Experiences Transitioning Automotive OEM Plants to Low GWP Refrigerant HFO-1234yf

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ABSTRACT: HFO-1234yf is a low GWP refrigerant developed for automotive air-conditioning (A/C) systems to replace HFC-134a. Industry-wide risk assessments found that HFO-1234yf can be safely used in mobile A/C applications with results previously presented. Various global automotive OEMs have transitioned to HFO-1234yf at selected manufacturing sites in different regions. This paper documents critical steps for successful transition, including installation, commissioning and startup of storage and vehicle charging facilities. Observations will also be shared concerning potential pit-falls that have been encountered during new refrigerant implementation at these sites

KEY WORDS: Heat Engine, HFO-1234yf, low global warming potential (GWP), refrigerant, air-conditioning (AC), installation, critical steps in commissioning, storage and vehicle charging facilities [A1]

1. INTRODUCTION

HFO-1234yf, or 2,3,3,3-Tetrafluoroprop-1-ene, is a recently developed non-ozone depleting, low global warming (GWP) refrigerant for automotive air conditioning systems which is intended to replace HFC-134a. HFC-134a is being phased out in the European Union due to higher global warming potential⁽¹⁾. HFC-134a has a 100 year GWP value of 1430 according to the Intergovernmental Panel on Climate Change Fourth Assessment Report ⁽²⁾. Additionally, in the US, HFO-1234yf can be used for CO₂ credits under the US EPA greenhouse gas (GHG) legislation⁽³⁾. Therefore, vehicle sales in these two regions continue to increase. HFO-1234yf is energy efficient, exhibits low toxicity, and can potentially be used in direct expansion automotive a/c systems with minimal design modifications ⁽⁴⁾.

Thermodynamic properties, boiling point, critical point, and liquid and vapor density are all comparable to HFC-134a. See figure 1 below for property comparison of HFO-1234yf to HFC-134a.

	HFC-134a	HFO-1234yf
Formula	CH ₂ FCF ₃	CF ₃ CF=CH ₂
Molecular Weight	102	114
ODP	0	0
GWP₁₀₀ (per AR4)	1430	4
T Critical Point	102 °C	95°C
Boiling Point	-26°C	-29°C
Flammability	Non-flammable	Flammable

Fig.1 Refrigerant property comparison

Significant work has been completed to confirm the mild flammability characteristics of HFO-1234yf⁽⁵⁾. Multiple industry-wide risk assessments have found that HFO-1234yf can be safely used in mobile air-conditioning applications with results being presented at various public forums^(6,7). In addition, several additional safety reviews were conducted by the German Motor Federation (also known as the KBA) and the European Commission Joint Research Centre (also known as the EU JRC) which re-validated the safety of HFO-1234yf in automotive use.⁽⁸⁾

In general, the product flammability, while it can be readily managed via all aspects, must be integrated into the implementation process and reviewed with a total site perspective in mind. Automotive OEMs manage flammable products (gasoline, brake fluid, lubricants, etc.) on a daily basis and can readily manage this fluid during site transition. The purpose of this work is just to highlight some of the timing and potential mis-steps that can be avoided with proper planning.

2. REFRIGERANT FLAMMABILITY

2.1. HFO-1234yf Flammability

HFO-1234yf has a lower flammability limit (LFL) of 6.2 vol% in air and upper flammability limit (UFL) of 12.3 vol% in air per ASTM E 681-04⁽⁵⁾. The auto-ignition temperature (AIT) of HFO-1234yf was found to be 405°C per ASTM E-659⁽⁵⁾. HFO-1234yf has a high minimum ignition energy, (MIE) ranging from 5,000-10,000 mJ, and a low burning velocity (BV) of 1.5 cm/sec⁽⁵⁾.

Evaluated for burning velocity by AIST, HFO-1234yf has been found to be mildly flammable, and falls within the new safety classification of “2L” per ASHRAE/ANSI standard 34 and ISO 817^(9,10,11). This “2L” safety classification is for those refrigerants which have burning velocity of < 10 cm/sec. Flammability classifications per these standards are divided into four categories with class 1 being virtually non-flammable under most use conditions. HFC-134a falls into class 1 as being virtually non-flammable Class 2L is considered mildly flammable due to the low burning velocity and lower heat of combustion. Class 3 and class 4 are used to denote the flammable and extremely flammable refrigerants. HFC-152a is a class 2 flammable refrigerant, while the hydrocarbons (propane, butane) generally populate the extremely flammable class 3. Toxicity classifications are divided into two groupings with lower toxicity refrigerants getting an A designation and those with higher toxicity given a B designation. HFO-1234yf is class A for toxicity.

