Updated situation about alternative refrigerant evaluation

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Agenda

1- Background

2- R-744: Clio results

3- R-1234yf: Clio, 207 and Panda results :
   *Drop-in performances, analyses, and enhanced systems*

4- Flammability

5- Conclusion
Preliminary

• To make the presentation easier to understand, we propose the following convention:

![Smiley face] I am happy

![Sad face] I am not happy
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3- R-1234yf : Clio, 207 and Panda results :
   Drop-in performances, analyses, and enhanced systems

4- Flammability

5- Conclusion
1- Background

1. R-744: is it possible to achieve the current R-134a MAC system fuel efficiency?

2. HFO-1234yf: What performance compared to current R-134a?

3. HFO-1234yf: What efficiency compared to current R-134a?

4. How to deal with the HFO-1234yf flammability open issues?
Agenda

1- Background

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5- Conclusion
2- R744 : Clio results

How to evaluate fuel consumption?

☑ Never compare absolute values.

*Because, even if comparing values with the same car, mileage will not be same, so AC OFF fuel consumption will be different.*

☑ How to compare relative values?

*In case of Clutch-less compressor, the AC OFF reference test must not depend on the parasitic torque performance. To get rid of the parasitic contribution, it is meaningful to break the torque limiter.*
At Renault:

- *Fuel test procedure has been created 1995,*
- *It is always performed in the same wind tunnel,*
- *For comparison, we always keep same cooling capacity (same HVAC airflow and same Evaporator T)*
- *Tests are always performed by our specialists, and they take care of:*
  *Trained drivers only,*
  *Tires pressure and type,*
  *Engine oil quantity and temperature is controlled*
  *Car mass is controlled,*
  *Batteries are charged.*
### 2- R-744 : Clio results

<table>
<thead>
<tr>
<th>Amb T°</th>
<th>20 °C</th>
<th>20 °C</th>
<th>30 °C</th>
<th>35 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td>Solar load (in W)</td>
<td>0 W</td>
<td>700 W</td>
<td>800 W</td>
<td>850 W</td>
</tr>
<tr>
<td>HR%</td>
<td></td>
<td>40 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blower speed</td>
<td>0</td>
<td>3/8</td>
<td>6/8</td>
<td>6/8</td>
</tr>
</tbody>
</table>

#### Fan Speed
- R-134a : controlled by ECM
- R-744 : controlled to get the optimum fuel consumption, but keeping same cooling capacity

#### Evap temp
- R-134a : controlled by the compressor (internal control)
- R-744 : manually controlled to get same cooling capacity (pre testing is necessary)

- 4 ECE cycles for stabilization
- Then 1 EUDC, and the 6 ECE (measurement is done at each cycle end)
- It takes 2 days for a test.
Extremely bad results. Renault decided to start an improvement program.
## 2- R-744 : Clio results

**Counter-measures?**

<table>
<thead>
<tr>
<th>Components</th>
<th>Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>Compressor change to a “best in class” compressor</td>
</tr>
<tr>
<td>Expansion</td>
<td>New FXV settings for COP optimization</td>
</tr>
<tr>
<td>Air inlet</td>
<td>Shroud totally closed with flaps, complete front sealing</td>
</tr>
<tr>
<td>IHX</td>
<td>Coaxial IHX with optimized COP performance (best balance between IHX performance and compressor suction T)</td>
</tr>
</tbody>
</table>

**R-134a** | **R-744a**
We got a remarkable important improvement, **but**:
2- R-744 : Clio results

Results explanation and possible improvements

- Improved performance at 35 °C is linked to fan speed optimization compared to R-134a reference (electrical power saving – possible also with R-134a)

- Fuel consumption **on this test** of R-744 is similar with R-134a but R-134a has a lot of potential improvements (**only state of the art**)

<table>
<thead>
<tr>
<th>Potential efficiency improvement now “state of the art techno”</th>
<th>Eff.</th>
<th>R-134a</th>
<th>R-744</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil separator on compressor</td>
<td>++</td>
<td>Possible</td>
<td>Already integrated</td>
</tr>
<tr>
<td>IHX</td>
<td>++</td>
<td>Possible</td>
<td>Already integrated</td>
</tr>
<tr>
<td>Sub cooled condenser</td>
<td>++</td>
<td>Possible</td>
<td>Not possible</td>
</tr>
<tr>
<td>Improved air inlet tightness and totally closed shroud</td>
<td>++</td>
<td>Possible</td>
<td>Already integrated</td>
</tr>
<tr>
<td>Improved heat exchanger efficiency</td>
<td>+</td>
<td>Possible</td>
<td>Already integrated</td>
</tr>
</tbody>
</table>
2- R-744 : Clio results

