Update on an Ultra-Low GWP Refrigerant For Mobile Air Conditioning Applications

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Acknowledgements

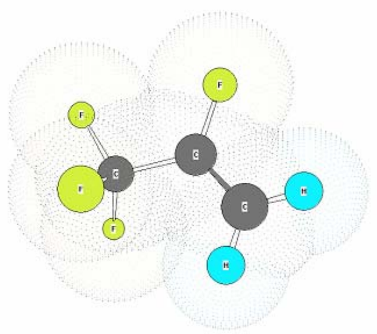
- Valeo Climate Control
- Visteon Climate Control & Hyundai
- Colleagues at Honeywell

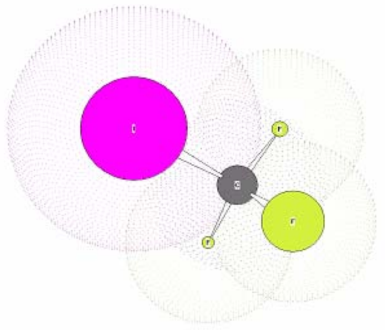
Introduction

- Due to a European Union directive on MAC refrigerants, there is a need to replace R-134a with a refrigerant that has a Global Warming Potential (GWP) of less than 150.
- CO2 (Carbon Dioxide, R-744) – is a leading alternative, however system cost and service issues remain.
- HFC-152a - has similar properties to 134a with a low GWP of <150, but flammability is an issue.
- Work began in 2002 to identify a new, low GWP, non-flammable 134a replacement that is primarily targeted to the European auto industry that is facing the phase-out of R-134a beginning in 2011.

R-134a Replacement For Auto A/C

No single component fluid met all the product requirements





Fluid H:

Azeotrope of:

$CF_3CF=CH_2$ (Major component)

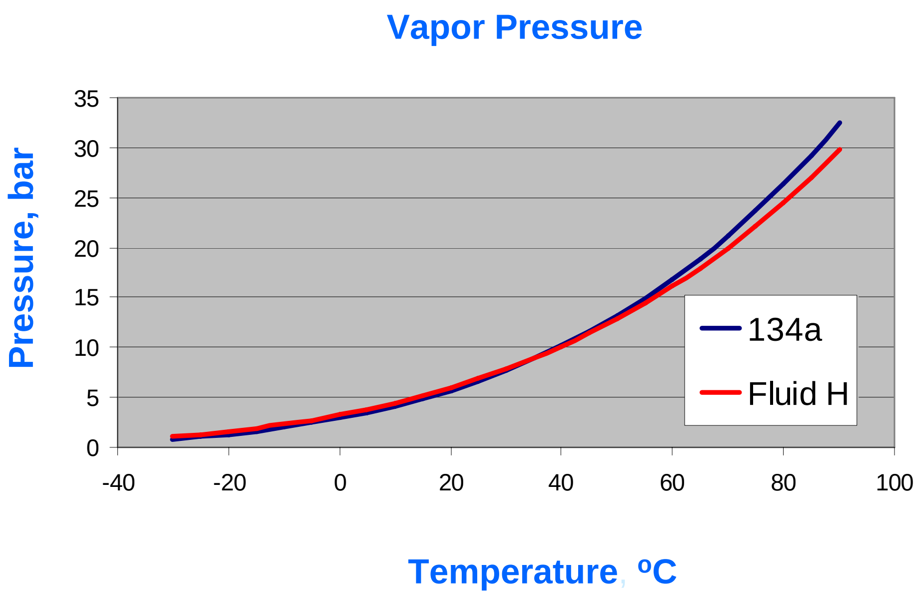
CF_3I (Minor component)

$CF_3CF=CH_2$:
1,1,1,2 Tetrafluoropropene
Fluorocarbon Number: 1234yf
New Material
Not Commercially Produced

CF_3I:
Trifluoromethyl iodide
Known Material
Produced In Small Quantities

Fluid H Physical Properties

	H	134a
Boiling Point, T_b	-30ºC	-26ºC
Critical Point, T_c	97ºC	102ºC
P_{vap}, kPa (5ºC)	381	350
P_{vap}, kPa (65ºC)	1795	1890
Flammable	No*	No*
GWP_{100}	< 10	1300



