IEA HPT Annex 58

High Temperature Heat Pumps

Final Webinar
23rd of April 2024

Benjamin Zühlsdorf, PhD
Innovation Director, DTI
Agenda

• Welcome and introduction
• Introduction to the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
• Introduction to Annex 58 about HTHPs
• Task 1 – High-temperature heat pump technologies
• Task 2 – Integration concepts for heat pump-based process heating
• Short Break
• Task 3 – Applications and transition towards heat pump-based process heating
• Task 4 – Defining and testing HTHP Specifications
• Outlook and follow-up activities
Proven Principles

• > 300 cases in IEA HPT Annex 48

• Proven technology < 100 °C

• Proven principles > 100 °C

https://waermepumpe-izw.de/
Process Heating in EU 28

Figure based on Heat Roadmap Europe

Heat Pumps:
Share of process heat: 37%
CO₂ emissions: 146 Mt/a
Application Potential for HTHPs

**HIGH POTENTIAL Industry Sectors**

- Food & Beverage: 123 TWh/a
- Pulp and Paper: 230 TWh/a
- Chemical: 119 TWh/a
- Machinery: 41 TWh/a
- Non Metallic Minerals: 43 TWh/a

**Transitioning industry to the USE of RENEWABLE electricity**

Heatpumps for **DECARBONIZATION of the LOW TEMPERATURE heat supply in industry**

**Potential to cover 37% of the process heat in industry**

Possible CO₂ emission **REDUCTIONS of 146 Mt/a**

**RE-USE of industrial waste heat, leading to INCREASED process EFFICIENCY**

**REDUCING final energy consumption by 487 TWh/a**

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*White Paper: Strengthening Industrial Heat Pump Innovation – Decarbonizing Industrial Heat & Webinar*

Danish Technological Institute
Electrification and energy efficiency are key for reaching sustainability targets

- IEA estimates that natural gas will be steadily phased out by heat pumps and electric heaters, especially for temperatures up to 200 °C to 250 °C

- Developed countries must go first and be front runners

- The Danish industry should reduce emissions by 1.9 mio. tons of CO2 per year. 25 % are to be obtained by “Electrification and heat pumps”, mainly implemented between 2025 to 2030 (Klimarådet)

- EU discusses an end of fossil fuel use for processes <200 °C by 2027 in the RED III, art. 21

The Road Towards Implementation

Technology Development
- Component and system development
- Testing and demonstration
- Variety of technologies
- Collaborative effort

End-user adoption
- Technology adoption life cycle
- Retrofitting of industries for HP-based heat supply
- Decarbonization strategies

Boundary conditions
- Cost for fuels and GHG
- Regulatory frameworks
- Subsidies & incentives
- Market developments

Market deployment
- Technology implementation within commercial projects
- Learning curve for operators and suppliers
- Supply chain covering considerable volumes
- Business models

Technology Awareness
- Commitment to sustainability and decarbonization
- Potentials, limitations and characteristics of the technology
- How to exploit the potentials?
- Variety of stakeholders involved

Danish Technological Institute
IEA HPT Annex 58 about HTHPs

- Heat pump technologies with supply temperatures above 100 °C

- Participants: Denmark (Operating Agent), Austria, Belgium, Canada, China, Finland, France, Japan, Germany, Netherlands, Norway, South Korea, Switzerland, US

- 01/2021 – 12/2023

- https://heatpumpingtechnologies.org/annex58/
Task 1 – HTHP Technologies

State of the Art Review & Realized Demonstrations

Final Webinar, Annex 58

Jonas L. Poulsen, DTI
Cordin Arpagaus, OST

23/04/2024
Collected Information for HTHP Supplier Technology Review

- 37 two-page descriptions

- Key information includes:
  - Performance data
  - Capacity range
  - Maximum temperatures
  - Working fluid
  - Compressor type
  - Specific investment cost
  - Technical Readiness Level (TRL)
  - Expected lifetime
  - Size & footprint
  - Project examples

All information in review were provided by the suppliers without third-party validation. The information was provided as an indicative basis and may be different in final installations depending on application specific parameters.
Technology Suppliers
Technology Suppliers
## Overview HTHP Technology Review

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Compressor type</th>
<th>Working fluid</th>
<th>Capacity [MW]</th>
<th>$T_{\text{max, supply}} [^\circ\text{C}]$</th>
<th>TRL indication</th>
<th>Spec. invest. cost [€/kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji Electric</td>
<td>Reciprocating</td>
<td>R-245fa</td>
<td>0.03</td>
<td>120</td>
<td>9</td>
<td>n/a</td>
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<tr>
<td>Emerson</td>
<td>Scroll and EVI scroll</td>
<td>R-245fa, R410a, R-718</td>
<td>0.03</td>
<td>120</td>
<td>6</td>
<td>n/a</td>
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<tr>
<td>Mayekawa (EcoSirocco)</td>
<td>Reciprocating</td>
<td>R-744</td>
<td>0.1</td>
<td>100</td>
<td>8-9</td>
<td>n/a</td>
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<tr>
<td>Mayekawa (EcoCircuit)</td>
<td>Reciprocating</td>
<td>R-1234ze(Z)</td>
<td>0.1</td>
<td>120</td>
<td>9</td>
<td>n/a</td>
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<tr>
<td>Skala Fabrikk</td>
<td>Piston (semihermetic)</td>
<td>R-290+R-600</td>
<td>0.3</td>
<td>115</td>
<td>7 (proto. demo)</td>
<td>500-700</td>
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<tr>
<td>Kobelco (SGH120)</td>
<td>Two stage twin -screw</td>
<td>R-245fa</td>
<td>0.37</td>
<td>120</td>
<td>9</td>
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<tr>
<td>Pars Makina</td>
<td>Rotary vane</td>
<td>R-1233zd(E)</td>
<td>0.015-0.48</td>
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<td>6</td>
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<td>Mitsubishi Heavy Ind.</td>
<td>Two-stage centrifugal</td>
<td>R-134a</td>
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<td>130</td>
<td>9</td>
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<td>Kobelco (SGH165)</td>
<td>Twin-screw</td>
<td>R-245fa+R-134a (mixture), R-718 for steam comp.</td>
<td>0.62</td>
<td>175</td>
<td>9</td>
<td>n/a</td>
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<td>Ecop</td>
<td>Centrifugal compression</td>
<td>ecop fluid 1</td>
<td>0.7</td>
<td>150</td>
<td>6-7</td>
<td>700</td>
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<tr>
<td>Mayekawa Europe (HS comp.)</td>
<td>Piston</td>
<td>R-600</td>
<td>0.75</td>
<td>120</td>
<td>7</td>
<td>450</td>
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<td>Kobelco (MSRC160)</td>
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<td>R-718</td>
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<td>175</td>
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<td>Mayekawa Europe (FC comp.)</td>
<td>Screw</td>
<td>R-601</td>
<td>1.0</td>
<td>145</td>
<td>5</td>
<td>720</td>
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<td>GEA Refrigeration</td>
<td>Semi-hermetic piston</td>
<td>R-744</td>
<td>0.1-1.2</td>
<td>130</td>
<td>8</td>
<td>200-300</td>
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<td>Netherlands</td>
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<td>Futraheat</td>
<td>Centrifugal</td>
<td>R-1233zd</td>
<td>0.3-1.5</td>
<td>150</td>
<td>6</td>
<td>250-400</td>
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<tr>
<td>Fenagy</td>
<td>Reciprocating</td>
<td>R-744</td>
<td>0.3-1.8</td>
<td>120</td>
<td>5-6 (concept study)</td>
<td>250-425</td>
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<tr>
<td>Rank</td>
<td>Screw</td>
<td>R-245fa, R-1336mzz(Z), R-1233zd(E)</td>
<td>0.12-2.0</td>
<td>160</td>
<td>7 (prototype demo.)</td>
<td>200-400</td>
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<tr>
<td>SRM</td>
<td>Screw</td>
<td>R-718</td>
<td>0.25-2.0</td>
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<td>5</td>
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<td>COMBITHERM GmbH</td>
<td>Screw</td>
<td>HFOs</td>
<td>0.3-3.3</td>
<td>120</td>
<td>9</td>
<td>200-400</td>
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<td>Sustainable Process Heat</td>
<td>Piston</td>
<td>HFOs</td>
<td>0.3-5.0</td>
<td>165</td>
<td>6-8</td>
<td>150-1000</td>
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<td>Johnson Controls</td>
<td>Reciprocating</td>
<td>R-717+R-600 (cascade)</td>
<td>0.5-5.0</td>
<td>120</td>
<td>7-8 (for HC top cyclc)</td>
<td>n/a</td>
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</tbody>
</table>
## Overview HTHP Technology Review

