



HFO-1234yf Technology Update – Part II

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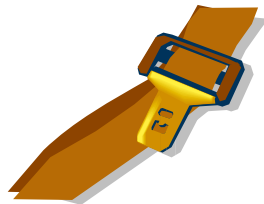
HFO-1234yf Solution



- Hydrofluoroolefin (HFO) 1234yf developed and extensively tested over a four-year period.
- Near drop-in replacement for R-134a – allowing for faster adoption.
- A global solution – able to cool in even the hottest regions.



- Global Warming Potential (GWP) of 4 – well below the EU regulations of 150.
- Atmospheric lifetime of only 11 days (compared to 13 years for R-134a and more than 500 years for carbon dioxide).
- Highly energy-efficient refrigerant, meaning autos with HFO-1234yf use less fuel and have fewer emissions than those that use alternatives.



- Safe to use in automobiles as verified through extensive third-party testing, including crash testing and thorough third-party toxicity testing, conducted by automotive OEMs.

HFO-1234yf and Toxicity

- Independent, global testing laboratories have conducted comprehensive toxicity tests on 1234yf and concluded it is safe for use in mobile air conditioning.
- In the event of a car fire, 1234yf -- like other materials found in an automobiles such as the current refrigerant, R-134a -- will burn and release hazardous materials.
- R-134a has been in use for 15 years and there have been no documented cases where combustion of automotive refrigerants has resulted in injury or death.
- Many materials used every day – including CO₂ -- can be toxic if exposures are too great. One government study called for risk mitigation devices to be installed in cars using CO₂-based A/C systems to avoid health effects ranging from dizziness to loss of consciousness if CO₂ concentrations become too high.

Extensive Toxicity Testing
at Leading Labs



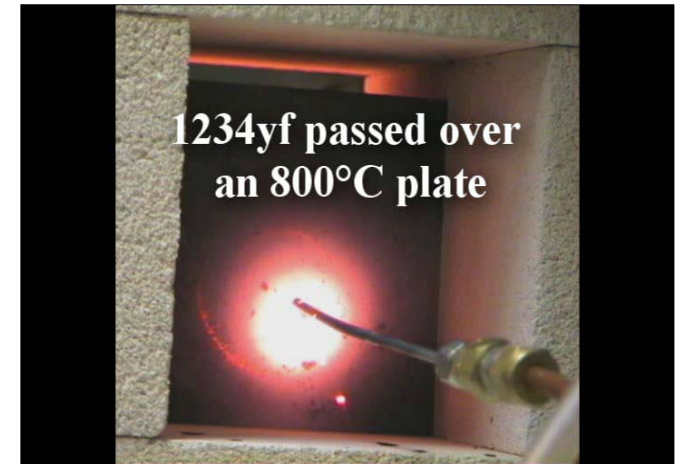
WIL Research Laboratories
The United States



TNO Pharma
The Netherlands

HFO-1234yf and Flammability

- CO₂ supporters have raised flammability questions about 1234yf, which is classified as having low flammability.
- Thorough independent tests, including independent, third-party, documented tests by the Society of Automotive Engineers and automakers using real-world conditions have demonstrated that 1234yf is safe to use in mobile air conditioning.
- Any potential risks associated with use of 1234yf are extremely minimal, and far outweighed by the environmental benefits of this solution.



Experiments were conducted to evaluate the ignition potential of 1234yf in real-life hot surfaces (up to 800°C – hotter than any engine surface). As seen here, 1234yf does not ignite.

HFO-1234yf Flammability and Safety Standards Update

- ASHRAE SSPC 34 voted (1/09) to approve R-1234yf with Safety Classification A2 and requested immediate publication upon approval by ASHRAE Standards. Expect publication about March-April.
- ASHRAE SSPC 34 Flammability Subcommittee recommended publication public review of new 2L flammability classification group to be added to the Standard.
 - HFO-1234yf with its low burning velocity would receive this classification, the lowest flammability classification available.
- SAE ICCC Committee developing Safety Standards for HFO-1234yf.
- New ISO Working Group (ISO/TC22/WG14) initiated development of an ISO safety requirements standard for use of HFO-1234yf and CO2 for MAC.

EU Flammability Classifications

- EU Flammability Classifications: MSDS (Material Safety Data Sheet)
 - Under the criteria set in Annex VI to Directive 67/548/EEC (OJ L225, 21.8.2001), the only category for flammable gases is R12/F+, extremely flammable: A gaseous substance is either not flammable or “extremely flammable”. Consequently, no distinction is made according to the actual risk a gaseous substance poses due to its intrinsic properties relevant for the flammability classification.

