Experimental Analysis of the Use of R134a, R1234ze(E) and R1234yf in a Small Water-to-water Heat Pump

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Purpose of the present study

- Experimentally assess the performance of R1234yf and R1234ze(E) in a water-to-water heat pump in a drop-in application.

- "Refrigerant point of view": the evaporating and condensing temperature are kept fixed.

- “Vapour compression system” point of view: the inlet and the outlet temperatures of the secondary fluids that flow through the heat exchanger are fixed. The system find its own operating point, that depends on the refrigerant used, the heat transfer area and the temperature levels of the cold heat source and hot heat sink. **Approach used in this study.**
Experimental set-up – Layout
### Experimental set-up – Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compressor</strong></td>
<td>Swept volume @ 50 Hz</td>
<td>13.15 m³·h⁻¹</td>
</tr>
<tr>
<td></td>
<td>Shaft rotational frequency</td>
<td>30 Hz - 87 Hz</td>
</tr>
<tr>
<td><strong>Condenser</strong></td>
<td>Height x Width x Depth</td>
<td>289 mm x 119 mm x 93.6 mm</td>
</tr>
<tr>
<td></td>
<td>N° of plates</td>
<td>40</td>
</tr>
<tr>
<td><strong>Evaporator</strong></td>
<td>Height x Width x Depth</td>
<td>376 mm x 119 mm x 71.2 mm</td>
</tr>
<tr>
<td></td>
<td>N° of plates</td>
<td>30</td>
</tr>
<tr>
<td><strong>Expansion valves</strong></td>
<td>Capacity range</td>
<td>1200 W - 12000 W</td>
</tr>
<tr>
<td></td>
<td>Capacity range</td>
<td>1690 W - 16900 W</td>
</tr>
<tr>
<td><strong>Liquid receiver</strong></td>
<td>Volume</td>
<td>2.8·10⁻³ m³</td>
</tr>
<tr>
<td><strong>Suction accumulator</strong></td>
<td>Volume</td>
<td>2.33·10⁻³ m³</td>
</tr>
<tr>
<td><strong>Oil separator</strong></td>
<td>Volume</td>
<td>2.8·10⁻³ m³</td>
</tr>
</tbody>
</table>
Experiment set-up – Data reduction

Heat pump heating capacity

\[ \dot{Q}_{COND} = \frac{1}{2} \left[ m_R (h_{R,IN,COND} - h_{R,OUT,COND}) + m_W c_p, W (T_{W,IN,COND} - T_{W,OUT,COND}) \right] \]

Heat pump COP

\[ COP = \frac{\dot{Q}_{COND}}{\dot{W}_{COMP}} \]
Experimental conditions

Two groups of tests:

- **Group 1**: tests with the **same rotational frequency** of the compressor shaft and the **same temperatures** of the secondary fluids at the outlet of the heat exchangers → different mass flow rates → **different heating capacities** and COPs.

- **Group 2**: tests with the **same mass flow rates** and the **same temperatures** of the secondary fluids at the inlet and outlet of the condenser → different rotational frequency of the compressor shaft → **same heating capacities** but different COPs.
Experimental conditions – Group 1

Reference conditions: conditions used to identify mass flow rates. $\Delta T$ across heat exchanger fixed to 5 °C.

Testing conditions: the mass flow rate and the outlet temperature are kept constant.

System charging conditions: $T_{G,\text{OUT},\text{EVAP}} = 5$ °C, $T_{W,\text{OUT},\text{EVAP}} = 35$ °C, $\Delta T_{\text{SUP}} = 5$ °C and $\Delta T_{\text{SUBC}} = 3$ °C.
Experimental conditions – Group 1 – Heating capacity

R1234yf shows 3.80% - 9.80% capacity reduction mainly due to the lower enthalpy difference across the condenser with respect to R134a.

R1234ze(E) shows 20.96% - 23.07% capacity reduction as a consequence of the lower refrigerant mass flow at compressor suction which, in turn, is related to a lower density at compressor suction.
Experimental conditions – Group 1 – Heating capacity

\[ T_{W,OUT,COND} = 55^\circ C \]

\[ T_{W,OUT,COND} = 75^\circ C \]
R1234yf shows 1.46% - 6.14% COP reduction whereas R1234ze(E) shows COP variation from - 2.50% to +0.59%.

This behaviour is related to the different thermophysical properties of the two alternative refrigerants, namely the critical temperature and the reference isobaric heat capacity, with respect to those of the R134a.
Experimental conditions – Group 1 – COP

$T_{W,OUT,COND} = 55^\circ C$

$T_{W,OUT,COND} = 75^\circ C$

$COP$ vs $T_{G,OUT,EVAP}[\text{°C}]$
## Experimental conditions – Group 2

<table>
<thead>
<tr>
<th>Run</th>
<th>f [Hz]</th>
<th>Evaporator</th>
<th>Condenser</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\dot{m}_G$ [kg·h$^{-1}$]</td>
<td>$T_{G,IN}$ [$^\circ$C]</td>
</tr>
<tr>
<td>26</td>
<td>Variable</td>
<td>Variable</td>
<td>10</td>
</tr>
<tr>
<td>27</td>
<td>Variable</td>
<td>Variable</td>
<td>10</td>
</tr>
<tr>
<td>28</td>
<td>Variable</td>
<td>Variable</td>
<td>10</td>
</tr>
<tr>
<td>29</td>
<td>Variable</td>
<td>Variable</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>Variable</td>
<td>Variable</td>
<td>10</td>
</tr>
</tbody>
</table>
Experimental conditions – Group 2 – Shaft frequency

R1234yf needs 5.21% - 16.52% increase of the rotational frequency of the compressor shaft.

R1234ze(E) needs 32.39% - 50.26% increase of the rotational frequency of the compressor shaft.

These results are consistent with the trend of the heating capacity previously discussed.
Experimental conditions – Group 2 – COP

R1234yf shows 2.77% - 7.38% COP reduction whereas R1234ze(E) shows 1.25% - 18.11% COP reduction.

This behaviour arises from the increase in the rotational frequency of the compressor shaft that causes an increase in mass flow rate which, in turn, forces the evaporating and condensing temperatures to separate and the COP to reduce.
Conclusions

- The two HFO generally show lower heating capacity and COP compared to the R134a under the same operating conditions (same compressor shaft rotational frequency and same temperatures of the secondary fluid at the heat exchangers outlets).

In this working conditions, R1234yf exhibit higher heating capacity than R1234ze(E) but R1234ze(E) provides higher COP than R1234yf.

- An increase of the rotational frequency of the compressor shaft is an effective way to bring the heating capacity of the heat pump working with the two HFOs back to the R134a level.

In this working conditions, the COP further reduces and R1234yf exhibit higher COP than R1234ze(E).
Future works

- **Short-term**: In-depth analysis of components (compressor and heat exchangers) behaviour.

- **Short-term**: Modelling and validation of the system (bottom-up approach) to run yearly simulations and assess energetic and environmental impact of alternative refrigerants.

- **Mid-term**: Analysis carried out on the use of synthetic refrigerants R450A and R513A.

- **Long-term**: Analysis of R410A alternatives (R32, R452B, R454B, R466A etc…). Experimental set-up update is needed.
THANK YOU FOR YOUR KIND ATTENTION!