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Compressor type</th>
<th>Working fluid</th>
<th>Capacity [MW]</th>
<th>T(_{\text{max, supply}}) [°C]</th>
<th>TRL indication</th>
<th>Spec. invest. cost [€/kW]</th>
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</thead>
<tbody>
<tr>
<td>Hybrid Energy</td>
<td>Piston, screw</td>
<td>R-717 and R-718</td>
<td>0.5-5.0</td>
<td>120</td>
<td>9</td>
<td>200-600</td>
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<tr>
<td>ToCircle</td>
<td>Rotary vane</td>
<td>R-717+R-718</td>
<td>1.0-5.0</td>
<td>188</td>
<td>6-7</td>
<td>250-430</td>
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<tr>
<td>Weel &amp; Sandvig</td>
<td>Turbo</td>
<td>R-718</td>
<td>1.0-5.0</td>
<td>160</td>
<td>4-9</td>
<td>150-250</td>
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<tr>
<td>Olondo</td>
<td>Piston (double acting)</td>
<td>R-704</td>
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<td>200</td>
<td>9</td>
<td>1200</td>
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<td>Heaten</td>
<td>Piston</td>
<td>HFO and HC</td>
<td>1.0-8.0</td>
<td>200</td>
<td>7-9</td>
<td>280-450</td>
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<tr>
<td>Enerin</td>
<td>Piston</td>
<td>R-704</td>
<td>0.3-10.0</td>
<td>250</td>
<td>7</td>
<td>600-800</td>
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<td>AGO</td>
<td>Piston, screw</td>
<td>R-717/R-718</td>
<td>0.7-10.0</td>
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<td>8-9</td>
<td>800-1600</td>
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<td>Aneo Industry</td>
<td>Centrifugal fan and piston</td>
<td>R-717, R-718</td>
<td>1.2-10.0</td>
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<td>7-8</td>
<td>n/a</td>
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<tr>
<td>Enertime</td>
<td>1 or 2 stage centrifugal</td>
<td>R1336mzz(Z), R1224yd(Z), R1233zd(E)</td>
<td>2.0-10.0</td>
<td>160</td>
<td>4-8 (depending on concept)</td>
<td>300-400</td>
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<tr>
<td>Spilling</td>
<td>Piston</td>
<td>R-718</td>
<td>1.0-15.0</td>
<td>280</td>
<td>9</td>
<td>100-400</td>
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<td>Turboden</td>
<td>Centrifugal (IGCC)</td>
<td>Hydrocarbons, R-1233zd, R-718</td>
<td>1.0-40</td>
<td>250</td>
<td>9 (MVR 5)</td>
<td>300-1000</td>
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<tr>
<td>MAN Energy Solutions</td>
<td>Centrifugal turbo with integrated expander</td>
<td>R-744</td>
<td>10.0-50.0</td>
<td>150</td>
<td>7-8</td>
<td>300-500</td>
</tr>
<tr>
<td>Piller</td>
<td>Turbo</td>
<td>R-718</td>
<td>1.0-70.0</td>
<td>212</td>
<td>8-9</td>
<td>850</td>
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<tr>
<td>Siemens Energy</td>
<td>Turbo (geared-type or single-shaft)</td>
<td>R-1233zd(E), R-1234ze(E)</td>
<td>8.0-70.0</td>
<td>160</td>
<td>9 (up to 90 °C), pilot plant at 120 °C being built</td>
<td>250-800</td>
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<td>Epcon</td>
<td>High-pressure centrifugal fan; positive displacement blower</td>
<td>R-718</td>
<td>0.5-100.0</td>
<td>150</td>
<td>9</td>
<td>200-400</td>
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<tr>
<td>Qpinch</td>
<td>Chemical adsorption heat transformer (no compressor)</td>
<td>Water, H3PO4 and derivatives</td>
<td>&gt; 2.0</td>
<td>230</td>
<td>9</td>
<td>1000-2000</td>
</tr>
</tbody>
</table>
Maximum Supply Temperature as a function of Capacity

- Higher max. supply temperatures for higher capacities
Specific Investment Cost and average expected Lifetime

- Trend with higher cost for higher temperature lift
- Average lifetime between 10 to 35 years
- Higher lifetime for higher capacities
COP and Lorenz Efficiency as a function of Temperature Lift

- Higher Lorenz efficiency for higher temperature lifts
- Depends on application type

- Higher COP at low temperature lifts
- Depends on application type
## Development Perspectives for HTHPs towards 2030

<table>
<thead>
<tr>
<th>Heating Capacity</th>
<th>Temperature</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
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<tr>
<td>200 kW to 10 MW</td>
<td>&lt; 120 °C</td>
<td>Prototypes available</td>
<td>Demonstrators available</td>
<td>Commercial roll-out</td>
<td>Established as preferred technology</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>120 °C - 160 °C</td>
<td>Prototypes available</td>
<td>Demonstrators available</td>
<td>Commercial roll-out</td>
<td>Established as preferred technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 160 °C</td>
<td>Prototypes available</td>
<td>Demonstrators available</td>
<td>Commercial roll-out</td>
<td>Established as preferred technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;10 MW</td>
<td>&lt; 120 °C</td>
<td>Technology transfer &amp; commercial project sales</td>
<td>Demonstrators available</td>
<td>Established as preferred technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 120 °C</td>
<td>Technology transfer &amp; commercial project sales</td>
<td>Demonstrators available</td>
<td>Established as preferred technology</td>
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</tbody>
</table>
Review of realized HTHP Demonstration Cases

- 15 two-page descriptions of realized HTHP demonstration cases (Download Link)
- Includes key information:
  ✓ Performance in design point
  ✓ Operating hours
  ✓ System manufacturer
  ✓ Installation year
  ✓ Working fluid
  ✓ Compressor technology
  ✓ Investment cost
  ✓ Energy savings
  ✓ Estimated annual CO₂ savings
  ✓ Contact information

All information in review were provided by the suppliers without third-party validation. The information was provided as an indicative basis and may be different in final installations depending on application specific parameters.
Overview of collected Demonstration Cases

Case Studies by industries and application processes

Max. supply temperatures:
- Conventional closed-cycle (CCHP): 138 °C
- MVR: 211 °C (saturation temperature)
- Stirling heat pump: 183 °C
Box-plot of Target Sink Temperatures and measured \( \text{COP}_{\text{heating}} \) as a function of Mean Temperature Lift

- Mean temperature lifts vary from 26 K to 145 K

\[
\Delta T_{\text{mean}} = \frac{\Delta T_{\text{sink}}}{\ln \left( \frac{T_{\text{sink,out}}}{T_{\text{sink,in}}} \right)} - \frac{\Delta T_{\text{source}}}{\ln \left( \frac{T_{\text{source,in}}}{T_{\text{source,out}}} \right)}
\]