2.2.3. Extremely flammable

• Substances and preparations shall be classified as extremely flammable and assigned the symbol .F+. and the indication of danger .extremely flammable. in accordance with the results of the tests given in Annex V. The risk phrase shall be assigned in accordance with the following criteria:

R12 Extremely flammable

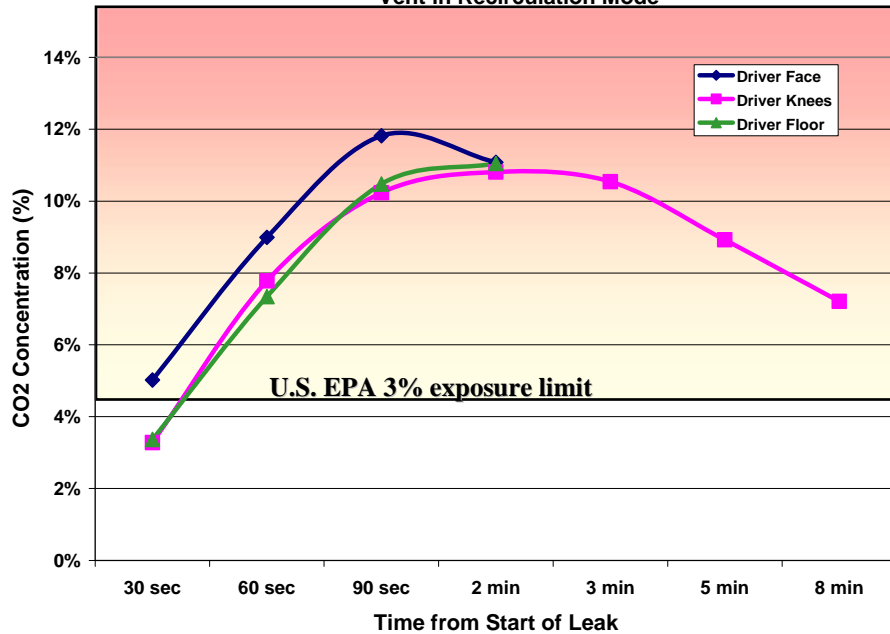
- Liquid substances and preparations which have a flash point lower than 0 °C and a boiling point (or in case of a boiling range the initial boiling point) lower than or equal to 35 °C.
- **Gaseous substances and preparations which are flammable in contact with air at ambient temperature and pressure.**

Refrigerant Concentration Tests - Small Car

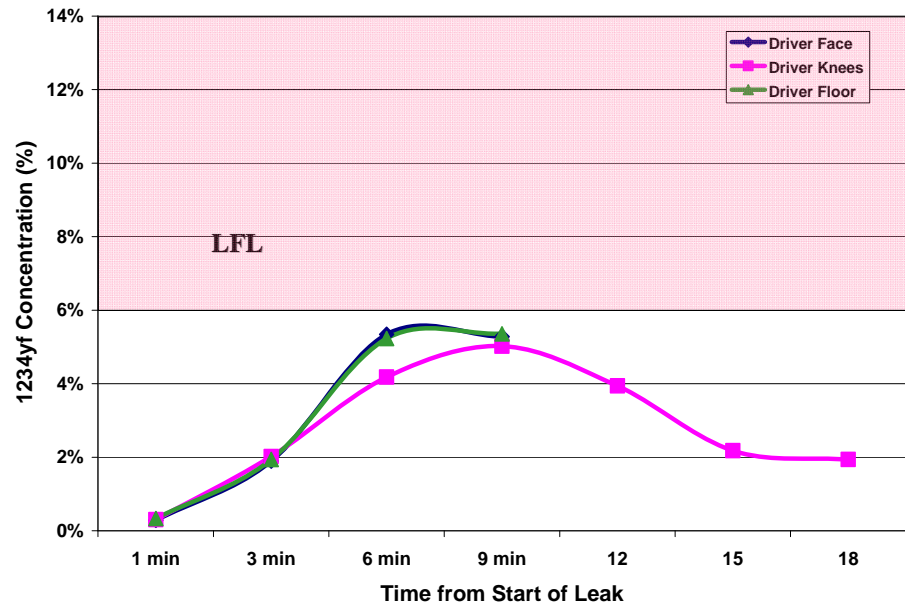
- Tests were conducted on a 2 passenger vehicle
- Volume of car = 1.41 m³ w/o passengers
 - Tests conducted with one passenger (75 liters), **Interior Cabin Free Vol. = 1.34 m³**
- Refrigerant leaks were carried out inside the HVAC module at the evaporator
 - Refrigerant flow rates were determined from previous tests and are consistent with values used in the SAE CRP risk assessments.
- Air samples collected throughout the cabin and refrigerant concentrations were determined by high accuracy gas chromatography.
- Test Matrix
 - Constructed of an array of MAC system operation modes
 - Following chart depicts the same system operating with both CO₂ and HFO-1234yf
 - Large corrosion leak in recirculation mode with vent outlets

Refrigerant Concentration Tests in a Small Car

CO₂ Concentration for Large Corrosion Leak (0.5mm dia hole)
Vent in Recirculation Mode