*ASHRAE Std. 34 & SAE J1657

Close Match To 134a Properties

Thermodynamic Properties of Fluid H

Conditions (Assumptions):		
	Evaporation Temperature	1.5^{o}C
	Condensing Temperature	65^{o}C
	Compressor Suction	10^{o}C
	Compressor Isentropic Eff.	65%

Analysis Results:		R-134a	Fluid H	Comments
	Suction Pressure (bar-abs)	3.1	3.4	Higher suction pressure - must change/adjust TXVs or higher superheat will result
	Condensing Pressure (bar-abs)	18.9	17.9	Slightly lower system pressure requirements, controls based on pressure must be adjusted
	Relative Mass Flow	1	1.43	Higher pressure drop but also better heat exchanger flow distribution. Optimization of hxs
	Relative Capacity	1	0.94	Slightly lower cycle capacity & COP but optimized heat exchangers likely will reduce or eliminate this deficit
	Relative COP	1	0.95	

Minor property differences between 134a and Fluid H

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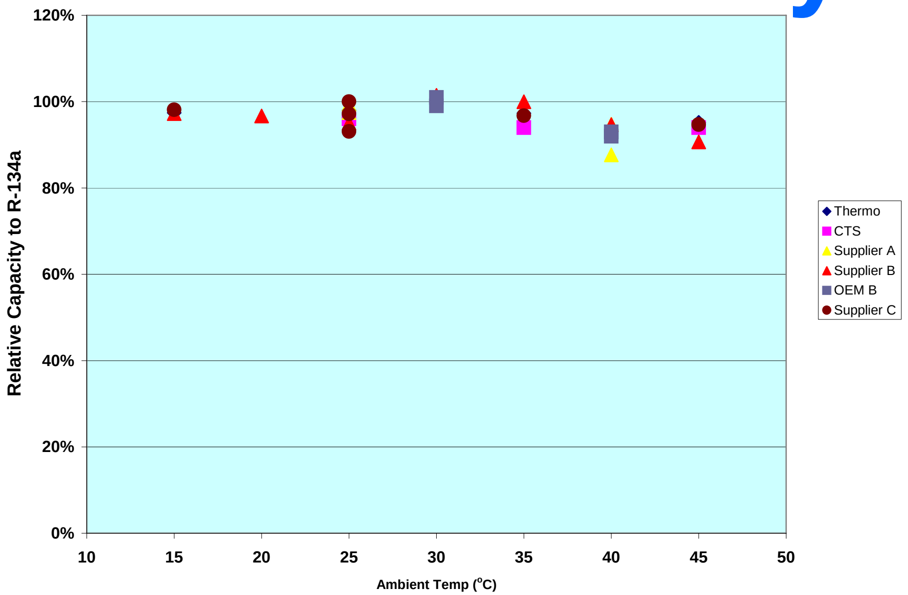
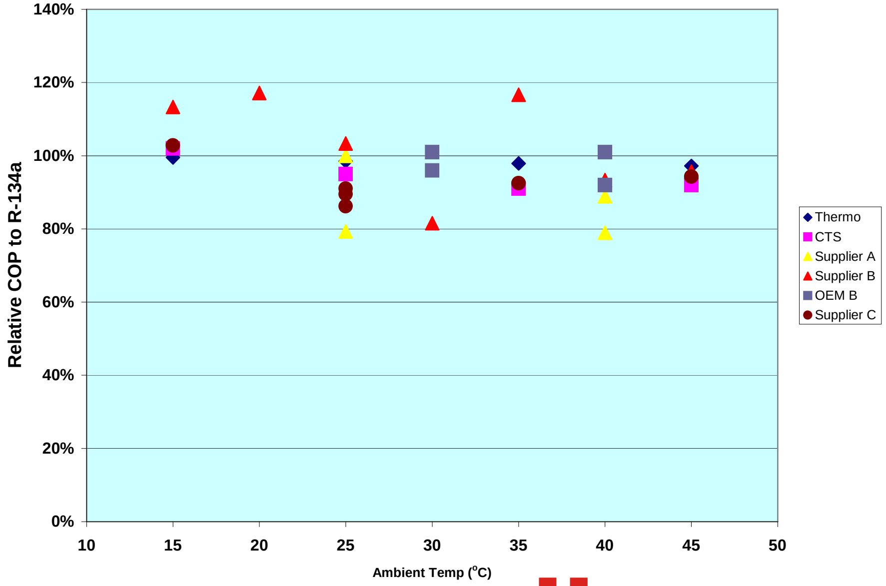
Performance Evaluation Summary

- Since the beginning of this year numerous evaluations have been performed.
  - About 8 sets of either vehicle wind tunnel or bench tests at OEMs & Tier 1's (summary of bench test data show here).
- Results show close performance to R-134a considering most do not involve any changes.
- Most recent tests reveal potential to match or exceed R-134a with optimized components.