- Target sink temperatures between 115 °C and 240 °C

Average Heating COP: 3.9
Average temperature lift: 65.1 K

CCHP: Closed Compression Heat Pump
MVR: Mechanical Vapor Recompression

<table>
<thead>
<tr>
<th>Data</th>
<th>n/a</th>
<th>distillation</th>
<th>mixing</th>
<th>140</th>
<th>MVR</th>
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<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Meyerkon</td>
<td>drying</td>
<td>30</td>
<td>120</td>
<td>CCHP</td>
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<tr>
<td>3</td>
<td>AMT-AIT</td>
<td>drying</td>
<td>66</td>
<td>116</td>
<td>CCHP</td>
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<td>4</td>
<td>Olivindo</td>
<td>steam generation</td>
<td>103</td>
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<td>Mixing HP</td>
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<td>5</td>
<td>Kobelco</td>
<td>steam generation</td>
<td>160</td>
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<td>MVR</td>
</tr>
<tr>
<td>6</td>
<td>Kobelco</td>
<td>distillation</td>
<td>114</td>
<td></td>
<td>CCHP + Flash Tank</td>
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<td>7</td>
<td>MHI</td>
<td>drying</td>
<td>110</td>
<td></td>
<td>CCHP</td>
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<td>8</td>
<td>Pilot</td>
<td>steam generation</td>
<td>131</td>
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<td>9</td>
<td>AMT-AIT</td>
<td>drying</td>
<td>121</td>
<td></td>
<td>CCHP</td>
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<tr>
<td>10</td>
<td>Splitting</td>
<td>steam generation</td>
<td>201</td>
<td></td>
<td>MVR</td>
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<tr>
<td>11</td>
<td>Splitting</td>
<td>steam generation</td>
<td>201</td>
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<td>MVR</td>
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<td>12</td>
<td>Boreas, Eager</td>
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<td>115</td>
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<td>MVR</td>
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<td>13</td>
<td>Shanghai, Shanghai</td>
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<td>210</td>
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<td>MVR</td>
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<td>14</td>
<td>Shanghai, Shanghai</td>
<td>steam generation</td>
<td>201</td>
<td></td>
<td>MVR</td>
</tr>
</tbody>
</table>

DTI / OST 13
Lorenz Efficiency vs. Mean Temperature Lift

\[ \Delta T_{\text{mean}} = \frac{\Delta T_{\text{sink}}}{\ln \left( \frac{T_{\text{sink,out}}}{T_{\text{sink,in}}} \right)} - \frac{\Delta T_{\text{source}}}{\ln \left( \frac{T_{\text{source,in}}}{T_{\text{source,out}}} \right)} \]

\[ \eta_{\text{Lorenz}} = \frac{\text{COP}_{\text{heating}}}{\text{COP}_{\text{Lorenz}}} \]

\[ \text{COP}_{\text{Lorenz}} = \frac{T_{\text{sink}}}{T_{\text{sink}} - T_{\text{source}}} \]

MVR: Mechanical Vapor Recompression
CCHP: Closed Compression Heat Pump

\[ \Delta T_{\text{mean}} \]

Mean Temperature lift [K]

MVR
CCHP

\[ \eta_{\text{Lorenz}} \]

Loesd Efficiency vs. Mean Temperature Lift

\[ \Delta T_{\text{mean}} = \frac{\Delta T_{\text{sink}}}{\ln \left( \frac{T_{\text{sink,out}}}{T_{\text{sink,in}}} \right)} - \frac{\Delta T_{\text{source}}}{\ln \left( \frac{T_{\text{source,in}}}{T_{\text{source,out}}} \right)} \]

\[ \eta_{\text{Lorenz}} = \frac{\text{COP}_{\text{heating}}}{\text{COP}_{\text{Lorenz}}} \]

\[ \text{COP}_{\text{Lorenz}} = \frac{T_{\text{sink}}}{T_{\text{sink}} - T_{\text{source}}} \]

MVR: Mechanical Vapor Recompression
CCHP: Closed Compression Heat Pump
DryFiciency heat pumps

CCHP: Closed loop compression heat pump

<table>
<thead>
<tr>
<th>No.</th>
<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Capacity [kW]</th>
<th>COP_H</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>AMT</td>
<td>food</td>
<td>starch drying</td>
<td>waste heat</td>
<td>drying</td>
<td>Unit Operation</td>
<td>T_out [°C]</td>
<td>Unit Operation</td>
<td>T_out [°C]</td>
<td>T_in [°C]</td>
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<td>9</td>
<td>Viking</td>
<td>minerals</td>
<td>brick drying</td>
<td>exhaust drying air</td>
<td>drying</td>
<td>Unit Operation</td>
<td>T_out [°C]</td>
<td>Unit Operation</td>
<td>T_out [°C]</td>
<td>T_in [°C]</td>
</tr>
</tbody>
</table>

Wienerberger brick production in Uttendorf, Austria

• **Twin-cycle with 8 piston compressors**
• Energy savings: 2’200 MWh/a
• CO₂ savings: 590 tCO₂/a at 120 °C
• Cost savings: 60’500 EUR/a

AGRANA Starch production in Pischelsdorf, Austria

• **COP of 2.87 at 81/78 °C → 102/152 °C**
• Energy savings: 2’400 MWh/a
• CO₂ savings: 660 tCO₂/a at 138 °C
• Cost savings: 42’900 EUR/a

**Installation:** 2019
Electric coil drying

<table>
<thead>
<tr>
<th>No.</th>
<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Capacity [kW]</th>
<th>COP_H</th>
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<tbody>
<tr>
<td>2</td>
<td>Mayekawa</td>
<td>electronic</td>
<td>coil drying</td>
<td>painting cooling</td>
<td>drying</td>
<td>120</td>
<td>20</td>
<td>CCHP</td>
<td>R744</td>
<td>piston</td>
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<td>7</td>
<td>MHI</td>
<td>electronic</td>
<td>coil drying</td>
<td>waste heat</td>
<td>drying</td>
<td>130</td>
<td>70</td>
<td>CCHP</td>
<td>R134a</td>
<td>centrifugal</td>
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</tbody>
</table>

130 °C Hot water supply heat pump at Oyama factory of Takaoka Toko, Japan

- COP of 3.0 at 55/50 °C → 70/130 °C
- CO₂ emissions reduction: 60%
- Energy cost reduction: 65%

Application:
- Drying/heating coils for electric transformers
- Coating of copper wires with paper using special resin melts
Steam generation via MVR

<table>
<thead>
<tr>
<th>No.</th>
<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Capacity [kW]</th>
<th>COP_H</th>
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<td>10</td>
<td>Spilling</td>
<td>pulp and paper</td>
<td>pulp drying</td>
<td>exhaust vapour</td>
<td>steam generation</td>
<td>201</td>
<td>n. a.</td>
<td>MVR</td>
<td>R718</td>
<td>11,200</td>
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<tr>
<td>11</td>
<td>Spilling</td>
<td>chemical</td>
<td>chemical</td>
<td>exhaust vapour</td>
<td>steam generation</td>
<td>211</td>
<td>n. a.</td>
<td>MVR</td>
<td>R718</td>
<td>12,000</td>
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</table>

Two 6-cylinder steam compressors at a paper mill in Sweden

- LP: 3.2 to 8 bar(a), HP: 8 to 16 bar(a)
- CO_2 savings of around 14'000 tCO_2/a
- Investment: 2.5 Mio EUR (without integration)

Steam compressor for recycling of excess steam installed at a chemical plant in the UK

Installation: 2018

- CO_2 savings: up to 14’000 tCO_2/a
- Investment: 2.2 Mio EUR (without integration)
Steam generation

MVR
+ flash tank

low-pressure steam
MVR

high-pressure steam
MVR

feed water
flash tank

waste heat source

CCHP
+ flash tank

pressurized hot water circuit

MVR
steam

CCHP: Closed loop compression heat pump

steam

waste heat source

CCHP
+ heat exchanger

condenser

waste heat source

evaporator
Steam generation via MVR

<table>
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<th>Heat sink</th>
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<th>Refrigerant</th>
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<th>COPₜₜ</th>
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<tr>
<td>12</td>
<td>Rotrex, Epcon</td>
<td>sewage</td>
<td>sludge drying</td>
<td>surplus steam</td>
<td>steam generation</td>
<td>MVR</td>
<td>R718</td>
<td>turbo</td>
<td>500</td>
<td>4.5</td>
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**Open-loop MVR steam heat pump dryer at Scanship in Drammen, Norway (DryFiciency)**