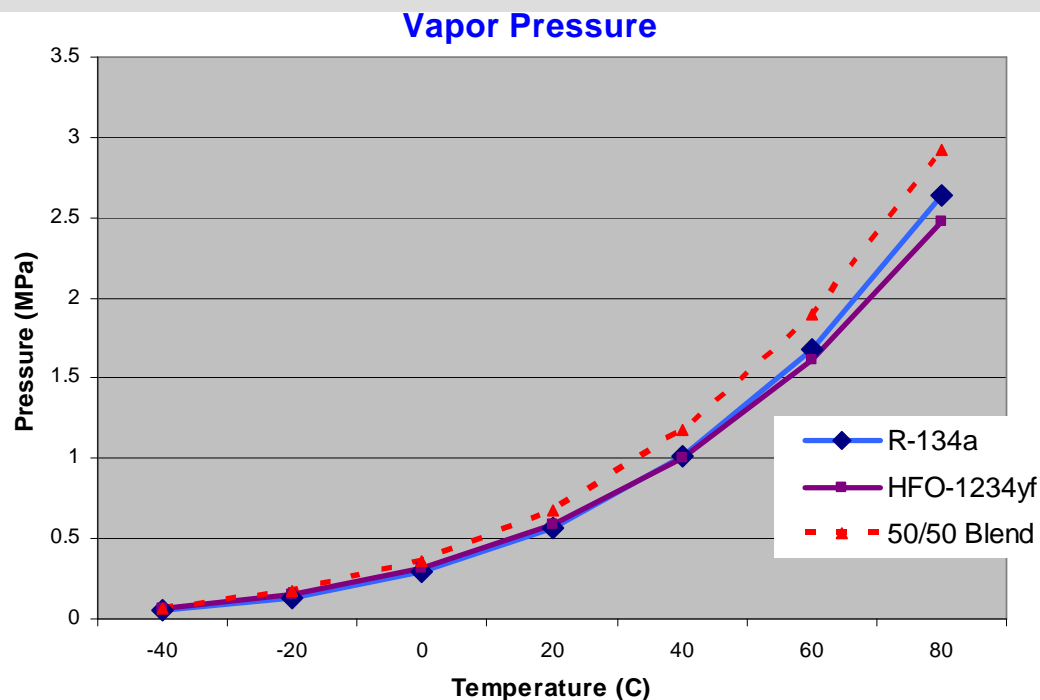


HFO-1234yf Concentration for Large Corrosion Leak (0.5mm dia hole)
Vent in Recirculation Mode



- 0.5 mm corrosion leak represents the worst case corrosion leak
 - Recirculation mode would yield higher concentrations than outside air mode.
- CO₂ concentrations are above the U.S. EPA exposure limit of 3% and do not include any background level due to the passengers.
- HFO-1234yf concentrations remain below the LFL.
- Higher risk associated with CO₂

Impact of Accidental Mixing



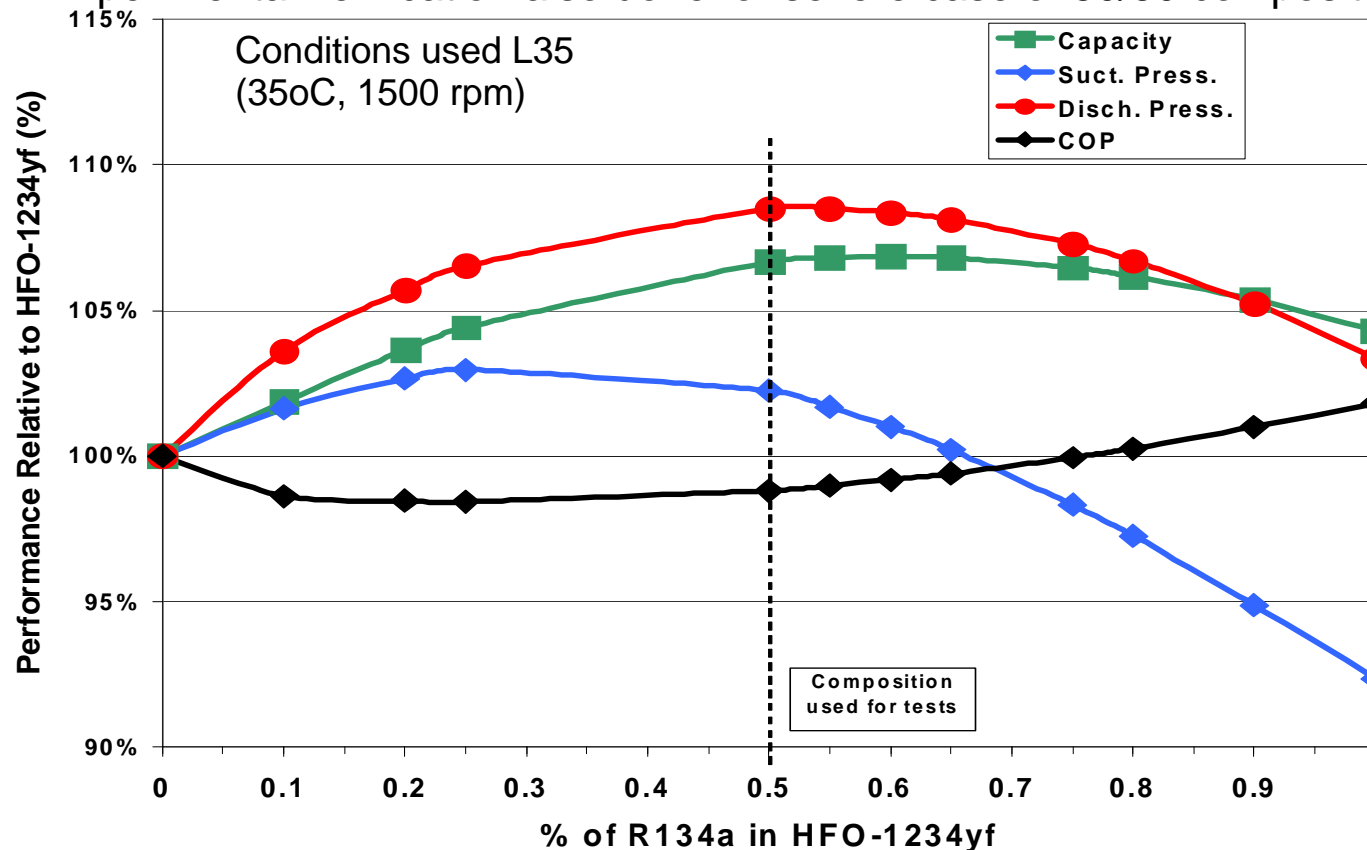
What will happen if HFO-1234yf is accidentally mixed with HFC-134a?