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System Stability

- Fluid H was developed to quickly breakdown in the atmosphere to significantly reduce any direct impact on global warming
- Tests in sealed tubes and in systems have been conducted with results demonstrating stability to 160°C
  - These results have previously been presented.
- Further testing is in progress to quantify the reliable operating envelope of this refrigerant.
  - It should be noted that R-134a is an extremely stable molecule and Fluid H is unlikely to be as stable.
  - However the industry has successfully used R-12 for many years and its stability is also less than R-134a.

Material Compatibility and Permeability

Commonly used material

Hose materials

- Butyl rubber
- Chlorinated butyl rubber (CIIR)
- PA materials (Nylon 6 or 6.6)

O-Rings/Sealing

- HNBR
- EPDM
- Neoprene or Chloroprene

Other

- Desiccant (e.g. XH7, XH9)
- Membrane (e.g. Kapron)
- Compressor materials (e.g. shaft seals, coatings)

In-house Compatibility Tests

- Commonly used materials in laboratory tests
  - ➔May to August 2006

Supplier Compatibility and Permeation Tests

- External tests at material suppliers
  - ➔May to November 2006
- Additional Tests at systems suppliers and OEMs

Material Compatibility and Permeability

Test condition: 50°C for 1 week	Percent change	
Material	**Volume**	**Wt**
NBR O-ring	-0.4±0.6	-0.8±0.4
Shaft Seal - HNBR	8.2±4.1	3.7±3.7
HNBR O-rings	3.6±0.5	2.8±0.6
Green Neoprene O-rings	1.2±1.0	6.0±1.0

150°C for 2 weeks	Percent change in properties		
Material	**Volume**	**Wt**	**Hardness**
NBR O-ring	4.2±1.2	4.6±0.2	0.3±3.0
Parker HNBR platen	6.4±3.6	7.3±3.7	1.5±1.1
General Guidelines	-5/+20 %	-10/+20%	+/- 10%