- Energy cost reduction: approx. 82%
- Primary energy consumption reduced: 76%

**Application:**
- Drying bio-slugde, wood chips, garden compost etc.

- **2-stage turbo-compressor** (up to 90'000 rpm)
- 1 bar(a) → 4.2 bar(a)
## Steam generation via MVR + flash tank

<table>
<thead>
<tr>
<th>No.</th>
<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Capacity [kW]</th>
<th>COP&lt;sub&gt;H&lt;/sub&gt;</th>
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<td>Kobelco</td>
<td>sewage</td>
<td>sludge drying</td>
<td>exhaust drying air</td>
<td>steam generation</td>
<td>160 160</td>
<td>MVR</td>
<td>R718</td>
<td>twin-screw, roots blower</td>
<td>675</td>
</tr>
<tr>
<td>8</td>
<td>Piller</td>
<td>plastics</td>
<td>thermal separation</td>
<td>exhaust vapour</td>
<td>steam generation</td>
<td>131 126</td>
<td>MVR</td>
<td>R718</td>
<td>turbo (8 blowers)</td>
<td>10,000</td>
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</table>

**MVR for sewage sludge drying at Hadano Water Treatment Center, Japan**

- **Installation:** 2016
- **Life cycle cost reduction:** 40%
- **Energy consumption reduction:** > 46%
- **CO₂ emissions reduction:** 51%

**EPDM plant: Steam regeneration using MVR Blower Technology**

- **Installation:** 2017
- **Investment:** 6.8 Mio EUR, Cost savings: 4 Mio. EUR/a
- **Energy savings:** > 80%
- **CO₂ emissions reduction:** 62% (12'400 t/a)
Steam generation via CCHP + flash tank

<table>
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<th>No.</th>
<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
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<th>COP_H</th>
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<tr>
<td>6</td>
<td>Kobelco</td>
<td>refinery</td>
<td>bioethanol distillation</td>
<td>process cooling</td>
<td>distillation</td>
<td>60</td>
<td>65</td>
<td>115</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CCHP + Flash Tank</td>
<td>R245fa</td>
<td>twin-screw</td>
<td>2,500</td>
<td></td>
<td>1.850</td>
<td>3.5</td>
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Steam supply heat pumps for distillation process at Hokkaido Bioethanol, Japan

- **Installation:** 2012

- **Energy cost reduction:** 54%
- **CO₂ emissions reduction:** 51%
- **Investment payback in about 3 years**

- 5 units of SGH120 by KOBELCO
- Flash tank
- 2 t/h steam to distillation column (70% of demand)
- Backup boiler (30%)
# Steam generation via CCHP + heat exchanger

<table>
<thead>
<tr>
<th>No.</th>
<th>Supplier</th>
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<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Capacity [kW]</th>
<th>COP_H</th>
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<tbody>
<tr>
<td>4</td>
<td>Olvondo</td>
<td>pharmaceutical</td>
<td>recooling</td>
<td>recooling</td>
<td>steam generation</td>
<td>Stirling HP</td>
<td>R704</td>
<td>piston</td>
<td>2,250</td>
<td>1.7</td>
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</tbody>
</table>

- **Stirling engine**
- **Piston compressor technology**
- **Working fluid: R-704 (Helium)**

- Heating capacity per unit: 500 to 750 kW
- COP of 1.7 at 36/34 °C → 178/183 °C
- Average operating hours: 6'100 h/a

- **Investment: 3 x HighLift heat pumps, approx. 1.8 Mio. EUR (excl. integration)**
- Energy savings: 9.4 GWh/a
- CO₂ savings: 600 tCO₂/a (estimate)

---

**HighLift Heat Pumps for Steam Production at AstraZeneca’s R&D facility in Gothenburg, Sweden**

Installation: 2017
Hot water production with cascade HTHP

<table>
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<tr>
<th>No.</th>
<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Capacity</th>
<th>COP&lt;sub&gt;H&lt;/sub&gt;</th>
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<td>16</td>
<td>SkaleUP</td>
<td>dairy</td>
<td>process hot water</td>
<td>(re)cooling</td>
<td>process hot water</td>
<td>115</td>
<td>95</td>
<td>CCHP</td>
<td>piston</td>
<td>300</td>
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</tbody>
</table>

SkaleUP HTHP for simultaneous ice-water and process hot water production, Trondheim Norway

- Cascade cycle with IHX
- R290/R600 (propane/butane)
- COP (dry cooler mode): 2.5 to 3.2
- COP (ice water mode): 3.4 ± 0.3  
  \(\Delta T_{\text{lift}} 95 \pm 10 \, \text{K}\)
- Investment: 500 to 700 EUR/kW
- Energy savings: up to 62%
- CO₂ savings: up to 94 %

Installation: 2021

DTI / OST 23
The first zero-emission distillery in Ireland

<table>
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<th>Supplier</th>
<th>Industry</th>
<th>Process</th>
<th>Heat source</th>
<th>Heat sink</th>
<th>HP Type</th>
<th>Refrigerant</th>
<th>Compressor</th>
<th>Heating capacity</th>
<th>COP</th>
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<tr>
<td>Oillon</td>
<td>Distillery</td>
<td>Process hot water</td>
<td>Cooling system return water</td>
<td>35 °C 60 °C</td>
<td>Process hot water 105 °C 115 °C</td>
<td>CCHP</td>
<td>R1223zd(E)</td>
<td>Piston</td>
<td>1 MW</td>
</tr>
</tbody>
</table>

Combined process heating (115 °C distillation, 85 °C hot water) & cooling at Ahascragh Distillery, Ireland

- 3 HTHPs: 2 x P450 series heat pumps (can generate 120 °C), 1 x P150 series heat pump

Sources: LinkedIn post and Ahascragh Distillery – Astatine, Marren, T. (2024): Implementation of HTHPs within the distillery and dairy sector, HTHP Symposium 2024, Copenhagen

- Design supply temperature: 115 °C (pressurized hot water)
- CCHP with subcoolers (85 °C hot water)
- Operating hours: > 6'300 h/a
- CO₂ savings: 736 tCO₂/a
- Turnkey project cost: 1 Mio. EUR
- Cost savings: 330'000 EUR/a
- Payback period: < 3 years
Summary – HTHP Technologies & Realized Demonstrations

HTHP technologies are being continuously developed, which increases the potential for further demonstrations and applications.

### HTHP Supplier Technology Review

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>TRL level</td>
<td>4 to 9</td>
</tr>
<tr>
<td>Average specific cost</td>
<td>200 to 1'500 EUR/kW</td>
</tr>
<tr>
<td>Capacity</td>
<td>0.02 to 100 MW</td>
</tr>
<tr>
<td>Max. supply temperature</td>
<td>100 to 280 °C</td>
</tr>
<tr>
<td>Availability</td>
<td>Geographical dependent, e.g. between Europe and Japan</td>
</tr>
<tr>
<td>Number of technologies</td>
<td>37 different technologies</td>
</tr>
</tbody>
</table>

### HTHP Demonstration Cases Review

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industries</td>
<td>9</td>
</tr>
<tr>
<td>Processes</td>
<td>Drying, hot water, steam, thermal separation</td>
</tr>
<tr>
<td>Number of demonstration cases</td>
<td>Information about 15 cases descriptions collected</td>
</tr>
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</table>

3 examples of dependencies for HTHP technologies
Task 1 Report – HTHP Technologies

- Task 1 Report and all HTHP Supplier and Demonstration Case descriptions are available at IEA HPT Annex 58 homepage: https://heatpumpingtechnologies.org/annex58/task1

- Task 1 Report Summary:
  - 173 pages with 33 contributing authors
  - Background information on HTHPs
  - Review of supplier technologies & demonstration cases
  - National perspectives for 13 countries about HTHP industry, market & application potential, technology development, and RD&D projects

- HTHP technology database will be continuously updated
## Task 1 Report – 33 contributing authors