- Minimal pressure effect, but will alter P-T relationship for servicing
- Potential impact on R/R/R segments (ease of separation, ARI 700 purity specs)
- Resulting blend will have small glide and may still be flammable
- Need proper service training, unique service fittings for HFO-1234yf vehicles

Regulations, training, industry Standards needed to prevent mixing of HFC-134a and HFO-1234yf during servicing

Performance Impacts of Mixing HFC-134a with HFO-1234yf

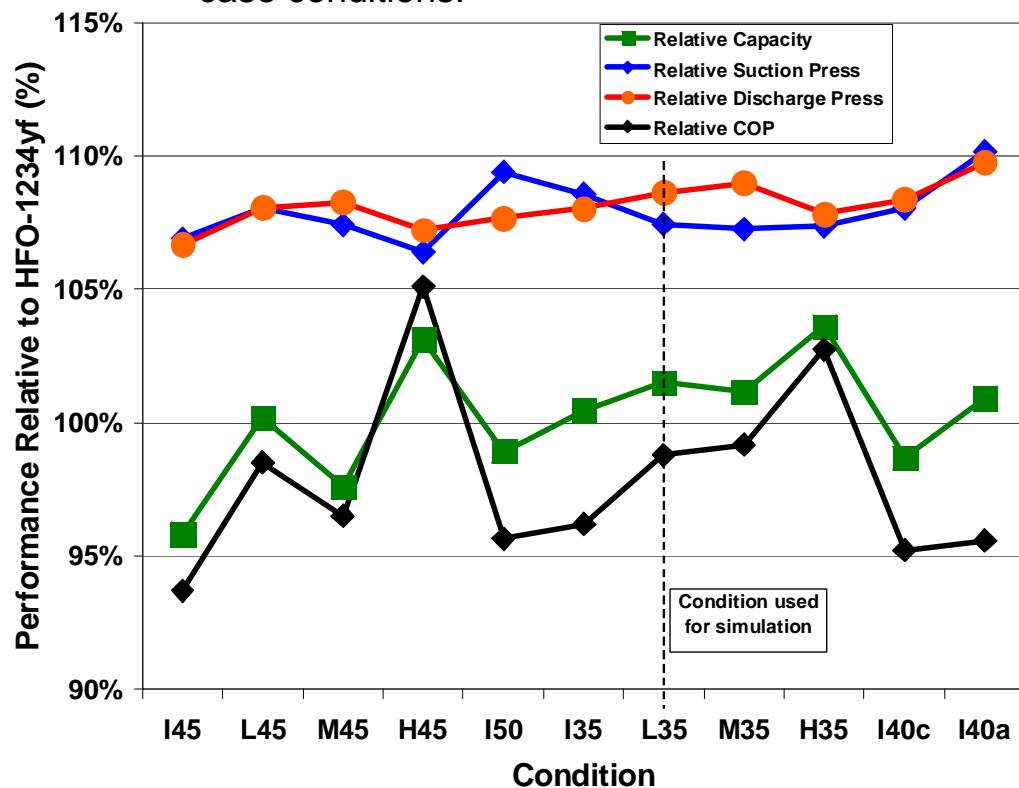
- System simulations conducted at various compositions
- Experimental verification also done for severe case of 50/50 composition



