THERMODYNAMIC ANALYSIS OF LOW GWP ALTERNATIVES FOR GROUND-SOURCE HEAT PUMPS (GSHP)

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IIR/IEA Annex 54 workshop – September 1st, 2021
LABORATORY OF THERMOPHYSICAL PROPERTIES OF REFRIGERANTS AND NANOFLUIDS
MEASUREMENTS OF THERMOPHYSICAL PROPERTIES OF LOW GWP REFRIGERANTS
MEASURED THERMOPHYSICAL PROPERTIES

SATURATED PRESSURE
pure fluids

VLE
binary mixtures

DENSITY
compressed liquid

SOLUBILITY in lubricants

### SATURATED PRESSURE
pure fluids

- **R1225ye(Z)**

### VLE
binary mixtures

- **R32+R290**

### DENSITY
compressed liquid

### SOLUBILITY in lubricants

- **CO₂+PEB7**

### UNCERTAINTIES

- **T** ± 0.02 K
- **P** ± 1 kPa
- **X** ± 0.03

- **T** ± 0.02 K
- **P** ± 1 kPa
- **X** ± 0.03

- **T** ± 0.05 K
- **P** ± 10 kPa
- **ρ** ± 0.1%
<table>
<thead>
<tr>
<th>ASHRAE Designation</th>
<th>Thermodynamic Properties</th>
<th>Other Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Critical point</td>
<td>Saturated pressure</td>
</tr>
<tr>
<td></td>
<td>Sets</td>
<td>Data</td>
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<tr>
<td>R1234ze (E)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1234yf</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>R1233zd(E)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1234ze(Z)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1336mzz(Z)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1224yd(Z)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1243fa</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>R1123</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>R1332a</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1354mzy(E)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1225ye(Z)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1336mzz(E)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RE356mzz</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R1354myf(E)</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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NEW APPARATUS: THERMAL CONDUCTIVITY METER

• TEMPERATURE
  - SENSORS: 2 Pt sensors calibrated to Class 1 (10 mK)
  - RANGE: from 233 K to 393 K (-40°C to 120°C)
  - STABILITY: 0.02 °K

• PRESSURE
  - RANGE: up to 20 MPa
  - ACCURACY: ±10 kPa

• WIRES
  - MATERIAL:
    - Platinum (Pt) (gases)
    - Tantalium (Ta) (liquids)
  - DIAMETER:
    - 12.5 micron (gases)
    - 25 micron (liquids)

λ OVERALL UNCERTAINTY <1% for both liquid and gases
SELECTION AND TEST
of
LOW GWP REFRIGERANTS
for
GEOTHERMAL HEAT PUMPS APPLICATIONS
**SCOPE** identify the most suitable alternatives to the present high GWP refrigerants used in geothermal heat pumps. New heat pump working with selected alternative refrigerants will be developed within the project.

**CONSTRAINT:** Regulation (EU) No 517/20, 2014

**REFERENCE FLUIDS:** R134a and R410A

**METHODOLOGY** Energetic and Exergetic analysis

**CYCLES:** basic, regenerative, interrefrigeration, …

**SIMULATION TOOLS:** homemade simulation programs developed in Matlab environment
ANALYSED REFRIGERANTS

- **HIGH PRESSURE** and **INTERMEDIATE GWP (<800)** refrigerants
- reference fluid **R410A**

<table>
<thead>
<tr>
<th>Fluid</th>
<th>GWP</th>
<th>ASHRAE Safety Class [27]</th>
<th>Composition (wt %)</th>
<th>$T_{\text{crit}}$ (K)</th>
<th>$P_{\text{crit}}$ (MPa)</th>
<th>T Glide (K)</th>
<th>NPB (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410A</td>
<td>2088</td>
<td>A1</td>
<td>R32/R125 (50/50)</td>
<td>343.32</td>
<td>4.770</td>
<td>0.05</td>
<td>212.15</td>
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<tr>
<td>R32</td>
<td>675</td>
<td>A2L</td>
<td>R32 (100)</td>
<td>351.55</td>
<td>5.816</td>
<td>-</td>
<td>221.15</td>
</tr>
<tr>
<td>R454B</td>
<td>466</td>
<td>A2L</td>
<td>R32/R1234yf (68./31.1)</td>
<td>350.15</td>
<td>5.041</td>
<td>1</td>
<td>222.15</td>
</tr>
<tr>
<td>R452B</td>
<td>698</td>
<td>A2L</td>
<td>R32/R125/R1234yf(67/7/26)</td>
<td>350.25</td>
<td>5.200</td>
<td>0.9</td>
<td>222.15</td>
</tr>
</tbody>
</table>
# ANALYSED REFRIGERANTS

- **LOW PRESSURE and INTERMEDIATE GWP (<800) refrigerants**
- **reference fluid R134a**