<table>
<thead>
<tr>
<th>Name</th>
<th>Role/Title</th>
<th>Organization &amp; Country</th>
<th>Contact information (e-mail)</th>
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<tbody>
<tr>
<td>Benjamin Zühlsdorf</td>
<td>Centre Project Manager, PhD</td>
<td>DTI, Denmark</td>
<td><a href="mailto:bez@teknologisk.dk">bez@teknologisk.dk</a></td>
</tr>
<tr>
<td>Jonas Lundsted Poulsen</td>
<td>Senior Specialist</td>
<td>DTI, Denmark</td>
<td><a href="mailto:jlp@teknologisk.dk">jlp@teknologisk.dk</a></td>
</tr>
<tr>
<td>Sabrina Dusek</td>
<td>Research Engineer</td>
<td>AIT, Austria</td>
<td><a href="mailto:Sabrina.Dusek@ait.ac.at">Sabrina.Dusek@ait.ac.at</a></td>
</tr>
<tr>
<td>Veronika Wilk</td>
<td>Senior Research Engineer</td>
<td>AIT, Austria</td>
<td><a href="mailto:Veronika.Wilk@ait.ac.at">Veronika.Wilk@ait.ac.at</a></td>
</tr>
<tr>
<td>Johannes Krämer</td>
<td>Research Engineer</td>
<td>AIT, Austria</td>
<td><a href="mailto:johannes.kraemer@ait.ac.at">johannes.kraemer@ait.ac.at</a></td>
</tr>
<tr>
<td>René Rieberer</td>
<td>Professor</td>
<td>TU Graz, Austria</td>
<td><a href="mailto:rene.rieberer@tugraz.at">rene.rieberer@tugraz.at</a></td>
</tr>
<tr>
<td>Manuel Verdnik</td>
<td>PhD student</td>
<td>TU Graz, Austria</td>
<td><a href="mailto:manuel.verdnik@tugraz.at">manuel.verdnik@tugraz.at</a></td>
</tr>
<tr>
<td>Toon Demeester</td>
<td>Postdoctoral researcher</td>
<td>Ghent University, Belgium</td>
<td><a href="mailto:toon.demeester@ugent.be">toon.demeester@ugent.be</a></td>
</tr>
<tr>
<td>Elias Vieren</td>
<td>PhD student</td>
<td>Ghent University, Belgium</td>
<td><a href="mailto:elias.vieren@ugent.be">elias.vieren@ugent.be</a></td>
</tr>
<tr>
<td>Chiara Magni</td>
<td>PhD student</td>
<td>KU Leuven, Belgium</td>
<td><a href="mailto:chiara.magni@kuleuven.be">chiara.magni@kuleuven.be</a></td>
</tr>
<tr>
<td>Hamed Abedini</td>
<td>Postdoctoral researcher</td>
<td>KU Leuven, Belgium</td>
<td><a href="mailto:hamed.abedini@kuleuven.be">hamed.abedini@kuleuven.be</a></td>
</tr>
<tr>
<td>Chantal Leroy</td>
<td>Manager</td>
<td>Natural Resources Canada, Canada</td>
<td><a href="mailto:chantal.leroy@nrcan-rncan.gc.ca">chantal.leroy@nrcan-rncan.gc.ca</a></td>
</tr>
<tr>
<td>Luwei Yang</td>
<td>Professor</td>
<td>TIPC-CAS, China</td>
<td><a href="mailto:lwyang2002@mail.ipc.ac.cn">lwyang2002@mail.ipc.ac.cn</a></td>
</tr>
<tr>
<td>Martin Pihl Andersen</td>
<td>PhD Student</td>
<td>DTU, Denmark</td>
<td><a href="mailto:mapian@dtu.dk">mapian@dtu.dk</a></td>
</tr>
<tr>
<td>Brian Elmegaard</td>
<td>Professor</td>
<td>DTU, Denmark</td>
<td><a href="mailto:brel@dtu.dk">brel@dtu.dk</a></td>
</tr>
<tr>
<td>Teemu Turunen-Saaresti</td>
<td>Assoc. professor</td>
<td>LUT, Finland</td>
<td><a href="mailto:teemu.turunen-saaresti@lut.fi">teemu.turunen-saaresti@lut.fi</a></td>
</tr>
<tr>
<td>Antti Uusitalo</td>
<td></td>
<td>LUT, Finland</td>
<td><a href="mailto:antti.uusitalo@lut.fi">antti.uusitalo@lut.fi</a></td>
</tr>
<tr>
<td>Florence De Carlan</td>
<td>Research Engineer</td>
<td>EDF, France</td>
<td><a href="mailto:Florence.de-carlan@edf.fr">Florence.de-carlan@edf.fr</a></td>
</tr>
<tr>
<td>Clément Gachot</td>
<td>Project manager</td>
<td>EDF, France</td>
<td><a href="mailto:clement.gachot@edf.fr">clement.gachot@edf.fr</a></td>
</tr>
<tr>
<td>Florian Schlösser</td>
<td>Postdoctoral researcher</td>
<td>Paderborn University, Germany</td>
<td><a href="mailto:Florian.schlosser@uni-paderborn.de">Florian.schlosser@uni-paderborn.de</a></td>
</tr>
<tr>
<td>Steffen Kloppe</td>
<td>Research Engineer</td>
<td>DLR, Germany</td>
<td><a href="mailto:Steffen.Kloppel@dlr.de">Steffen.Kloppel@dlr.de</a></td>
</tr>
<tr>
<td>Omar Abu Khass</td>
<td>Research Engineer</td>
<td>DLR, Germany</td>
<td><a href="mailto:Omar.AbuKhass@dlr.de">Omar.AbuKhass@dlr.de</a></td>
</tr>
<tr>
<td>Robert Schaffrath</td>
<td>Research Engineer</td>
<td>DLR, Germany</td>
<td><a href="mailto:Robert.Schaffrath@dlr.de">Robert.Schaffrath@dlr.de</a></td>
</tr>
<tr>
<td>Ursula Wittstadt</td>
<td>Research Engineer</td>
<td>Fraunhofer ISE, Germany</td>
<td><a href="mailto:Ursula.wittstadt@ise.fraunhofer.de">Ursula.wittstadt@ise.fraunhofer.de</a></td>
</tr>
<tr>
<td>Stefan Henninger</td>
<td>Research Engineer</td>
<td>Fraunhofer ISE, Germany</td>
<td><a href="mailto:Stefan.henninger@ise.fraunhofer.de">Stefan.henninger@ise.fraunhofer.de</a></td>
</tr>
<tr>
<td>Hannah Teles de Oliveira</td>
<td>Research Engineer</td>
<td>Fraunhofer ISE, Germany</td>
<td><a href="mailto:Hannah.teles.de.oliveira@ise.fraunhofer.de">Hannah.teles.de.oliveira@ise.fraunhofer.de</a></td>
</tr>
<tr>
<td>Takenobu Kaida</td>
<td>Research Engineer</td>
<td>CRIEPI, Japan</td>
<td><a href="mailto:kaida@criepi.denken.or.jp">kaida@criepi.denken.or.jp</a></td>
</tr>
<tr>
<td>Miguel Ramirez</td>
<td>Research Engineer</td>
<td>TNO, Netherlands</td>
<td><a href="mailto:miguel.ramirez@tno.nl">miguel.ramirez@tno.nl</a></td>
</tr>
<tr>
<td>Jan-Aiso a Nijeholt</td>
<td>Project Manager</td>
<td>TNO, Netherlands</td>
<td><a href="mailto:jan-also.lycklamaanijnijeholt@tno.nl">jan-also.lycklamaanijnijeholt@tno.nl</a></td>
</tr>
<tr>
<td>Christian Schlemminger</td>
<td>Research Scientist / PhD</td>
<td>SINTEF, Norway</td>
<td><a href="mailto:christian.schlemminger@sintef.no">christian.schlemminger@sintef.no</a></td>
</tr>
<tr>
<td>Ole Marius Moen</td>
<td>Research Scientist</td>
<td>SINTEF, Norway</td>
<td><a href="mailto:ole.moen@sintef.no">ole.moen@sintef.no</a></td>
</tr>
<tr>
<td>Gilbong Lee</td>
<td>Research Engineer</td>
<td>South Korea</td>
<td><a href="mailto:giblee@kier.re.kr">giblee@kier.re.kr</a></td>
</tr>
<tr>
<td>Cordin Arpagaus</td>
<td>Senior Research Engineer, Dr. sc. techn.</td>
<td>OST, Switzerland</td>
<td><a href="mailto:cordin.arpagaus@ost.ch">cordin.arpagaus@ost.ch</a></td>
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</table>
IEA HPT Annex 58
Task 2 - Integration concepts for heat pump-based process heating