- **Results show pressures increase, but less than R12/R134a mixtures**
- **Slight shifts in capacity, COP**

HFC-134a / HFO-1234yf Mix Test Results

- System bench tests were performed on a Opel Astra A/C system at Honeywell's Refrigerant Application Laboratory.
 - A 50/50 wt% mixture was compared against the pure refrigerants.
 - No changes made to the system.
 - Tests were run at the SAE CRP 45°C and 35°C conditions since these represented worst case conditions.



- The testing at 50/50 composition confirmed the conclusions from the simulation.
 - Modest increases in operating pressures
 - Slight changes in performance.

Handling/Recyclability

HFO-1234yf Will Be Handled Similar to R-134a

- Distribution of HFO-1234yf along supply chain similar to R-134a
- Minor changes to plant charging equipment and procedures
- Can be recovered, recycled and reused on site at service shops
- Leaks can be detected with same equipment as R-134a
- Unique fittings will be used ensure no cross contamination with R-134a

Recovery Networks/Service Shops

- Third party recovery networks expected to function similar to HFC-134a
- HFO-1234yf can reclaimed/recycled on site.
- Slightly modified R/R/R equipment, same procedure.

PAG Compatibility

Temp/Time	Moist, ppm	Shrieve RFL 46X HFO-1234yf			
		Total Acid Number mg KOH/g	Total Halide Ions	Total Organic Ions	Total Inorganic Ions
Unaged	Unaged	0.06	0	37	0
Unaged	Unaged	0.06	0	32	0
190C/24hr	993	0.10	55	48	0
190C/24hr	30,000	0.08	29	527	0
175C/14days	993	0.18	103	33	0
175C/14days	30,000	0.13	66	716	0

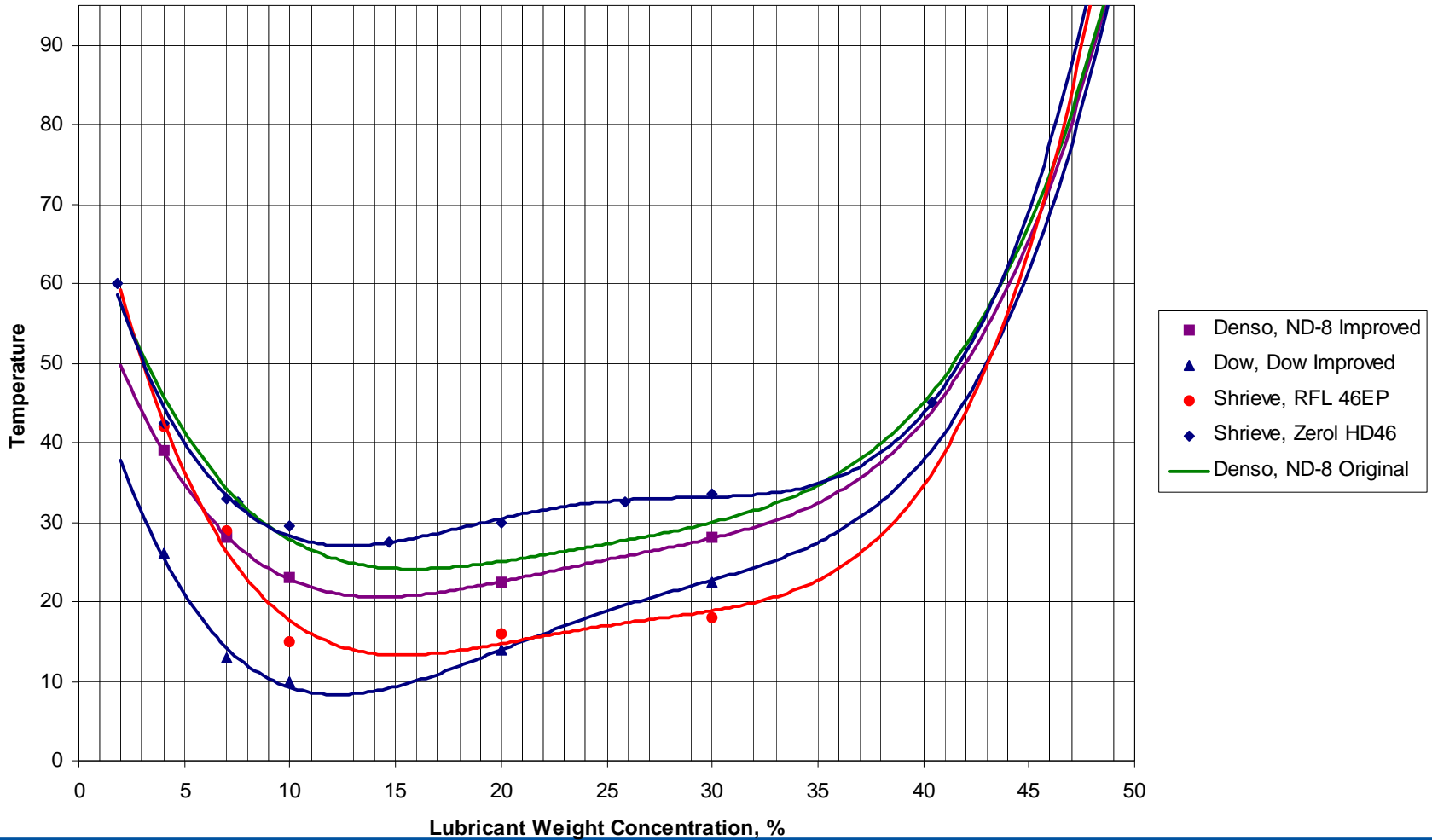
Comment: 30,000 ppm is free water; Saturation 18,130 ppm