No significant issues seen in initial compatibility tests

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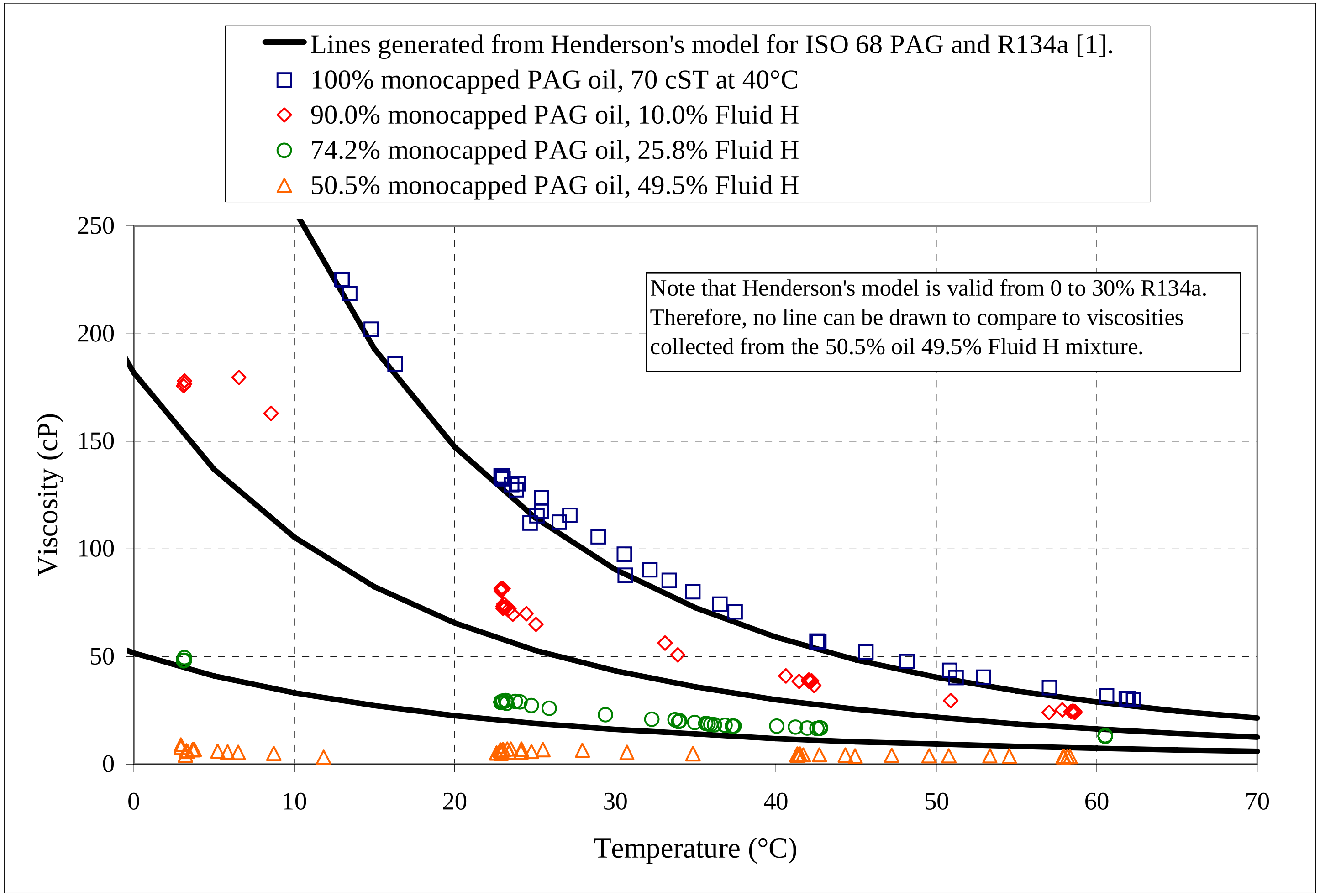
Viscosity of Refrigerant/Oil Mixtures



Slightly higher viscosity of Fluid H/PAG mixtures

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Honeywell / Valeo Demonstration Vehicle

Converted a 2006 VW Jetta a/c system to Fluid H

- GLI version with 2.0 liter turbocharged engine.
- Modification made:
  - Adapted expansion valve for Fluid H.
- Tests ran at Valeo in France:
  - System test bench.
  - Vehicle wind tunnel test of similar vehicle (same engine and a/c system).

Test Conditions

Vehicle cool down procedure used:

Test conditions : 45°C & 40% RH with sun load of 1000 W/m^2

- **30 minutes : 40 km/h 3rd gear**
- **30 minutes : IDLE**
- **20 minutes : 90 km/h 5th gear**