Final Webinar of IEA HPT Annex 58 about High-Temperature Heat Pumps

Virginia Amato, Benjamin Zühlsdorf | Danish Technological Institute
Florian Schlosser | Paderborn University
Cordin Arpagaus | OST – Eastern Switzerland University of Applied Sciences

*All contributors of integration concepts listed in the report of Annex 58 Task 2
Agenda

1. Scope, terms and templates of Annex 58 Task 2 – Integration concepts
2. Example for heating along large temperature glides: Spray Drying
3. Example for steam production: Distillation
4. Example for hot water production: Processing of oil and gas
   a. Process & Systems
   b. Integration Concepts
   c. Heat Pump Concepts
5. Lessons learned
   a. Overview of integration concepts
   b. Conclusions
Scopes – Annex 58

Task 1 – Technology
- Heat pump systems (cycles, component types, configurations, …)
- Supplier specific technologies (component technologies, protected solutions, …)
- Irrespective of specific applications

Task 2 – Integration Concepts
- Blueprint solution for reference process (hot water production, steam production, spray dryer, …) or system (dairy, slaughterhouse, hospital, …)
- Can include several HP system types, irrespective of supplier

Task 3 – Application
- Addressing the conversion from existing systems towards concept solutions
- Focus on case specific characteristics and challenges
- Consideration of local boundary conditions
Annex 58 Task 2: Terms & definitions

Reference process or system defined by:
• Process layout
• Process characteristics (mass flows, heating and cooling demands, temperatures, ...)
• Production patterns (batch, continuous, shift-based, ...)

For each process, different integration concepts can be defined

Specific HP Applications can be found in many integration concepts

For each heat pump application, there can be multiple suitable heat pump concepts.

Possible integration concepts described by:
• Process layout
• Heat exchanger network, heat transfer media
• Buffer storages for dynamic demands
• Heat supply technologies as black-boxes
• Combinations of various technologies
• Specifications for each HP application

HP Technologies are supplier specific but can be classified/grouped according to their underlying principles to HP concepts. There can be multiple suppliers providing technologies based on the same concept.

Possible HP technologies characterized by:
• Manufacturer
• Working fluid and system layout
• Compressor type
• Part-load and off-design behavior
• Investment
• Physical foot-print

→ Overview defined by Task 1
Annex 58 Task 2: Templates

Template for the development of integration concepts for processes or systems

Reference process

Integration Concept A

Integration Concept B

Integration Concept ...

Template for the development of heat pump concepts for selected heat pump applications

Specific HP Applications (steam production, hot water production, ...)

Reference process or system defined by:
- Process layout
- Process characteristics (mass flows, ...)
- Buffer storages for dynamic demands
- Heat supply technologies as black boxes, ...)

For each heat pump application, there can be possible integration concepts described by:

- Simple Technology
- Technology X
- Technology Y
- Technology Z

HP Technologies are supplier specific but can be classified/grouped according to their underlying principles to HP concepts. There can be...

Virginia Amato and Florian Schlosser · Task 2 – Integration concepts for heat pump-based process heating · 23rd of April 2024
Example for heating along large temperature glides: Spray Drying

Current process (without heat pump)

Grand Composite Curve
Example: Milk Spray Drying

Example for heating along large temperature glides: Spray Drying

Integration Concept A

Integration Concept B

Example for heating along large temperature glides: Spray Drying

Heat Pump Concept A
Reversed Brayton Cycle

Heat Pump Concept B
Transcritical Cascade

Virginia Amato and Florian Schlosser ∙ Task 2 – Integration concepts for heat pump-based process heating ∙ 23rd of April 2024
Example for steam generation: Distillation

Current process (without heat pump)

Example for steam generation: Distillation

Integration Concept A

Integration Concept B

Example for steam generation: Distillation

Heat Pump Concept A

Heat pump + flash tank

Heat Pump Concept B + C

Evaporator + MVR

Integration Concept B

Heat Pump + MVR

Example for hot water production: Processing of oil and gas

Current process (without heat pump)

Source: Moen, O. M.: Greenfield HP implementation O&G. HigHEFF annual consortium meeting (2021); 2021-05-19 - 2021-05-20 ENERGISINT
Example for hot water production: Processing of oil and gas

**Integration Concept A**

*on process level*

- 1st stage heater
- 1st stage separ.
- 2nd stage separ.
- HP
- 85 °C
- 105 °C
- 70 °C
- 50 °C
- Separated gas
- Separated oil
- Separated water

**Integration Concept B**

*on supply level*

- Central heating system based on hot-oil
- 80-120°C
- Central cooling system based on water-glycol
- 30-40°C
- 25-35°C
- 40-50°C
- Sea water
- 20-25°C
- 125-155°C
- 120-150°C
- HP
Example for hot water production: Processing of oil and gas

Heat Pump Concept A

Single stage heat pump

- Heat Pump Concept B

Cascade heat pump

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>85 °C</td>
<td>Mixture of oil, gas and water</td>
</tr>
<tr>
<td>105 °C</td>
<td>Heated mixture of oil, gas and water</td>
</tr>
<tr>
<td>50 °C</td>
<td>Cooled Oil</td>
</tr>
<tr>
<td>70 °C</td>
<td>Separated Oil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 °C</td>
<td>100 °C → 140 °C</td>
</tr>
<tr>
<td>35 °C</td>
<td>35 °C → 45 °C</td>
</tr>
</tbody>
</table>

Virginia Amato and Florian Schlosser ∙ Task 2 – Integration concepts for heat pump-based process heating ∙ 23rd of April 2024
Matching for blueprint integration concepts

**Unit Operations / Processes**
- Drying
  - Spray drying
  - Brick drying
  - Bio sludge drying
  - Granulates drying
  - Molded fiber dryers
  - Painting / drying
- Hot water heating
- Thermal separation
  - Distillation
- Thermal preservation
  - Sterilisation
  - Pasteurisation
- Thermal treatment
  - Cooking
  - Surface treatment
  - Baking

**Heat Source**
- Medium / Temperature / Glide
  - Humid air
  - Water
  - Water-glycol
  - Steam

**Heat Sink**
- Medium / Temperature / Glide
  - Air
  - Oil
  - Water
  - Steam

**Temperature Lift**
- Transcritical cascaded
- Stirling
- Reversed Brayton cycle
- Transcritical single stage
- Single, multistage, cascade HP
- Hybrid absorption/compression HP
- Direct steam generating
- HP + flash tank
- Steam compression

**Heat Pump Concept**
- Heating of media with large temperature glide
- Hot water heating
  - Steam generation

**Heat Pump Application**
- Steam compression

**Production Pattern**
- Continuous
- Non-continuous

**Integration Level**
- Process
- Unit
- Utility

Virginia Amato and Florian Schlosser · Task 2 – Integration concepts for heat pump-based process heating · 23rd of April 2024
## Overview of integration concepts