Highly Flammable	A3	B3
Flammable	A2	B2
Mildly Flammable	A2L	B2L
Practically Non-Flammable	A1	B1

Fig. 2 Refrigerant Safety Classification per ASHRAE/ANSI Standard 34 and ISO 817

2.2. Flammable Refrigerant Markings

While HFO-1234yf is considered to have “low” or “mild” flammability, the flammability characteristics still need to be reviewed with respect to automotive site implementation and appropriately taken into consideration during.

At the current time, there is no differentiation with regards to shipping/ transport and product bulk storage in terms of product flammability safety class designation. To further exemplify this point, HFO-1234yf, under the Global Harmonized System (GHS), is marked as a flammable, compressed gas and will need the markings or similar markings as shown below in Figure 3.

HFC-134a
*Non-flammable
Compressed Gas*

HFO-1234yf
*2L Flammable
Compressed Gas*

Fig. 3. HFO-1234yf and HFC-134a container markings per GHS

As was discussed in a previous work, there may be opportunities within the automotive manufacturing facility to use non-classification (essentially staying below the LFL) type strategies at the different locations in the site.⁽¹²⁾ However, as was noted before, there are areas due to the volume of refrigerant available and potential for large release under a catastrophic event, such as the bulk storage area, that need to follow a classification strategy. Therefore, these areas will require compliance with flammable product standards and regulations.

3. AUTOMOTIVE MANUFACTURING FACILITY IMPLEMENTATION

3.1. General Rules of Thumb for Flammable Refrigerant Product Implementation

1) Don't wait to initiate or start the implementation process.

Facility design and implementation (lines, storage tanks, charging systems) and subsequent commissioning may take upwards of 9-12 months.

2) Expect the unexpected during the implementation process.

There will be many parameters outside of the automotive facility team's control, such as regulating authorities, building codes, clearances that may cause delays in the planning process. Therefore, it may be appropriate to build in extra time into the planning process.

3) Stay ahead of the crowd and try to prepare the site for flammable gas use earlier rather than later.

Facility commissioning inspectors/regulators and vendor resources from parts and vendors may not be available on short notice. OEMs waiting until the last minute may find additional challenges. Advance planning OEMs will have greatest amount of resources and least amount of anxiety.

4) **Complete the process and beta test the system.** OEMs have a strong preference for conducting vehicle trials from the fully commissioned system. It is suggested that first product delivery is at least 3 months before vehicle pretesting begins and at least 6 months before full vehicle production begins.

3.2 Code Enforcement Officers, Certifying Bodies, Insurance Inspectors

Use of HFO-1234yf will more than likely require an OEM to engage a code enforcement officer, a certifying body or an insurance inspector or any combination of the above. While the automotive facility team may have a very robust implementation plan, failing to engage these entities in the beginning of the process is a potential mis-step. Early and frequent engagement of these entities and careful joint review of the site overall potential implementation plan is key to staying on track with the project timeline and budget. These groups can also provide critical feedback to the process and can highlight any unrecognized project pitfalls, particularly regarding overlapping or secondary codes.

Obviously these entities will have the a strong determination on how the transition will need to occur. Therefore, if they are not engaged early, there is a possibility of delaying the project by 1-3 months if they determine electrical panel boxes, piping, pumps or other system parts need to be moved or altered to meet codes, certify a site or to comply with an insurance rider.

3.3 Bulk Storage Tank Installation

Some OEMs have opted to retrofit or repurpose their existing HFC-134a tanks to enable use with HFO-1234yf. While this is possible, it does require effort to 1) ensure the tank is sound for re-use and 2) to bring the current tank into regulatory compliance. Depending on the history of the bulk storage container shell, there will be a need to assure there is no degradation of the interior shell surfaces (no pitting, gouges, etc.). The same issue will apply to the exterior of the bulk storage container. Obviously any issue encountered will require additional time added to the overall conversion plan. New bulk container shells will not typically be a concern with regard to surface issues. However, new bulk tanks will need to be checked for possible manufacturing residue which could impact future refrigerant product quality.