<table>
<thead>
<tr>
<th>FLUID</th>
<th>GWP</th>
<th>NBP (°C)</th>
<th>Safety class (ASHRAE)</th>
<th>Components</th>
<th>Compositio (wt%)</th>
<th>T glide (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REFERENCE</td>
<td>R134a</td>
<td>2088</td>
<td>-26.1</td>
<td>R32/R125</td>
<td>50/50</td>
<td>0</td>
</tr>
<tr>
<td>POTENTIAL ALTERNATIVES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R513A</td>
<td>631</td>
<td>-29.2</td>
<td>A1</td>
<td>R1234yf/R134a</td>
<td>56.0/44.0</td>
<td>0</td>
</tr>
<tr>
<td>R515A</td>
<td>393</td>
<td>-18.0</td>
<td>A1</td>
<td>R1234ze(E)/R227ea</td>
<td>88/12</td>
<td>0</td>
</tr>
<tr>
<td>R515B</td>
<td>293</td>
<td>-19.1</td>
<td>A1</td>
<td>R1234ze(E)/R227ea</td>
<td>91.1/8.9</td>
<td>0</td>
</tr>
<tr>
<td>R516A</td>
<td>142</td>
<td>-29.4</td>
<td>A2L</td>
<td>R134a/R1234yf/R152a</td>
<td>8.5/77.5/14</td>
<td>0</td>
</tr>
</tbody>
</table>
**Base cycle**

- Thermal power 7 kW
- Ideal heat exchangers
- Countercurrent heat exchangers
- Evaporator: $\Delta T_{\text{pinch-point}} = 6^\circ C$
- Condenser: $\Delta T_{\text{pinch-point}} = 3^\circ C$

**Rigenerative cycle**

- Thermal power 7 kW
- Ideal heat exchangers
- Countercurrent heat exchangers
- Condenser/evaporator $\Delta T_{\text{pinch-point}} = 3^\circ C$

### GROUND SOURCE

<table>
<thead>
<tr>
<th>T inlet [°C]</th>
<th>T outlet [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

### UTILITY

<table>
<thead>
<tr>
<th>T inlet [°C]</th>
<th>T outlet [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>50</td>
<td>55</td>
</tr>
</tbody>
</table>
BASIC CYCLE
WINTER OPERATION – HEAT PUMP

Geothermal fluid inlet temperature: 0 °C

Example of results

Utility Temperature (°C)

R513A
R515A
R515B
R516A
R134a

T ground source 0°/-3°C

25 30 35 40 45 50 55 60

VRE (kJ/m³)

Utility Temperature (°C)

R513A
R515A
R515B
R516A
R134a

T ground source 0°/-3 °C

25 30 35 40 45 50 55 60

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WINTER OPERATION – HEAT PUMP

Geothermal fluid inlet temperature: 0 °C

Δ% COP (ref. R134a)

Example of results

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Task 3.2

WINTER OPERATION – HEAT PUMP

Geothermal fluid inlet temperature: 0 °C

\[ \Delta \% \text{ VHE (ref. R134a)} \]

- **BASIC CYCLE**
- **REGENERATIVE CYCLE**
- **INTERREFRIG. CYCLE**

Utility Temperature (°C)

R513A  R515A  R515B  R516A

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PRELIMINARY RESULTS

HIGH PRESSURE Refrigerants – reference R410A

- **R454B** is the most promising substitute for R410A with all the analyzed cycles

LOW PRESSURE Refrigerants – reference R134a

- **R516A** is the MOST EFFICIENT refrigerant (COP +10% with reference to R134a)
- The BEST CYCLE looks to be the one with FLASH TANK+ AUXILIARY COMPRESSOR

**NEXT STEP** identify VERY LOW GWP REFRIGERANTS (GWP<150) with equal or increased energy efficiency with respect to traditional refrigerants, good volumetric properties and acceptable flammability.

- Not only pure compounds (e.g. R1233zd(E)) will be considered but also new MIXTURES
GROUND SOURCE HEAT PUMPS (GSHPs) MONITORING SYSTEM

• **PROJECT:** GEO4CIVHIC – Horizon 2020
  Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings

• **SCOPE:** evaluate energetic performance of GSHPs with intermediate GWP refrigerant and different control systems

• **GSHPs:** 2 different reversible water/glycol to water HPs
  – **CONTROL SYSTEM:** 1 ON/OFF; 1 INVERTER
  – **HEAT SOURCE:** 3 different types of geothermal probes
  – **HEAT SINK:** heating and SHW in small commercial building

• **REFRIGERANT:** R454B

• **MONITORING SYSTEM:**
  33 temperature sensors
  16 pressure sensors
  2 mass flowmeters
  3 volumetric flowmeters
  6 electric energy meters

• **ACQUISITION PROGRAM:** at least 12 months acquisition
  acquisition time step: 15 s

• **STATUS:** due to the COVID-19 restrictions, the beginning of the monitoring has been postponed and will start in the next weeks