DECARBONIZATION OF HIGH-TEMPERATURE HEAT FOR INDUSTRY

RD&D ACTIVITIES IN HIGH-TEMPERATURE-HEAT PUMPS IN GERMANY

Omar Abu Khass
DLR-Institute of Low-Carbon Industrial Processes
High-Temperature Heat Pumps
Agenda:

- Overview of national HTHP industry
- Development perspectives for HTHP technologies
  - DLR-Institute of Low-Carbon Industrial Processes
  - The Pilot CoBra demonstration
  - The Pilot ZiRa concept and development
  - The pre-pilot ZiRa – Compressor test rig
- Handover to ISE
Overview of national HTHP industry

Siemens Energy

- Turbo compressor technology as geared-type or single-shaft depending
- 8 to 70 MW in one unit with one turbo compressor
- Working fluid: R1233zd(E) and/or R1234ze(E) depending on application
- Laboratory demonstration of a kW-size heat pump with temperatures up to 160 °C with R1233zd among other tested refrigerants
- Project example (district heating in Berlin):
  - Pilot plant with 8 MW capacity and 120 °C supply temperature
  - Heat recovery of existing turbo chillers at ~30 °C

<table>
<thead>
<tr>
<th>T_{source,in} [°C]</th>
<th>T_{source,out} [°C]</th>
<th>T_{sink,in} [°C]</th>
<th>T_{sink,out} [°C]</th>
<th>COP_{heating} [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.5</td>
<td>43</td>
<td>105*</td>
<td>2.5</td>
</tr>
<tr>
<td>35</td>
<td>30</td>
<td>60</td>
<td>120*</td>
<td>2.7</td>
</tr>
<tr>
<td>115</td>
<td>105</td>
<td>105</td>
<td>150**</td>
<td>4.1</td>
</tr>
<tr>
<td>80</td>
<td>60</td>
<td>20</td>
<td>190***</td>
<td>2.9</td>
</tr>
</tbody>
</table>

*pressurized hot water
**steam
***steam, incl. steam compression
Overview of national HTHP industry
COMBITHERM GmbH

- BITZER Semi-hermetic compact screw
- Temperature range:
  - Hot water supply 80-120 °C
  - Hot water return 5-30 K below supply
  - Heat source temperature 35-90 °C
- Working fluid: R1233zd(E)
- The heating capacity ranges from 0.3 MW (1 compressor, 35 °C heat source) to 3.3 MW (3 compressors, 90 °C heat source)
- Project example (aqua feed production):
  - Four high temperature heat pumps with a total heating capacity of 3.5 MW
  - First electric Counterflow Dryer with COP 4
  - CO₂ and energy reduction by 3000 t and 15,000 MWh per year respectively

Table: HTHP performance

<table>
<thead>
<tr>
<th>T_{source, in}</th>
<th>T_{source, out}</th>
<th>T_{sink, in}</th>
<th>T_{sink, out}</th>
<th>COP_{heating}</th>
</tr>
</thead>
<tbody>
<tr>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
<td>[1]</td>
</tr>
<tr>
<td>45</td>
<td>40</td>
<td>110</td>
<td>120</td>
<td>2.2</td>
</tr>
<tr>
<td>45</td>
<td>40</td>
<td>70</td>
<td>80</td>
<td>4.7</td>
</tr>
<tr>
<td>50</td>
<td>45</td>
<td>110</td>
<td>120</td>
<td>2.4</td>
</tr>
<tr>
<td>50</td>
<td>45</td>
<td>70</td>
<td>80</td>
<td>5.3</td>
</tr>
</tbody>
</table>

O. Abu Khass (DLR) – IEA Annex 58 14th Status Meeting, Aarhus 25.04.2023
Source: https://heatpumpingtechnologies.org/annex58/task1/
Overview of national HTHP industry

Spilling Steam compressor

- Electric driven steam piston compressor
- Modular design with 1 to 6 cylinders
- Promising for:
  - source side above 120 °C at 2 bar(a)
  - sink side 250 °C and 40 bar
- Pressure ratio of 3 for each compression stage → $\Delta T > 100$ K possible with three compression stages
- Steam flows between 2 t/h to 20 t/h and thermal loads between 1 MW to 15 MW
- Project example (reactor cooling):
  - 1 x 6-cylinder compressor (double stage)
  - 1 x 3-cylinder-compressor (double stage)

<p>| $T_{\text{source,in}}$ = $T_{\text{evap}}$ | $T_{\text{sink,out}}$ = $T_{\text{cond}}$ | COP heating * |</p>
<table>
<thead>
<tr>
<th>[°C]</th>
<th>[°C]</th>
<th>[-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>151</td>
<td>9.5</td>
</tr>
<tr>
<td>133</td>
<td>230</td>
<td>3.5</td>
</tr>
<tr>
<td>148</td>
<td>175</td>
<td>10.3</td>
</tr>
<tr>
<td>152</td>
<td>211</td>
<td>5.3</td>
</tr>
<tr>
<td>175</td>
<td>215</td>
<td>8.4</td>
</tr>
</tbody>
</table>

O. Abu Khass (DLR) – IEA Annex 58 14th Status Meeting, Aarhus 25.04.2023
Source: https://heatpumpingechnologies.org/annex58/task1/
DLR- Institute of Low-Carbon Industrial Processes

Establishment June 2019
Institute of Low-Carbon Industrial Processes

**Aim**
Reduce CO$_2$- and pollutant emissions from industrial processes and power plants

**Mission**
Research and development for a successful energy transition in industry
Research goal of DLR:

- Provision of CO₂-neutral high-temperature process heat of relevant scale for industry
- Sink-temperature: > 300 °C (up to 500 °C ), power: Megawatt range
- Development of the HTHP-system and the main components
Pilot plant „CoBra“ (Cottbus Brayton)

