R1234yf System Enhancements and Comparison to R134a

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R1234yf Agenda

► System Performance Evaluation
  – TXV (Egelhof) and MCV (TGK) tuning
  – Baseline and enhanced system test results
    » IHX
    » Oil Separator
    » High Effectiveness Evaporator

► Compressor Durability
P-T for R134a and R1234yf

Cross at \( \sim 30^\circ C \)

- R1234yf has higher saturation pressure
- R1234yf has lower saturation pressure

Graph showing pressure vs. temperature for R134a and R1234yf, with R1234yf having a lower saturation pressure than R134a.
► Production system used for analysis
► 160cc variable displacement compressor
► 16mm IRD condenser
► 2.0T cross-charged TXV
► 58mm plate-fin evaporator
► Slightly modified discharge and liquid line
  – Modified for installation on stand
► Slightly modified SL
  – To allow for *in situ* torque calibration
Changes to R134a system hardware

- Same 16mm IRD condenser
- Same 58mm plate-fin evaporator
- Same VS16 compressor, new MCV set points
- Same 200 cc PAG
- 2.0T, 2.5T, 1.75T TXVs at high & low SH settings evaluated
- Same slightly modified discharge and liquid line
- Same slightly modified SL to allow for torque calibration
## Evaluation Matrix

<table>
<thead>
<tr>
<th>Compressor</th>
<th>Condenser Airflow</th>
<th>Evaporator Airflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM</td>
<td>l/s</td>
<td>Temp °C</td>
</tr>
<tr>
<td>1</td>
<td>2500</td>
<td>700</td>
</tr>
<tr>
<td>2</td>
<td>1800</td>
<td>650</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>2500</td>
<td>700</td>
</tr>
<tr>
<td>5</td>
<td>1800</td>
<td>650</td>
</tr>
<tr>
<td>6</td>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td>7</td>
<td>2500</td>
<td>700</td>
</tr>
<tr>
<td>8</td>
<td>1800</td>
<td>650</td>
</tr>
<tr>
<td>9</td>
<td>800</td>
<td>600</td>
</tr>
</tbody>
</table>
R134a Charge Determination

560 g chosen
R1234yf Charge Determination

The graph shows the relationship between pressure and temperature with respect to charge for different states:

- Pdisch
- Evap SH
- SC
- disch air

The charge at which the graph peaks is marked as 550 g.
TXVs have a “set screw” to adjust SH setting

Each valve was evaluated at a high and low SH setting

35C, 1800RPM (pt 5)
1.75T TXV (blue) seems to lose Control of SH at high loads.
Cross charge TXVs from Egelhof

- 2.0, 2.5, and 1.75T valves tested
- 1.75T TXV is undersized

TXV at low SH
- Although no strong indication that low SH leads to improved performance:
  - Low SH facilitates IHX integration
  - Improved evaporator discharge air stratification

MCVs from TGK

- Initial MCV calibration slightly off
- Gen II MCVs better tuned for this system
4x4 thermocouple matrix on evaporator outlet
- Stratification = $T_{\text{max}} - T_{\text{min}}$

With similar SH settings, R1234yf shows slightly improved stratification
Same compressor, heat exchangers, lines, lubricant

2.0T TXV from Egelhof at “low” SH setting

“GEN II” MCV from TGK
R1234yf Enhancements

► Internal Heat Exchanger (IHX)
  – Production Intent (SOP ‘09)
  – Fully validated with R134a
► Oil Separator
► High efficiency evaporator
  – Tube-fin
  – Same package
  – Lower air-side pressure drop
R134a vs 1234yf – IHX; Capacity

MCV controls capacity
R134a vs 1234yf – IHX; Efficiency

- R134a baseline
- R134a IHX
- R1234yf baseline
- R1234yf IHX

COP [-]

Temperature:
- 25C
- 35C
- 43C

Environments:
- 800
- 1800
- 2500

Comparison of R134a and R1234yf with and without IHX in different COP environments.
Discharge and Pressure Ratio

P-T relationship predicts ~100kPa lower discharge pressure for R1234yf
R134a vs 1234yf – IHX; Compressor Discharge Temperature
R134a vs 1234yf – Oil Separator & High Efficiency Evaporator; Capacity

MCV controls capacity

<table>
<thead>
<tr>
<th>Temperature</th>
<th>R134a baseline</th>
<th>R1234yf baseline</th>
<th>R1234yf Oil Sep</th>
<th>R1234yf HE evap</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>25C</td>
<td>35C</td>
<td>43C</td>
<td></td>
</tr>
</tbody>
</table>
R134a vs 1234yf – Oil Separator & High Efficiency Evaporator; Efficiency
Higher quality = less liquid = lower capacity

- **Inputs**
  - 10°C Subcool
  - 5°C Evaporation temp
  - Supercritical R744 high-side pressure = 13MPa

- **8% Less Liquid**
Higher quality = less liquid = lower capacity

Inputs:
- 10°C Subcool
- 5°C Evaporation temp
- Supercritical R744 high-side pressure = 13MPa

8% Less Liquid
29% Less Liquid
Baseline R1234yf system used same tonnage TXV with modified bulb charge and adjusted MCV

R1234yf has approximately 8-10°C cooler compressor discharge temperature vs R134a

As near drop-in, capacity and efficiency fall slightly short of R134a
R1234yf Performance Summary (cont)

► R1234yf with IHX
  – ~Matches/exceeds R134a baseline capacity
  – Has slightly higher average efficiency than baseline R134a across all points
  – ~Matches R134a compressor discharge temperature

► R1234yf with Oil Separator
  – Small increase in capacity and efficiency
  – Falls short of baseline R134a at high ambient

► R1234yf with High Efficiency Evaporator
  – Small increase in capacity and efficiency
  – Falls short of baseline R134a at high ambient
Initial Compressor Durability

- High Pressure Low Charge – high load and temperature test
  » Completed initial testing - No issues

- High Speed – high friction and high temperature test
  » Completed initial testing – No issues
Durability Teardown Results
Thanks to:

- TGK for prototype MCVs
- Egelhof for prototype TXVs
- JCS for tube-fin evaporator
- Honeywell and DuPont for R1234yf