Reversible Air-Conditioners and Heat Pumps Using Carbon Dioxide (CO$_2$, R744) as Working Fluid

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R744 RAC split-type unit

- R744 RAC Split-type unit
  - Two stage compressor + external oil separator
  - Internal Heat Exchanger with HP bypass
  - Shown in AC-mode
R744 RAC split-type unit

The results demonstrate that it is possible for a R744 RAC split-type unit to match the energy efficiency of the best R410A unit on the market in heating mode and in cooling mode in colder climates.

Further development and optimization of the R744 unit, e.g. by utilizing microchannel heat exchangers, applying a compressor with a higher isentropic efficiency and/or using an ejector or expander for expansion work recovery, is required in order to achieve the same or higher energy efficiency in cooling mode in warmer climates.
Reversible R744 systems

- Refrigerant reversing unit
  - Several valves required
  - Additional cost
  - Heat exchanger mode changes

Alternative: Reverse Air flow!
Set-up (heating)

OUTDOOR cooling

INDOOR heating
Animation
Picture of the R744 turn-table ECU
Results

- COP heating
- COP cooling
- Q Heizen
- Q Kühlen

Indoor temperature

Ambient temperature [°C]

COP [-] & Heiz-/Kühlleistung [kW]

Indoor temperature [°C]
Temperature bin / Climate / Location

Number of annual hours

Temperature range [°C]

24 h/day (total 8760h)

Beijing
Baghdad
New Delhi
Energy Demand & CO2 Emissions

Office hours
(8 a.m. – 5 p.m.)

- 3-3.2 MWh/a
- Dieselgenerator
  2.3-2.5 m.ton/a
- Coal power p.
  2.8-3 m.ton/a
- China / India
  2.25 / 2.7 m.ton/a
Summary: Air reversing unit

- An air reversing, turn-table ECU was designed and experimentally investigated with promising results.
- The refrigerant circuit can be unchanged, when directing the air through the designated heat exchanger by rotating the entire refrigeration unit.
- The function of the heat exchanger does not change, i.e. the gascooler can be optimized for a low temperature approaches.
- No refrigerant charge issues, this can be handled since no ‘dead’ lines are present.
MAC Mobile Air Conditioning

- Misuse of GreenMACLCCP, when comparing Non-Natural Alternatives with R744 MACs
- Reduction of fuel consumption of R744 MACs versus NNA’s (= energy saving potential), vehicle measurements by leading TIER 1 and OEM’s
Phase II Simulation results for energy

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Mid – size</th>
<th>Full Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive cycle</td>
<td>NEDC</td>
<td>US FTP 75</td>
</tr>
<tr>
<td>Cycle duration</td>
<td>1180 sec.</td>
<td>2138</td>
</tr>
<tr>
<td>System Demand</td>
<td>Energy/ cycle [kJ]</td>
<td>Energy/ cycle [kJ]</td>
</tr>
<tr>
<td>R 134a</td>
<td>Base</td>
<td>Base</td>
</tr>
<tr>
<td>R 152a</td>
<td>-3%</td>
<td>-7%</td>
</tr>
<tr>
<td>R 744*</td>
<td>-11%</td>
<td>-9%</td>
</tr>
</tbody>
</table>

Based on analysis of the accuracy and repeatability of the data, it is estimated that these values are within +/- 6%.

February 23-24, 2005
Saalfelden, Austria
SAE ARCRP II Results, European Scenario

Figure VII-22 Compared energy demands for the European scenario
ARCRP II US Scenario

Figure VII-23 Compared energy demands for the US scenario

16-March-2005

Energy Analysis of Cycles
SAE ARCRP II Results -> LCCP

LCCP CO₂-Equivalent Emissions during Vehicle's Lifetime

- Baseline - R-134a
- R744

**.xls soon on www.R744.com
Indirect Emissions Reduction AC ON

NEDC Ambient conditions: 25°C @ 50% RH no sun load; Mode: fresh air

Off line for 2008 average
Fuel consumption according to 99 / 100 7 EG
Total l/100km: 5.8
CO₂-Emission: 140 g/km
Values without A/C
R134a with EVDC
+ 0.1l/100km (off mode)
R744 with EVDC
+ 0.05l/100km (off mode)

FDC - Fix Displacement Compressor
EVDC - Externally controlled Variable Displacement Compressor
Vehicle Test Results – Fuel Consumption

NEDC Fuel Consumption Test R134a vs. R744
VW Touran TDI 1.9l; $T_{\text{ambient}} = 20/28/35 \degree C$

Additional Fuel Consumption R134a
Additional Fuel Cons. R744

<table>
<thead>
<tr>
<th>$T_{\text{ambient}}$</th>
<th>R134a</th>
<th>R744</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>20$\degree$C</td>
<td>0.37</td>
<td>0.17</td>
<td>-54%</td>
</tr>
<tr>
<td>28$\degree$C</td>
<td>0.84</td>
<td>0.46</td>
<td>-45%</td>
</tr>
<tr>
<td>35$\degree$C</td>
<td>1.53</td>
<td>1.31</td>
<td>-14%</td>
</tr>
</tbody>
</table>
Test Results: Fuel Consumption

- Significant, absolute fuel reduction of 0.3 and 0.5 l/100 km at ambient temperature of 25°C and 35°C for R744
- Add on fuel reduction of 25% at 25°C and 35°C of R744 in comparison to R134a
Fuel consumption: NEDC

- Increased fuel consumption with “Drop-in“ AC1 vs R134a (+0.2 l/100 km @ 25°C and 35°C)
- Significant reduction in fuel consumption with R744 vs R134a (-0.3 l/100 km @ 25°C and 35°C)
Fuel Consumption Test Results

R744 MAC Status and System Standardisation

relative comparison of
A/C caused fuel consumption

vehicle A

NEDC (warm start)
28 °C, 40 % r.h.
40 % Evap. Air Mass flow, OS-Air
Evaporator Setting 5°C

vehicle B

vehicle C

*Improved System with integrated IHX

vehicle D

VDA Wintermeeting, 13.02.2008

Morgenstern, BMW, VDA Wintermeeting 2008
Small European Vehicle Fuel Consumption

1.5l gasoline engine  \( T_{\text{amb}} = 35^\circ \text{C} \), \( \text{SunLoad} = 850\text{W} \)

HVAC setting: Outside Air and Blower Position 6 of 8

- **R134a**
- **R744**
- **Competitor A**
- **OE/DOOWON**
General Conclusion

- Efficient R744 RAC split-type units are possible.

- Turn-table residential AC-units, applying R744 as working fluid, are a viable option for many global areas, where both heating and cooling is required during a year.

- R744 MAC systems are the most efficient, sustainable, non-flammable, environmental safe and global solutions for cooling and heating of vehicles in the future.
Thank you for your attention!

Questions are welcome!!!

Please ask for a copy of the presentation

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