„First of its kind“ – pilot plant

- Performance data:
  - 280 °C
  - 180 kW\textsubscript{th}
  - Working medium Air
- Also unique:
  - Cooling @ – 80 °C
  - Cooling capacity 60 kW

First operation in May 2023
High-Temperature Heat Pumps using steam

Challenges

Compression of the “light” gas – water steam

- Molar mass: 18 g/mol compared to 29 g/mol of air
- Small pressure ratio and high superheating per stage

State of the art

- Mechanical vapor recompression (MVR) with $\Delta T = 10 \, K - 20 \, K$
- Available only for high mass flow rates

Research and development goal

- Compressor for $\Delta T \geq 35 \, K$
- Reduced number of stages, compact design, easier integration
- Heat sink temperature $\geq 250 \, ^\circ C$

O. Abu Khass (DLR) – IEA Annex 58 14th Status Meeting, Aarhus 25.04.2023
HIGH-TEMPERATURE HEAT PUMPS USING STEAM
Design Process

**goal: Temperature lift : ~100 K**

Concept outdated (summer / falls 2022)

- Two staged compression is too big of a technical challenge
- Pressure lift needs the done by three compressor stages
- Complete overhaul of the concept required at this point
Current Concept and Key values

Operation Point 1

- $Q_{\text{high}} = 860 \text{ kW} @ 200 ^\circ \text{C}$
- $P_{\text{el}} = 245 \text{ kW}$
- Mass flow = 0.4 kg/s
- $Q_{\text{low}} @ 120 ^\circ \text{C}$
- COP$_{\text{id}} = 5.9$

- COP = 3.5 (60 % of ideal)

Operation Point 2

- $Q_{\text{high}} = 450 \text{ kW} @ 180 ^\circ \text{C}$
- $P_{\text{el}} = 135 \text{ kW}$
- Mass flow = 0.2 kg/s
- $Q_{\text{low}} @ 100 ^\circ \text{C}$
- COP$_{\text{id}} = 5.7$

- COP = 3.3 (58 %)

O. Abu Khass (DLR) – IEA Annex 58 14th Status Meeting, Aarhus 25.04.2023
Pilot plant „ZiRa“ (Zittau Rankine)

„First of its kind“ – pilot plant
- Performance data:
  - 200 °C
  - 860 kW\(_{th}\)
  - COP = 3.5
  - Working medium water steam

First operation in 2024
THE PILOT ZIRA CONCEPT
Procurement of the compressors

**HTP contribution to the development**
- Broad cooperation throughout whole development process
- Impeller, Volute, Diffusor Design
- Structural Mechanics
- Rotordynamics
- Almost none
- Off the shelf compressor

**Schedule and finances**
- **Ongoing tendering process**: almost finished
- Date of delivery: **first quarter of 2024**
- Date of delivery: **June 2023**
- Delivered
THE PREPILOT

Off the shelf compressor
Turbocharger compressor for compressing air
We adopt it to compress steam

Goal: testing of steam compressors, gaining experience
First operation very soon
Update on work on High Temperature Heat Pumps at Fraunhofer ISE

Dr.-Ing. Ursula Wittstadt
14th Status Meeting IEA HTP Annex 58
Aarhus, 25.04.2023
www.ise.fraunhofer.de
Fraunhofer ISE
Project activities on High-Temperature/Industrial/Large-scale Heat Pumps

Project KETEC
High-Temperature Heat Pump with A2L-A3 refrigerant, long-term objective: full-automatic, remote controllable HTHP test bench

Project Reallabor
Large-scale Heat Pumps in district heating networks – Installation, Operation, Monitoring and System Integration
Integration of Large-scale Heat Pumps at five sites (B, S, MA, ROS) in district heating network

Project FernWP
District heating supply by Heat Pumps to replace coal combustion
Large Heat Pumps: Demonstration and construction of prototype with industrial partner
HTHP: Assessment of different refrigerants and evaluation of possible configurations and components, Pinch Analysis
Project KETEC
Motivation and Objectives

Boundary Conditions
- Rising costs for CO₂ certificates
- Rising costs for fossil fuels
- Regulative changes

Needs
- Information on HTHP technology Esp. 100-150°C
- Reference Systems & Best practice
- Technology limits and Integration guidelines
- Training and education

Identification of suitable design and refrigerant for high temperature heat pumps

Test bench for research and education

Train students on most important cycle concepts
Multi-Purpose high-temperature heat pump test bench

- Flexible design for various compression cycle options (standard cycle, IHX, 2-stage, oEco, cEco, mass variation of refrigerant)
- Refrigerant: Butane R600
- Layout of condensation temperature of 120 °C
- Coupled to a hydraulic module → simulates various heat sources and sinks
Project FernWP – District heating supply by Heat Pumps replacing coal
Fraunhofer ISE

High Temperature Heat Pump for District heating (focus of Fraunhofer IEG) and industrial processes (focus of Fraunhofer ISE)

- Heat Pump for steam production (150 °C condensing temperature)
- → identified as important show case for many applications
- Refrigerant: Butane / Pentane
- Prototype testing of upper stage at Fraunhofer ISE
- Partner Johnson Controls (HTHP) and GESMEX (plate-shell heat exchanger)

→ In parallel: assessment of refrigerants, cycle combinations and pinch analysis for integration
Thanks for your attention!

Dr.-Ing. Ursula Wittstadt
Wärme und Kältetechnik
Tel. +49 12 3456-2817
ursula.wittstadt@ise.fraunhofer.de

Fraunhofer ISE
Heidenhofstraße 2
79110 Freiburg
www.ise.fraunhofer.de