Conclusion

We are still not confident that R-744 today’s technology could reach the same fuel efficiency than R-134a up to date technology.
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3- R-1234yf : Clio, 207 and Panda results :
   \textit{Drop-in performances, analysis, and enhanced systems}

4- Flammability

5- Conclusion
3- R-1234yf : Clio, 207 and Panda results : *Drop-in* performances, analyses, and enhanced systems

- Step 1 : drop in with R-1234yf
- Step 2 : analysis and solutions
- Step 3 : enhanced systems
3- R-1234yf : Clio, 207 and Panda results : Drop-in performances, analyses, and enhanced systems

- Step 1 : drop in with R-1234yf (207 and Panda)
- Step 2 : analysis and solutions (Panda and 207)
- Step 3 : enhanced systems (Clio and 207)
3- R-1234yf: Clio, 207 and Panda results

Drop-in test with R-1234yf

Cooldown tests at 45 °C, 40%, 1000 W

Baseline R-134a

Drop-in 1234yf

Avg breath level

Avg vents

+ 1,3 °C

+ 2 °C

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3- R-1234yf: Clio, 207 and Panda results

*Drop-in test with R-1234yf*

Cooldown test at 43 °C, 30%, 900 W

- **32 kph**
- **64 kph**
- **96 kph**
- **Idle**

Baseline R-134a

Drop-in 1234yf

Avg breath level

Avg vents

+3 °C

+2 °C

0 °C to 40 °C

0 30 60 90 120
3- R-1234yf : Clio, 207 and Panda results :

*Drop-in performances, analysis, and enhanced systems*

- Step 1 : drop in with R-1234yf (207 and Panda)
- Step 2 : analysis and solutions (Panda and 207)
- Step 3 : enhanced systems (Clio and 207)
3- R-1234yf: Clio, 207 and Panda results

How to optimize Panda system for R-1234yf?

Sub-cooling should be increased

Super-heating should be decreased

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3- R-1234yf: Clio, 207 and Panda results

Cycle analysis of 207 drop-in behaviour @30mn

\[
\frac{\rho \times \Delta h}{\rho \times \Delta h} = \frac{14.9 \times 106}{12.2 \times 134} = 96.6\% 
\]

Increase subcooling by 30% to reach baseline cooling capacity

\[
\Delta h = 106 \text{ kJ/kg} \\
\Delta h = 134 \text{ kJ/kg} \\
\rho = 14.9 \text{ kg/m}^3 \\
\rho = 12.2 \text{ kg/m}^3 
\]
3- R-1234yf: Clio, 207 and Panda results

*How to optimize all systems for R-1234yf?*

**Targets**

- Increase subcooling by 30%
- Reduce evaporator superheat

**Constraints:**

- Same discharge pressure
- Same packaging

- Optimized condenser design (sub-cooling optimization)

- Increase TXV setting: 2.0 → 2.3 bars
3- R-1234yf: Clio, 207 and Panda results

Cool-down result with R-1234yf optimized system

Cooldown tests at 45 °C, 40%, 1000 W

- 45 kph, 3rd
- 90 kph, 5th
- Idle
- Idle, 2000rpm

Baseline R-134a

Drop-in 1234yf

1234yf optimized

+1 °C in idle due to evaporator temperature distribution

Avg breath level

Avg vents
3- R-1234yf: Clio, 207 and Panda results

Measured effect of condenser and TXV optimizations

COP Analysis:
- R-134a Baseline: 2.24
- 1234yf Drop-in: 2.18
- 1234yf Optimized: 2.24

Optimized condenser designed by CalsonicKansei
3- R-1234yf: Clio, 207 and Panda results

Effect on discharge pressures

- Discharge pressure with R-1234yf and CK condenser is equivalent to current R-134a system
- Using R-134a in a system designed for R-1234yf would lead to higher discharge pressures (not acceptable)

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3- R-1234yf : Clio, 207 and Panda results :

* Drop-in performances, analysis, and enhanced systems

- Step 1 : drop in with R-1234yf (207 and Panda)
- Step 2 : analysis and solutions (Panda and 207)
- Step 3 : enhanced systems (Clio and 207)
3 configurations tested on Renault Clio 1.5 dCi:

<table>
<thead>
<tr>
<th></th>
<th>R-134a baseline</th>
<th>R-134a enhanced</th>
<th>1234yf enhanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>Wobble plate variable displacement internally controlled</td>
<td>Swash plate variable external control with oil separator</td>
<td></td>
</tr>
<tr>
<td>Evaporator</td>
<td>Plates &amp; fins 48 mm thick</td>
<td>Plates &amp; fins 40 mm thick (new gen)</td>
<td></td>
</tr>
<tr>
<td>TXV</td>
<td>R-134a setting</td>
<td>R-134a setting</td>
<td>R-1234yf setting</td>
</tr>
<tr>
<td>Condenser</td>
<td>Flat tubes, No sub-cooling</td>
<td>Flat tubes with sub-cooling</td>
<td>Flat tubes with R-1234yf optimized sub cooling</td>
</tr>
</tbody>
</table>
COP of current R-134a has been improved using new heat exchangers, and subcooled condenser (Clio R-134a optimized).