Bulk storage tanks will need to meet required regulatory codes and standards. Conversion from an existing HFC-134a bulk storage tank to HFO-1234yf can require significant planning to meet the requirements needed for flammable storage. While it may appear to be a trivial task to retrofit or install new safety devices and valves which meet flammable codes, the bulk storage tank will not have the same general access as a new constructed tank which has not yet been attached to a pad site.

Experience has shown that retrofitting an existing storage tank for use with HFO-1234yf may take anywhere from 19-24

weeks. Purchasing a new bulk storage tank for use with HFO-1234yf may take 20-24 weeks for a fresh build and that is once an order has been placed. Several OEMs have tried the re-purpose route and found that small mis-steps in the planning process actually increased the time to successfully complete bulk storage tank installation to 24-26 weeks. Additional costs associated with fixing incorrect pressure relief devices increased the overall costs which made purchase of new tanks almost neutral from a cost perspective.

3.4. Bulk Storage Tank Location

Location of the storage tank and a suitable off-load area will have to be considered and may be impacted by the product change. Tank safety devices and equipment will require modification to the existing system to assure regulatory compliance. In the past, this bulk storage tank location was not a large consideration as HFC-134a is considered non-flammable.

Proper HFO-1234yf tank location is imperative. A less than desirable location can cause problems in the future with off-loads and site access.

While many OEMs have flammable storage tank farms (areas where several flammable tanks are located together), it may not always be feasible to add another flammable storage tank to this area for various reasons. The site can be constrained by adjacent roadways, fencing, additional buildings, and pump houses. Additionally, flammable storage tank orientation, off-loading, overhead piping, and general tank access all need to be reviewed and considered in the planning. Based on the pertinent codes and standards, there will probably be a required radius or classification zone around the tank and line connection points during off-load. See figure 4 for potential classification zones that need to be addressed during off-load.

Fig. 4 Refrigerant off-loading to bulk storage tank. Two potential classification radii are shaded in green.

Even the off-load can be challenging if not properly planned. Not all suppliers will use the same type of off-loading equipment and/or hose connections. Therefore, it is extremely beneficial to

engage the refrigerant supplier early in the process. The refrigerant supplier can provide the necessary information on what size/type of hoses are required for off-load, what connections used, who will supply and keep the hoses in between shipments and any additional power requirements.

3.5. Piping and lines

Pipe lines which convey HFO-1234yf will have to be compliant for flammable gas. In general, steel or stainless steel lines that are used for HFC-134a can be re-used for HFO-1234yf, but need to be checked for additional flammable gas requirements. Changing the lines from HFC-134a to HFO-1234yf will also require that new O-rings and seals are used. The general rule is that once the line is broken the seals/O-rings lose integrity and can be a potential leak point. The time to convert an existing refrigerant line set can range anywhere from 1-2 weeks depending on the length of the lines, upgrades needed for flammable refrigerant, re-labeling, cleaning, new O-rings/seals and general complexity of the site.

Most OEMs cannot shut down an existing HFC-134a refrigerant pipe line and therefore opt to install at least one new set of refrigerant pipe lines for HFO-1234yf so that both refrigerants will co-exist within the plant. Any designed relief valve protection location must consider the outlet stream so it does not impact operations, change classification of areas or impact personnel. The same point holds true for vent down lines. New line installation can range from 2-6 weeks depending on length and type of lines installed, labelling, cleaning and again, general complexity of site.

There has been a tendency to overlook the small points in refrigerant line installations. One common point that can have major impact on future refrigerant quality is line cleanliness. While lines are new, there will be residual particles, etc., from the welding process that can impact the quality. Another point that can cause confusion is proper labeling of lines. It may seem obvious that lines need to be adequately labeled, but sites can be extremely complex and proper labeling will enable facility team and potential inspectors to clearly see how lines traverse site.

3.6. Bulk Storage Tank and Line Preparation

Bulk tank and refrigerant line preparation is needed to assure integrity of HFO-1234yf as it is used in the bulk fluid process. As mentioned above, the cleanliness and preparation of the storage system and piping is crucial. Refrigerant pipe lines should be cleared of contaminant from the installation process (cutting

fluids, weld debris, etc.) and checked. The preparation before first fill is to ensure that the storage tank and pipeline are clean, dry and properly evacuated before the first off-load. A minimum of 28.5 in Hg vacuum is recommended. This step should take only about 1-2 days, but can take longer depending on level of contamination.