Aerothermal test bench: two sets of conditions were used

A/C loop sizing points

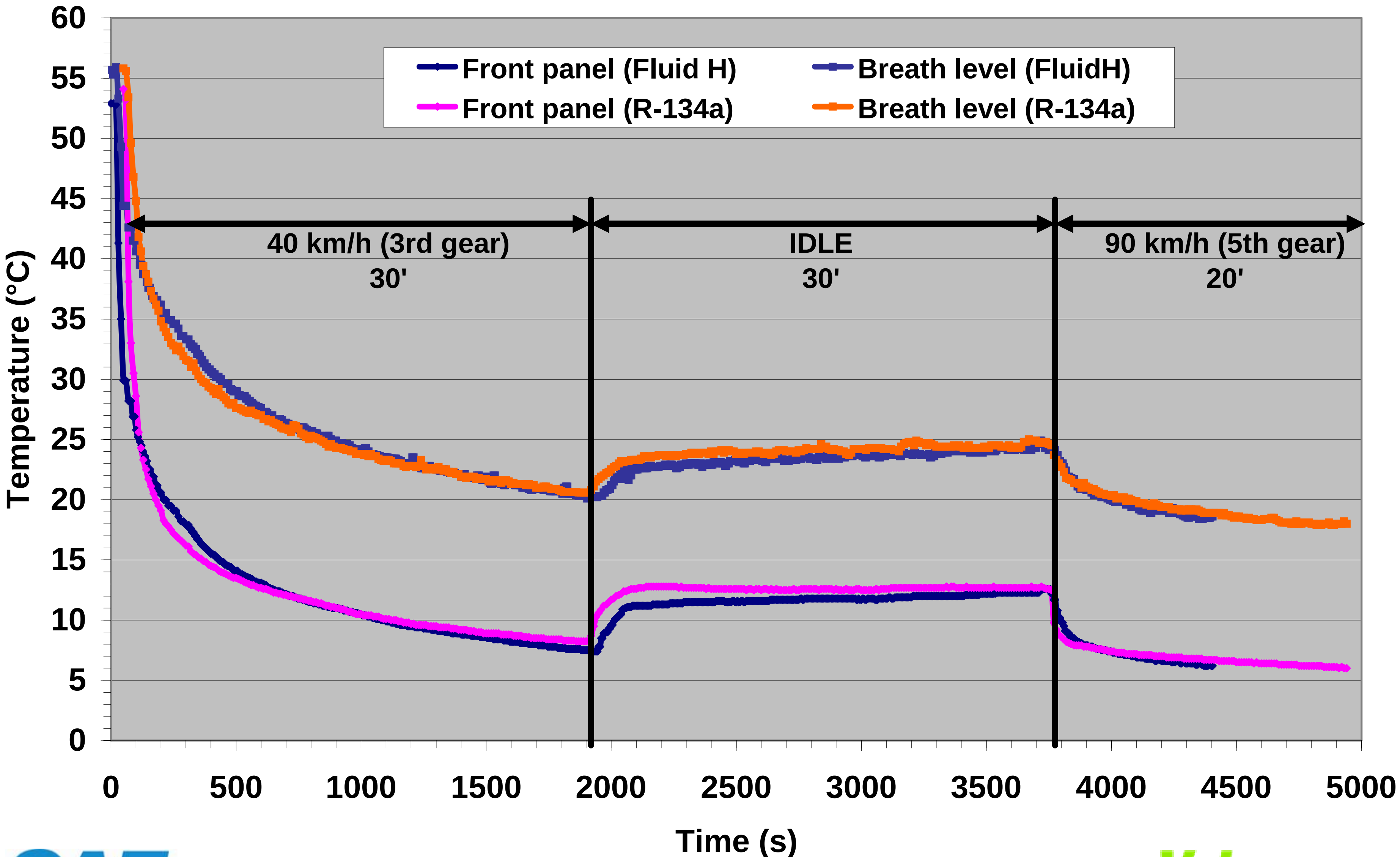
	Evap Blower	Evap T° (°C)	Evap RH (%)	Car speed	Cond air speed (m/s)	Cond T° (°C)	Comp (rpm)	Air T° target (°C)
Sizing	Max	45	40	40 km/h	2,3	45	2500	Min
IDLE				0 km/h	1,3	45	1000	