With a new TXV setting, and an optimized condenser (but same packaging), R-1234yf can reach optimized R-134a system efficiency in a Clio.
3 configurations tested on Peugeot 207 1.6 HDi:

<table>
<thead>
<tr>
<th></th>
<th>R-134a baseline</th>
<th>R-134a enhanced</th>
<th>1234yf enhanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>Wobble plate variable</td>
<td>Swash plate variable “high efficiency”, with oil separator, externally controlled</td>
<td></td>
</tr>
<tr>
<td></td>
<td>displacement externally controlled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporator</td>
<td>Plates &amp; fins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TXV</td>
<td>2.0 / 2.7</td>
<td>2.0 / 2.7</td>
<td>2.3 / 3.0</td>
</tr>
<tr>
<td>Condenser</td>
<td>Flat tubes, 4 passes, integrated receiver</td>
<td>Microchannel, 2 passes, integrated receiver</td>
<td>Microchannel, 2 passes, integrated receiver, increased subcooling area</td>
</tr>
</tbody>
</table>

Tests and enhanced components supported by Delphi

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3- R-1234yf: Clio, 207 and Panda results

Results of 207 enhanced systems

Cool down tests at 45 °C, 40%, 1000 W

- Baseline R-134a
- Enhanced R-134a
- Enhanced 1234yf
- Drop-in 1234yf

Time:
00:00:00 00:10:00 00:20:00 00:30:00 00:40:00 00:50:00 01:00:00 01:10:00 01:20:00 01:30:00

Temperature:

- Cooling capacity of R-134a is dramatically increased
- 1234yf slightly warmer but still shows very good performance
3- R-1234yf: Clio, 207 and Panda results

Measurement of fuel consumption

- Targets:
  - Evaluate the impact of 1234yf on the vehicle fuel consumption in A/C mode
  - Evaluate the potential of FC improvement with 1234yf using state-of-the-art technologies

- Long experience of fuel consumption tests. Always done by expert technicians & drivers.
- Measurement under 3 climatic conditions: 15 °C-90%, 27 °C-50%, 35 °C-45%
- Equal cooling capacity checked on every test:

![Fuel consumption test at 35°C ambient - Evap target 3°C](image)
3- R-1234yf: Clio, 207 and Panda results

Comparison of A/C efficiency: R-134a vs R-1234yf

- Equivalent fuel efficiency between R-134a and R-1234yf
- Both R-134a & R-1234yf can benefit from “High Efficiency” state-of-the-art components (average 5% improvement)

* Former tests on Peugeot 207 – 1.6 HDi
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   Drop-in performances, analyses, and enhanced systems

4- Flammability

5- Conclusion
# 4 - Flammability

<table>
<thead>
<tr>
<th>Item</th>
<th>Status</th>
<th>Who</th>
<th>When</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flammability study to assess risks in the <em>car cabin</em>.</td>
<td>✔️</td>
<td>INERIS</td>
<td>-</td>
</tr>
<tr>
<td>2. Risk Assessment in case of leakage in the <em>engine compartment</em>.</td>
<td>On going</td>
<td>INERIS SAE</td>
<td>Oct 08</td>
</tr>
<tr>
<td>3. To formalize those 2 steps results by <em>ISO standard</em>. PSA volunteered for leading the ISO group.</td>
<td>Starting (SAE group led by W.HILL)</td>
<td>PSA</td>
<td>End 09</td>
</tr>
</tbody>
</table>

- Thanks to INERIS, we know the flammability conditions.
- Design standards are now under development to insure vehicle safety
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Conclusion (1)

1. We are still not confident that R-744 technology can ever reach R-134a “state of the art” technology, at least on small vehicles,
2. Pure drop-in of R-1234yf may lead to poor AC performance,
3. State-of-the-art R-134a technology will enhance efficiency and performance of current AC systems,
4. With TXV and Sub-cooling optimization, R-1234yf can match both performance and efficiency of enhanced R-134a systems,
5. As flammability and toxicity assessments are still ongoing, refrigerant decision is delayed until completion of those assessments.
Thank you
for your attention
<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Department/Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roberto MONFORTE</td>
<td>FIAT</td>
<td>Engineering &amp; Design – Interiors</td>
</tr>
<tr>
<td>Bruno ROSE</td>
<td>PSA</td>
<td>Engineering - Interiors A/C &amp; heating system</td>
</tr>
<tr>
<td>Jean Marie L’HUILLIER</td>
<td>Renault</td>
<td>HVAC Manager, Engineering department</td>
</tr>
</tbody>
</table>

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