3.7 Refrigerant Charging

Properly rated refrigerant charging units compliant and manufactured for HFO-1234yf will need to be in place. There are a variety of manufacturers which have developed refrigerant charging units. Different charging equipment manufacturers employ different strategies for implementing HFO-1234yf. Some equipment manufacturers require additional ventilation, leak detectors and/or vent lines. These items need to be taken into consideration and will impact the process timeline. Equipment manufacture, while not an issue, can be a custom build as OEMs may want a multi-fluid type unit. Several manufacturers have stated long lead times as they prepare equipment that meets customer requirements and the codes in the region of use. Therefore, it should be noted that lead times can range from a few months to 6-12 months on the longer end.

Generally implementation and testing of safety interlocks will be required to satisfy that the flow of material given an upset condition does not exceed some pre-set percentage (typically 40-60%) of the LFL. Additional equipment, such as gas monitors, may be required to meet safety codes. This process can add another 1-2 months to the installation.

4. TIMELINE OBSERVATIONS AND RECOMMENDATIONS

It has been at least three years since global automotive OEMs first implemented HFO-1234yf at their manufacturing sites. OEMs have known about the EU MAC directive regulation since 2006. A large percentage of global OEMs have transitioned at least one site and are expected to transition more sites in the near future.

While resources at facilities are always stretched it is never too early to start planning even if a site is coming on in 1-3 years. The time horizon may seem long, but when the cumulative parts of the whole process are put together it can easily take 9-12 months to transition a facility and that is once a plan has been developed. Mis-steps in planning and implementation can quickly expand upon this timeline.

Information on estimated lead-times presented within this paper is tabulated in the table 1 below. It should be noted that these lead times are approximate and can easily expand or contract.

Table 1-Estimated lead-times

	Est Leadtimes to Manufacture System Parts and/or Install
Bulk Storage Tank Re-purpose	19-23 weeks
Bulk Storage Tank New Build	20-24 weeks
Bulk Storage Tank/Utilities Installation	2-6 weeks
Bulk Storage Tank Cleaning	1-2 days
Pipe Line Installation	2-6 weeks
Refrigerant Charging Equipment Mfg	12-52 weeks
	1-2 weeks
Refrigerant Charging Equipment Installation	(may depend on plant shut-down)
Ancillary Equipment (gas detectors, etc.)	2-4 weeks

Putting this information together with cost approvals, it is easy to see how the transition and implementation can expand. Given below is Table 2 showing an estimated OEM process timeline if the OEM started in April of 2015.

Table 2. Estimated OEM complete timeline

Estimated OEM Initial Fill Scale Up Timeline	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Mar 2016	Apr 2016	May 2016	Jun 2016
Equipment design, configuration, code approvals															
Capital approval for equipment purchase															
Order bulk storage and refrigerant fill equipment															
System fabrication															
System delivery and installation															
Production trials (2-3 phases via pkg product)															
First bulk delivery															

5. CONCLUSION

While HFO-1234yf has low or mild flammability per refrigerant industry standards, it is *flammable* and *should be handled differently from HFC-134a to some degree*. The appropriate changes will need to be made with respect to bulk storage tank installation, commissioning and startup. Additional equipment, such as gas monitors, may be required to meet safety codes. Equipment used for vehicle charging and on-site refrigerant OEM recovery will need to be properly rated for flammable products.

So, with these items in mind, it will be helpful to follow this guidance:

- **Don't wait to initiate-** Facility implementation (lines, storage tanks, charging systems) and subsequent commissioning may take from 9-12 months.
- **Expect the unexpected-** There will be many parameters outside of the facility team control, such as regulating authorities, so expect some delays in the process and plan accordingly.

- **Stay ahead of the crowd** – Facility commissioning inspectors and resources from vendors may be squeezed by those OEMs who wait until the last minute to complete their commissioning process – those OEMs who plan ahead will get the greatest flexibility and have the least amount of anxiety.
- **Complete the process-** A facility team can only tell if full implementation is successful by charging a few vehicles, so suggest first product delivery at least 3 months before vehicle pretesting begins and at least 6 months before full vehicle production begins.

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