<table>
<thead>
<tr>
<th>Process</th>
<th>Source</th>
<th>Sink</th>
<th>Temperature ranges [°C]</th>
<th>Mean AT_{in} [K]</th>
<th>Integration Level</th>
<th>Heat Pump Concept</th>
<th>Heat Pump Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Baking ovens</strong></td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>110, 90, 20</td>
<td>90, 80</td>
<td>Unit</td>
<td>Transcritical cascaded</td>
</tr>
<tr>
<td>Baking</td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>110, 90, 20</td>
<td>90, 80</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>2. Molded fiber dryers</strong></td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>150, 70, 80</td>
<td>90, 100</td>
<td>Process</td>
<td>Reversed Brayton cycle</td>
</tr>
<tr>
<td>Drying</td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>150, 100, 50</td>
<td>90, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>3. Spray Drying</strong></td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>50, 20, 30</td>
<td>102, 100</td>
<td>Process</td>
<td>Reversal</td>
</tr>
<tr>
<td>Drying</td>
<td>Continuous</td>
<td>Steam</td>
<td>Air</td>
<td>50, 20, 30</td>
<td>102, 100</td>
<td>Reversal</td>
<td></td>
</tr>
<tr>
<td><strong>4. Brick Drying</strong></td>
<td>Continuous</td>
<td>Air (Water intermediate circuit)</td>
<td>Air (Water intermediate circuit)</td>
<td>50, 20, 30</td>
<td>102, 100</td>
<td>Process</td>
<td>Reversal</td>
</tr>
<tr>
<td>Drying</td>
<td>Continuous</td>
<td>Air (Water intermediate circuit)</td>
<td>Air (Water intermediate circuit)</td>
<td>50, 20, 30</td>
<td>102, 100</td>
<td>Process</td>
<td>Reversal</td>
</tr>
<tr>
<td><strong>5. Painting &amp; Drying</strong></td>
<td>Continuous</td>
<td>Humid air</td>
<td>Liquid</td>
<td>28, 22, 8</td>
<td>116, 100</td>
<td>Unit</td>
<td>Cascaded HP</td>
</tr>
<tr>
<td>Drying</td>
<td>Continuous</td>
<td>Liquid</td>
<td>Liquid</td>
<td>28, 22, 8</td>
<td>116, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>6. Biogas drying</strong></td>
<td>Continuous</td>
<td>Steam</td>
<td>Steam</td>
<td>120, 100, 20</td>
<td>116, 100</td>
<td>Unit</td>
<td>Cascaded HP</td>
</tr>
<tr>
<td>Drying</td>
<td>Continuous</td>
<td>Steam</td>
<td>Steam</td>
<td>120, 100, 20</td>
<td>116, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>7. Plastic granules</strong></td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>60, 30, 30</td>
<td>116, 100</td>
<td>Unit</td>
<td>Transcritical single stage</td>
</tr>
<tr>
<td>Drying</td>
<td>Continuous</td>
<td>Humid air</td>
<td>Air</td>
<td>60, 30, 30</td>
<td>116, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>8. Batch Sterilization</strong></td>
<td>Continuous</td>
<td>Batch</td>
<td>Water</td>
<td>40, 20, 20</td>
<td>95, 100</td>
<td>Utility</td>
<td>Transcritical HP</td>
</tr>
<tr>
<td>Thermal preservation</td>
<td>Continuous</td>
<td>Batch</td>
<td>Water</td>
<td>40, 20, 20</td>
<td>95, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>9. Distillation</strong></td>
<td>Continuous</td>
<td>Water</td>
<td>Steam</td>
<td>35, 5, 5</td>
<td>95, 100</td>
<td>Utility</td>
<td>Flash tank + MVR</td>
</tr>
<tr>
<td>Thermal separation</td>
<td>Continuous</td>
<td>Water</td>
<td>Steam</td>
<td>35, 5, 5</td>
<td>95, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>10. Anodizing</strong></td>
<td>Non-continuous</td>
<td>Water</td>
<td>Water</td>
<td>60, 50, 10</td>
<td>95, 100</td>
<td>Unit</td>
<td>Single HP</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Non-continuous</td>
<td>Water</td>
<td>Water</td>
<td>60, 50, 10</td>
<td>95, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>11. Oil and Gas</strong></td>
<td>Continuous</td>
<td>Oil</td>
<td>Oil</td>
<td>70, 50, 20</td>
<td>35, 100</td>
<td>Unit</td>
<td>Transcritical single stage</td>
</tr>
<tr>
<td>Processing</td>
<td>Continuous</td>
<td>Oil</td>
<td>Oil</td>
<td>70, 50, 20</td>
<td>35, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
<tr>
<td><strong>12. Extrusion cooking</strong></td>
<td>Continuous</td>
<td>Humid air</td>
<td>Water</td>
<td>50, 45, 5</td>
<td>83, 100</td>
<td>Unit</td>
<td>Transcritical single stage</td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Continuous</td>
<td>Humid air</td>
<td>Water</td>
<td>50, 45, 5</td>
<td>83, 100</td>
<td>Heating along large temperature glides</td>
<td></td>
</tr>
</tbody>
</table>

(*: depending on the exact design and application)
Summary of Annex 58 Task 2 about integrations concepts of High-Temperature Heat Pumps

- Understanding of process requirements is crucial for proper integration of heat pumps
- Pinch Analysis offers graphical representation for proper targeting of integration points
- A comprehensive overview of application potentials could be created and assigned to the three basic applications: steam generation, hot water production and heating along large temperature glides
- 12 Processes
- 27 Integration Concepts
- 15 Heat Pump Concepts
- Thanks to all contributors of integration concepts listed in the report of Annex 58 Task 2
Bibliography


Moen, O. M.: Greenfield HP implementation O&G. HighEFF annual consortium meeting (2021); 2021-05-19 - 2021-05-20 ENERGISINT
IEA HPT Annex 58 Task 3 – Applications and transition towards heat pump-based process heating

Guideline for decarbonizing industrial process heating

Sabrina Dusek
AIT Austrian Institute of Technology GmbH

Annex 58 High-Temperature Heat Pumps Final Webinar
23.04.2024, Online
Decarbonization has a high priority for industry → decarbonization strategy

Well thought-out strategy with a holistic approach → Minimizing problems

External conditions and company's goals can influence the strategy

Developing a decarbonization strategy requires a lot of knowledge

High-temperature heat pumps are a key technology for decarbonized process heat supply

https://heatpumpingtechnologies.org/annex58/task-3/
Objective: supporting industrial companies in decarbonization strategy development

Main topics: goal setting, analyzing current status, developing concepts and driving strategy

Focus on decarbonization of the heat supply

https://heatpumpingtechnologies.org/annex58/task-3/
HOW TO DEFINE A DECARBONIZATION GOAL?

What is important for you?

**Start:** overarching goal that must be defined including timeframe

Elaborate importance of driver and clarify ambition level

Clear and well-communicated goals are important

Drivers
- Alternative technology available
- Legal requirements exist
- Financial advantages available
- Improving the image
- Reducing environmental impact
- Meeting customer expectations

Ambition level

Goal

Source: AIT Austrian Institute of Technology GmbH

https://heatpumpingtechnologies.org/annex58/task-3/
HOW TO DESCRIBE THE CURRENT STATUS / REFERENCE SCENARIO?

Which information is needed?

- Process cooling demand:
  - Medium
  - Temperature
  - Pressure
  - Target temperature
  - Cooling capacity (or mass flow)
  - Contamination condition
  - Current system

- Waste heat:
  - Medium
  - Contamination condition
  - Temperature
  - Pressure
  - Humidity
  - Mass flow

- Process heating demand:
  - Medium
  - Temperature
  - Pressure
  - Heating capacity (or mass flow)
  - Purity
  - Current supply system

Interconnections between processes

Boundary conditions

Source: AIT Austrian Institute of Technology GmbH and Fraunhofer Institute for Solar Energy Systems ISE

What do I need in the future?

- We will increase production capacity by 30% by 2027!
  
  Source: AIT Austrian Institute of Technology GmbH

- The steam boiler will reach the end of its lifetime in 2030!

https://heatpumpingtechnologies.org/annex58/task-3/
WHAT TECHNOLOGIES ARE AVAILABLE FOR DECARBONIZATION OF HEAT DEMAND?

