Time of leak**
\[ t = 48 \text{ sec} \]

**ACH rate**
\[ r = 0 \]

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

**Job:** 370603  Var:FMOLE (m3/m3)/log10/ Time= 48.000 (s)

\[ X = -0.3 \text{ to } 7.3, \ Y = -0.3 \text{ to } 3.3, \ Z = 0.05 \text{ to } 2.8 \text{ m} \]
Leak in Garage - Leak does hit surface

Distance to surface = 0.85m

Time of leak
\( t = 48 \text{ sec} \)

ACH rate
\( r = 0 \)

Plume fully formed but less extension vs non-impingement case
CFD Model Results

- Actual results will depend on the size/shape of the hole and direction of the release versus air currents. Resultant refrigerant plumes are highly affected by distance to impinging surface.
- When the leak is in a garage and does not hit a surface, the plume is about 1m from the leak point. The flammable portion is 10 cm in x direction, 2 cm (+/-1 cm) in z direction.
- When the leak source is within 0.1 m from the surface, the plume is continually dispersed by surface. There is almost no flammable zone available and the flammable zone extends about 2-4 cm from the leak point.
- When leak source is within 0.22 m from surface, there is quick initial plume dispersion, then the plume feeds back within itself. There is almost no flammable zone available and the flammable zone extends about 2cm from the leak point.
- When the leak source is within 0.85 m from surface, the plume is formed, but there is less extension of the plume versus the non-impingement scenario. Flammable portion is <10cm x direction.
Summary

OEM Implementation

Three basic potential automotive OEM plant implementation strategies have been listed along with a high-level overview of potential automotive implementation strategies. Different refrigerant implementation methods can be employed.

Service Implementation

Depending on the service shop (size of shop, amount of refrigerant used, regional/country regulations) a risk assessment may need to be performed.

- While HFO-1234yf is very similar to R-134a, it is mildly flammable
- Local, regional or country regulations may be different for usage limits, storage, etc, which may also require risk assessments

Understanding potential service leak scenarios will be valuable for any necessary service risk assessments and subsequent service implementation.

- CFD modeling was used to simulate releases of HFO-1234yf under some potential air-conditioning (A/C) line rupture scenarios.
- Refrigerant concentration was determined as a function of distance from the leak point during the leak event.
- The size and shape of the portion of the refrigerant plume above the lower flammability limit (LFL) was also noted.
- Results from all simulations show an extremely small flammability envelope, on the order of centimeters.
Thank You!

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