Cool down representative test points

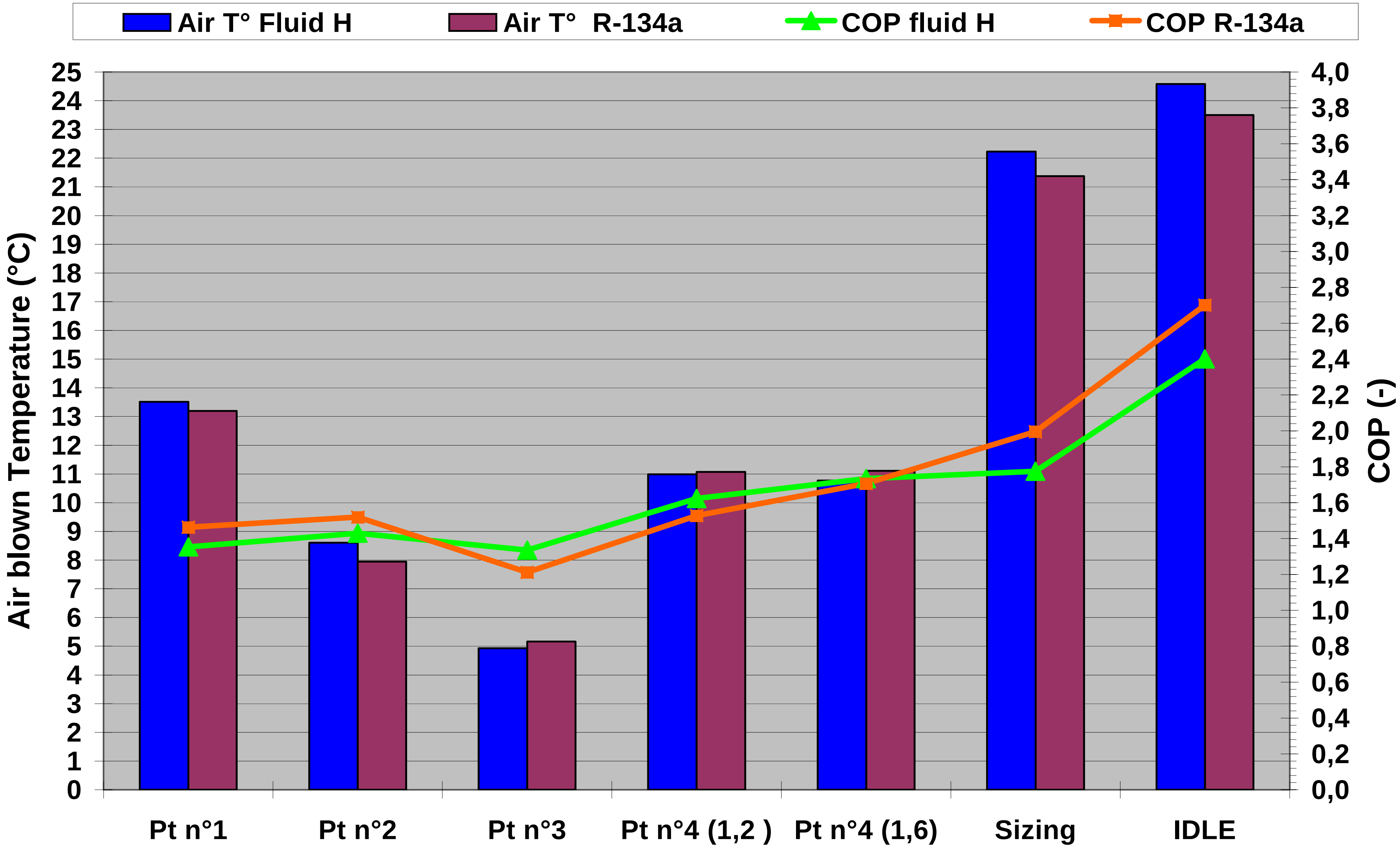
	Evap Blower	Evap T° (°C)	Evap RH (%)	Car speed	Cond air speed (m/s)	Cond T° (°C)	Comp (rpm)	Air T° target (°C)
Pt n° 1	Max recirculation mode	46,5	15	40 km/h	2,3	46	2500	Min
Pt n° 2		37	17					
Pt n° 3		28	24					
Pt n° 4 (1,2)		30	30	0 km/h	1,2	55	1000	
Pt n° 4 (1,6)					1,6			

R-134a : standard production system; Fluid H: same system with adapted TXV

Vehicle Cool Down



Bench Test Results



Visteon / Hyundai System Development

- Fluid H integrated into Visteon CAE tools
  - Used to design components that take full advantage of Fluid H characteristics
- Extensive refrigerant sub-system testing
  - Validated CAE models
  - Fully characterized performance attributes of H
- Designed new components using R134a sub-component "building blocks" (tubes, plates, fins, hoses, etc)