PAG lubricants Daniel Chart Comparison

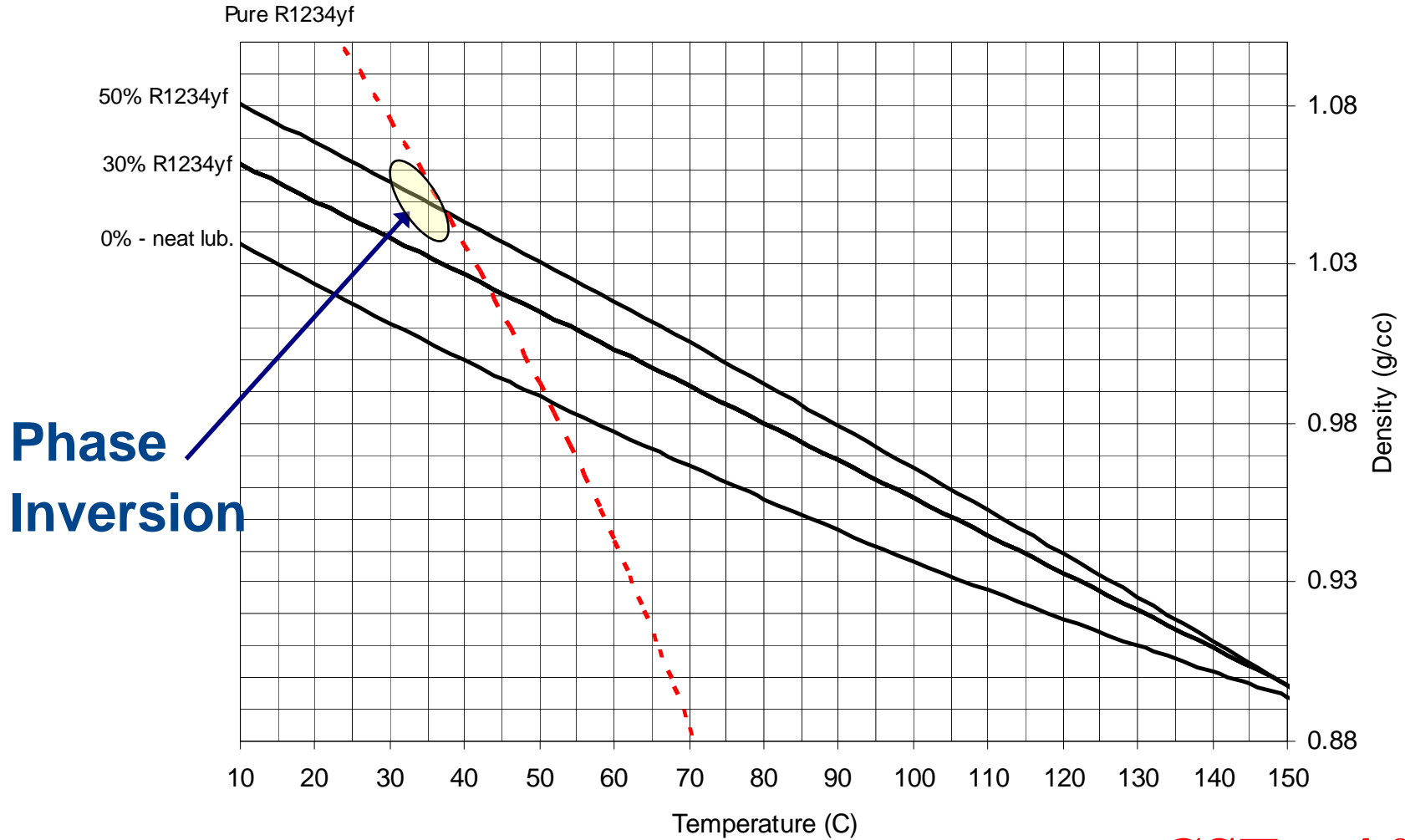
	Shrieve RFL 46X HFO-1234yf	Shrieve HD46 HFO-1234yf	ND-8 R-134a
50°C Compressor Sump Pressure @ 2°C Sat. Evap.	21.8 cSt	21.5 cSt	22.9 cSt
100°C Compressor Sump Pressure @ 2°C Sat. Evap.	8.4 cSt	8.4 cSt	9.1 cSt
50°C Compressor Sump Pressure @ 15°C Sat. Evap.	16.9 cSt	16.7 cSt	17.4 cSt
100°C Compressor Sump Pressure @ 15°C Sat. Evap.	7.8 cSt	7.9 cSt	8.5 cSt
Viscosity Maximum 2°C Sat. Evaporator	24 °C 31.8 cSt	26 °C 29 cSt	26 °C 30.2 cSt

