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

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Agenda

• HFO-1234yf Properties
• Flammability of HFO-1234yf
• Automotive OEM Plant Implementation
• Automotive Service Implementation
• 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

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

• High MIE indicates HFO-1234yf is very difficult to ignite

• Burning velocity of HFO-1234yf is only 1.5 cm/sec – weak flame not easily propagated
Dual input process for successful product implementation. Customer/Supplier giving input into process is needed to make this a success!
Product Plant Site Implementation

• Customer Driven Process
  • Specific to each customer plant site (country, local regulations, etc.)
  • Key Aspects
    • Regulations (ATEX, Serveso, ADR, etc.)
    • Site constraints (available land, etc.)
    • Volumes (types of storage)

• Supplier Driven Process - Product Stewardship
  • Can customer safely handle the product?
  • Does customer have the correct information to make implementation a success?
HFO-1234yf Automotive OEM Plant Implementation

POSSIBLE STRATEGIES

- Leak Detection
- Ventilation
- Mitigation

Strategy employed will depend on location, volume, potential amount of refrigerant in area, potential leak scenarios, etc.
### HFO-1234yf Automotive OEM Plant Implementation

#### Potential 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 amt of refrigerant, but multiple stations</td>
<td>No Zone</td>
<td>30 seconds</td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zone 2</td>
<td>30 seconds</td>
<td>ATEX 137 / ATEX 95</td>
</tr>
<tr>
<td>Inside Auto Plant - Refrigerant Lines</td>
<td>Intermediate, limited by line size</td>
<td>No Zone</td>
<td></td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td>Inside Auto Plant - Refrigerant Filled Vehicles on Assembly Line</td>
<td>Minimal &lt; 1 kg per vehicle</td>
<td>No Zone</td>
<td></td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td>Outside Auto Plant - Refrigerant Lines leading into Plant</td>
<td>Intermediate, limited by line size, high ventilation</td>
<td>No Zone</td>
<td></td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zone 2</td>
<td></td>
<td>ATEX 137 / ATEX 95</td>
</tr>
<tr>
<td>Outside Auto Plant - Bulk Storage</td>
<td>Large, 20 metric tonnes per storage tank</td>
<td>No Zone</td>
<td>No release of refrigerant, only during leak situation</td>
<td>Directive 98/24/EC (Chem Agents @ Work)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zone 2</td>
<td></td>
<td>ATEX 137 / ATEX 95</td>
</tr>
<tr>
<td>Outside Auto Plant - Bulk Unloading of Refrigerant</td>
<td>Large, considered part of bulk, but limited in duration</td>
<td>Zone 1 or 0</td>
<td>Several hours to off-load refrigerant</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.
HFO-1234yf Automotive OEM Plant Implementation

Comparison of Some Appropriate Regulations for Germany
HFO-1234yf vs HFC-134a

<table>
<thead>
<tr>
<th>HFO-1234yf</th>
<th>HFC-134a</th>
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<tbody>
<tr>
<td>Ordinance on Industrial Safety and Health / Technical Rules for Industrial safety (BetrSichV / TRBS)</td>
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<tr>
<td>Technical Regulations for Pressure Vessels (TRB)</td>
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</tr>
<tr>
<td>Technical Regulations for Pressurized Gases (TRG)</td>
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</tr>
<tr>
<td>Rules for Safety and Health at work issued by the Professional Associations (BGR)</td>
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</tr>
<tr>
<td>National German regulation on water hazard classification (VwVwS)</td>
<td>National German regulation on water hazard classification (VwVwS)</td>
</tr>
<tr>
<td>Ordinance on Hazardous Substances (GefStoffV)</td>
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</tr>
<tr>
<td>International Transport of Dangerous Goods by Road and by Rail (ADR / RID)</td>
<td>International Transport of Dangerous Goods by Road and by Rail (GGVS/ADR)</td>
</tr>
<tr>
<td>Pressure Equipment Directive (PED)</td>
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</tr>
<tr>
<td>REACH regulation 1907/2006</td>
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</tr>
<tr>
<td>Explosion Protection Directions (Ex-RI)</td>
<td></td>
</tr>
<tr>
<td>Equipment or Protective System Intended for use in Potentially explosive atmospheres (Directive 94/9/EC (ATEX))</td>
<td></td>
</tr>
</tbody>
</table>

Regulations are similar for both products. HFO-1234yf has some additional regulations that need to be considered due to mild flammability.
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

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-AlChE 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
- 0.1 m/sec
- Below 0.1 m/sec

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

• Potential automotive OEM plant implementation strategies have been investigated.

• Potential automotive service leak scenarios have been investigated for use in service implementation (risk assessments.)

• As with any substance, customers will need to follow appropriate regulations and best practices for product implementation.
More Information

www.SmartAutoAC.com

Please feel free to contact the author at Mary.e.Koban@usa.dupont.com for any additional information.
Thank You!