Visteon / Hyundai Vehicle Development

Production Vehicle

- 2006 Hyundai Accent

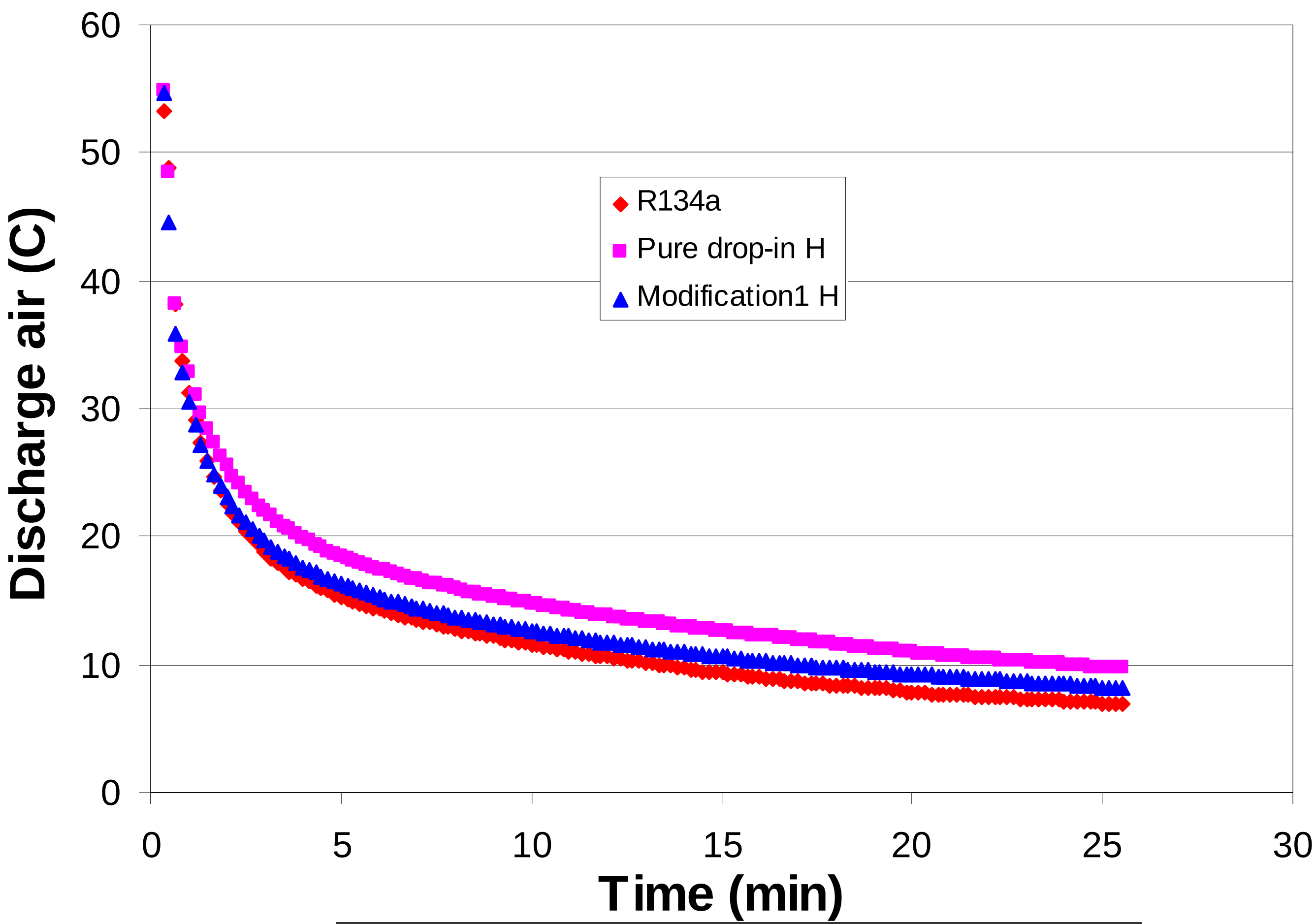
Production R134a System

- VS16 variable swashplate compressor
- 45mm plate-fin evaporator
- 16mm condenser with integrated receiver drier
- TXV

Vehicle Configurations Evaluated

- Production R134a
- Fluid H as pure drop-in
- Modified hardware #1 – "minor modifications"
- Modified hardware #2 (Test vehicle shown here)
  - Production compressor, pulley ratio, engine cooling fan
  - Other refrigerant system components modified to take advantage of H properties (same package & core depth as production)

Wind Tunnel Results



Modification 2 (demonstration vehicle) not yet tested in wind tunnel

Conclusions

- Development work continues on a very low GWP non-flammable refrigerant. Evaluation results are promising.
- System and Vehicle Test Results
  - Initial drop in tests were encouraging but more recent testing of systems that have had modest modifications show very close and even better performance to that of R-134a
  - Any reduction in capacity seen in “drop-in” tests was shown to be overcome by slight modifications to the system:
    - Change expansion device, modify suction lines, and/or modify heat exchanger flow paths.
- Investigation of material compatibility, stability, toxicology, and environmental impact continues. Results to date have not revealed any major obstacles to the successful development of this refrigerant.
- This refrigerant has the potential to be a more cost-effective replacement than other R-134a alternatives currently in development.