PAG Lubricant Miscibility

Miscibility Separation Temperatures
1st Gen. PAG Lubricants (ISO 46) with HFO-1234yf



Density of PAG 46 with HFO-1234yf

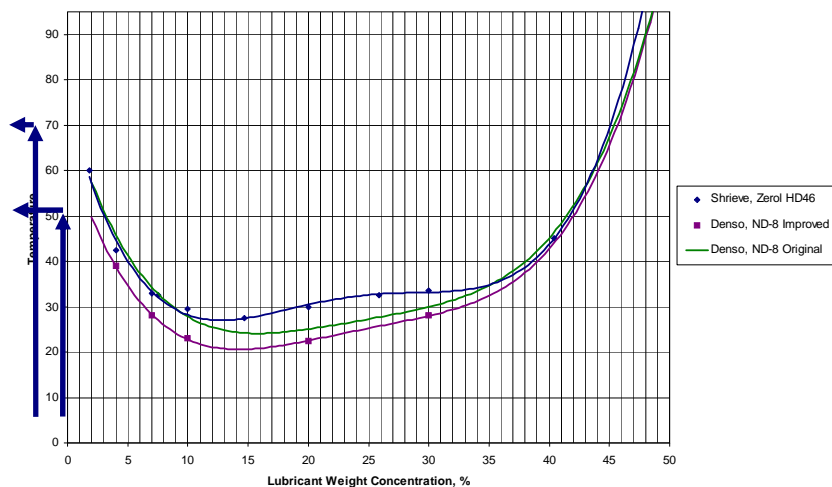


CST ~ 4 °C

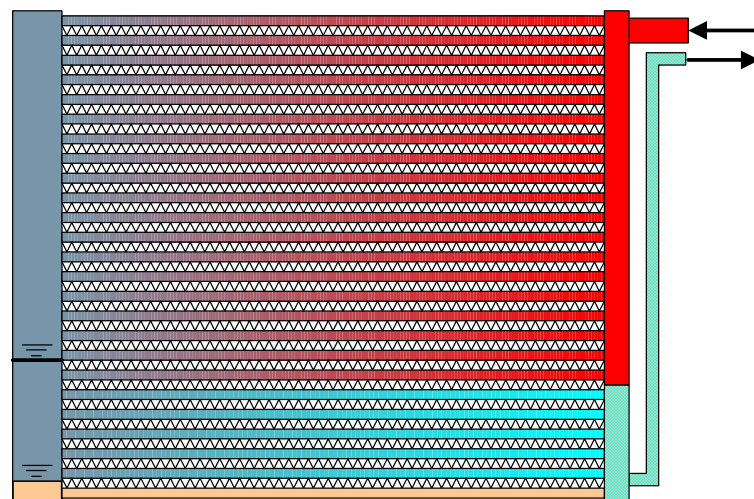
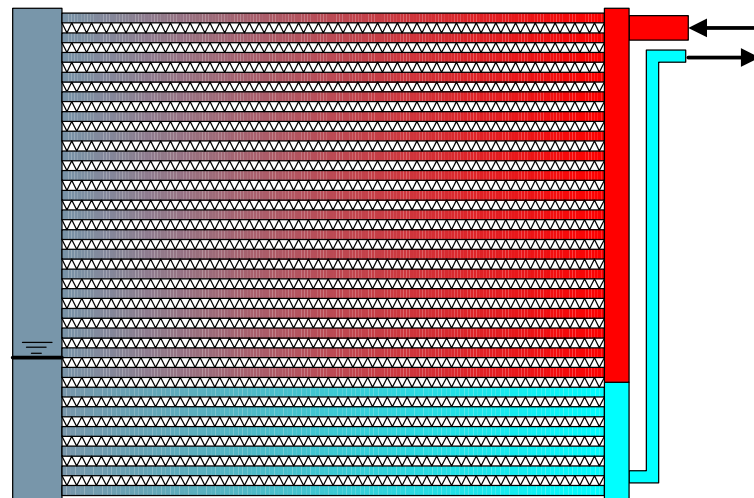
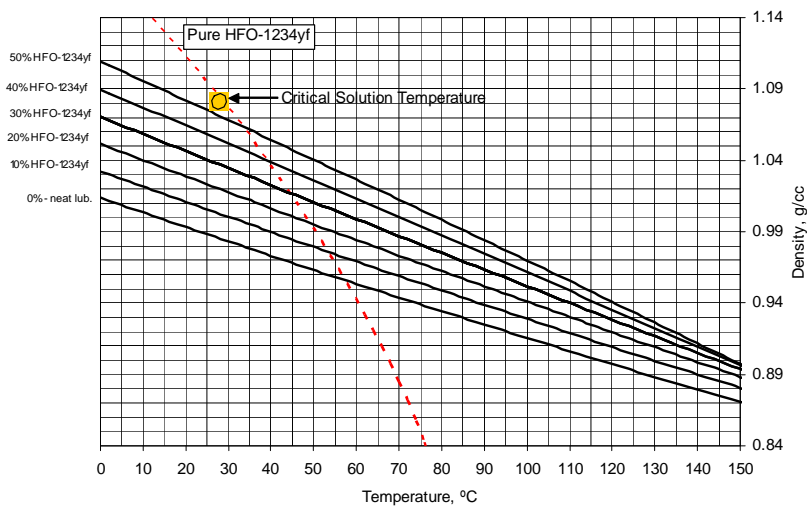
Idemitsu Pag 46 PS

OCR & Density Lubs without Phase Inversion

Miscibility Separation Temperatures
1st Gen. PAG Lubricants (ISO 46) with HFO-1234yf



Density of Zerol HD46 PAG with HFO-1234yf



Compressor Test Results

	Compressor Discharge Temperature	Compressor Discharge and Suction Pressure	Refrigerant Stability	Lubricant Acidity	Electric Leakage Current
Var. Displacement R134a / PAG 46	stable	stable	No decomposition	≤0.1 mg KOH/g	---
Var. Displacement HFO-1234yf / PAG 46	stable	stable	No decomposition	≤0.1 mg KOH/g	---
Scroll HFO-1234yf / PAG 46	stable	stable	No decomposition	≤0.1 mg KOH/g	---
Hybrid Electric HFO-1234yf / POE 68	stable	stable	No decomposition	≤0.1 mg KOH/g	none
Hybrid Electric HFO-1234yf / PAG 46	stable	stable	No decomposition	≤0.12 mg KOH/g	none

Lubricant Testing Summary

- **Miscibility represents an opportunity for improvement.....BUT**
 - **Early 134a/PAG systems had similarly low CST and were improved**
- **Lube manufacturers will continue to make refinements for 1234yf**
- **The unique 1234yf/PAG temp/density relation mitigates concerns**
- **To our knowledge, compressor and system tests to date have not surfaced any significant oil return and oil retention deficiencies with 1234yf, or any significant refrigerant / lubricant decomposition.**
- **Good results obtained on both refrigerant / lubricant thermal stability and material compatibility, consistent with SAE CRP1234-2 reports.**

1234yf vs CO₂ Summary

	1234yf	CO₂
Environmental Impact	Lower total greenhouse gas emissions than either 134a or CO ₂	20-30% more total global warming emissions than 1234yf
Atmospheric Lifetime	11 days	> 500 years
Drop-in Solution?	Near drop-in solution	New system design required
Ability to Cool Auto Interior	Superior performance in all climates	Less effective/efficient in hot climates – where air conditioning is used more
Safety	Safe for use in automotive air conditioning applications	Safe for use in automotive air conditioning applications

1234yf: safe and environmentally friendlier than CO₂

HFO-1234yf Overall Summary

- **Excellent environmental properties**
 - Very low GWP of 4, Zero ODP, lowest LCCP
 - Atmospheric chemistry determined and published
- **Low toxicity**
 - Low acute and chronic toxicity
 - Significant testing completed
- **System performance very similar to R-134a**
 - Excellent COP and Capacity, no glide
 - From both internal tests and OEM tests
 - Thermally stable and compatible with R-134a components
 - Potential for direct substitution of R-134a
- **Mild flammability (manageable)**
 - Flammability properties significantly better than 152a; (MIE, burning velocity, etc)
 - Potential for “A2L” ISO 817 classification versus “A2” for 152a based on AIST data
 - Potential to use in a direct expansion A/C system - better performance, lower weight, smaller size than a secondary loop system
- **Global Solution**
 - Good performance in all climates
 - "Near drop in" allows for rapid global adoption

Additional Information

For further information on HFO-1234yf please visit:

- www.genetron.com
- www.1234facts.com
- www.refrigerants.dupont.com
- www.SmartAutoAc.com

Thank you!

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