- Efficiency increase
  - Heat exchanger
  - Heat pump
  - Storage

- Electrification
  - Heat pump
  - Heating element
  - Electric boiler

- Renewable gases
  - Biogas
  - Synthetic methane
  - Hydrogen

- Biomass
  - Wood
  - Energy crops
  - Waste materials

Source: AIT Austrian Institute of Technology GmbH

https://heatpumpingtechnologies.org/annex58/task-3/
HOW TO DEVELOP AND EVALUATE CONCEPT SOLUTIONS FOR DECARBONIZED SYSTEMS?

How to get a concept solution?

- Consider also site-specific parameters: e.g. available connection power and limited space availability
- IEA HPT Annex 58 Task 2: Integration concepts

Source: Danish Technological Institute

https://heatpumpingtechnologies.org/annex58/task-3/
What is the level of integration?

Optimal integration level depends on:
• current system layout
• available heat sources
• temporal planning horizon

Source: Danish Technological Institute

https://heatpumpingtechnologies.org/annex58/task-3/
How to develop and evaluate concept solutions for decarbonized systems?

**Will it pay off?**

**KPI examples:**
- Operating cost
- Investment cost
- Levelized Cost of Heat
- Payback period
- Energy consumption
- Operating characteristics
- Technology readiness level
- CO₂ emission reduction
- Space requirement
- Implementability
- Market availability
- Flexibility

**Most important KPIs for the company must be selected**

**Economic and Non-economic evaluation criteria can be important**

Source: Danish Technological Institute

**https://heatpumpingtechnologies.org/annex58/task-3/**
HOW TO DERIVE THE DECARBONIZATION PATH?

How to define an implementation roadmap?

Tips for minimizing risk:
• Test critical solutions or technologies with a lower TRL on a smaller scale
• Include redundancies
• Ongoing reassessment of the current status and targets
• Consider backup strategies

https://heatpumpingtechnologies.org/annex58/task-3/

Source: AIT Austrian Institute of Technology GmbH
HOW TO DERIVE THE DECARBONIZATION PATH?

How can a roadmap look like?

Source: AIT Austrian Institute of Technology GmbH

- **2024**: Heat losses reduced
  - Measures to reduce heat losses implemented
  - Required maintenance and service completed
  - Measure reassessed and strategy adjusted accordingly

- **2026**: Requirements established for electrification
  - PV modules installed and in operation
  - Electrical infrastructure extended as far as necessary
  - Required maintenance and service completed
  - Measure reassessed and strategy adjusted accordingly

- **2030**: Heat pumps implemented for hot water production
  - Related processes optimized
  - Heat pumps integrated and in full operation
  - Hot water production system optimized, and storages included
  - Required maintenance and service completed
  - Measure reassessed and strategy adjusted accordingly

- **2040**: Remaining electrification measures implemented
  - Related processes optimized
  - Required maintenance and service completed
  - Remaining use of fossil fuels replaced by electrification

https://heatpumpingtechnologies.org/annex58/task-3/
CONCLUSION

Developing a decarbonization strategy is a complex process

Many factors must be considered during the development

Clear goals and a good database on the current status are necessary

Concept development is very site or process-specific

Evaluation criteria must be clearly defined

**Target**: clear and implementable decarbonization roadmap

https://heatpumpingtechnologies.org/annex58/task-3/
THANK YOU!

Sabrina Dusek
AIT Austrian Institute of Technology GmbH
Sabrina.Dusek@ait.ac.at

The Austrian project is being carried out as part of the IEA research cooperation on behalf of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology.

https://heatpumpingtechnologies.org/annex58/
Definition and testing of HP specifications

Annex 58 - Task 4
Emil N. Pedersen, DTI
Webinar 23-04-2024
Annex 58 Task 4 – In short

• This is a reference work relevant for all parties involved in a HTHP project.

What should be agreed upon by all parties during the project?

How does the supplier promise the HP performance in a transparent way?

How is the HP performance tested and verified?

Link to the Task 4 report:
https://heatpumpingtechnologies.org/annex58/task-4/
Industrial HP projects and relevant standards
Typical industrial HP project structure

**Idea**
- Identify:
  - Heat demand
  - Available heat source

**Conceptual design**
- Gather basic info:
  - Outline the HP design
  - Establish contact with suppliers
  - Estimate budget

**Basic design**
- Expand on the design:
  - Determine operating conditions in detail
  - Determine non-functional requirements
  - Prepare tender material

**CAPEX approved**
- Gate 3

**Detailed design & implementation**
- Gate 4
  - Finalize:
    - Send out tender material
    - Finalize heat pump design
    - Construction
    - Perform FAT & SAT?

What is the benefit of a FAT?
Boundary conditions must be as detailed as possible.

When possible, the tender should be open to all types of system designs.

Offers should be evaluated based on criteria important to the end user. Criteria should be weighted by importance.

Penalties and bonuses can be a tool to ensure quality.
Guidelines

Specification guideline

Laboratory testing guideline

On-site testing guideline
Guideline for specification of HTHP projects

Mainly consists of:

• Boundary conditions, design, and performance of the HTHP
• Equipment specifications
• Safety and environmental specifications
• Test standards and protocols
• Certification requirements
• Warranty

What information should the end-user and the supplier have agreement on?

Consult the Annex 58 specification guideline
Example of performance map

- Supplier should specify a map of the promised performance, instead of single points
- End-user could require this in the tender
Guideline for laboratory testing

Recommended tests

• Full load test
  • Test a range of boundary conditions

• Partial load test
  • Test a range of boundary conditions

• Ramping test

• Stand-by and off-mode test

Example of FAT results:

Ramping test visualization:
Testing facilities of Annex 58 RTO’s

Sink type: Water, Oil, Steam, Air

Sink temperature [°C] vs. Heating capacity [KW]

- Water: Diamond (blue)
- Oil: Square (black)
- Steam: Triangle (green)
- Air: Cross (red)

Danish Technological Institute
Guideline for on-site testing

1. Define promised performance
   - Operating range
   - Allowable dead-band

2. Define steady-state
   - Max allowable deviations
   - Max allowable uncertainties
   - Could take place as part of test program

3. Perform measurements
   - Record all values of interest throughout the period
   - Define the operating point that was achieved

4. Compare results
   - Compare results for the operating point with promised performance
Defining steady state

Example of measurement data

Example of allowable deviations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Allowable deviation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sink inlet temperature</td>
<td>± 1</td>
<td>K</td>
</tr>
<tr>
<td>Sink mass flow rate</td>
<td>± 1.5</td>
<td>%</td>
</tr>
<tr>
<td>Source inlet temperature</td>
<td>± 1</td>
<td>K</td>
</tr>
<tr>
<td>Source mass flow rate</td>
<td>± 1.5</td>
<td>%</td>
</tr>
</tbody>
</table>

The report also contains
• Recommended sensor measurement uncertainties
• Calculations of the resulting uncertainty of COP and heating output.
Simulation for heat pump rating

Do your measurements look more like this?

A simulation-based approach may be the way forward

- Build model
- Validate model for the SAT conditions
- Run model at design conditions
- Compare model with promised performance in contract
- Simulation model can be used for optimization, etc.

Danish Technological Institute
Thank you!
Practical examples from tendering processes

Cases – focus on test

1. Surplus heat to district heat
2. Data centre cooling to district heat
3. Process cooling to district heat
4. Process to process
1. Surplus heat to district heat
Surplus heat to district heat
Case 1 – example of extend and testing period

Case description
Case 1 involves a project where surplus heat from distillation processes was utilized for producing district heat for the local district heating company. The project included both direct heat exchange and indirect heat exchange by at heat pump.

FAT and SAT test
The heat pumps where both given a FAT and a SAT test. The test were made on heating and cooling performance, COP, motor and frequency efficiency, start and regulation, vibration, temperature and pressure.
The test were done by an independent institute.

Lessons learned
Whas the test over kill?
To what extend should the test be designed based on the maturity of the technology?
Should the FAT and SAT test be made on the same parameters?
Long term testing?
Could a penalty scheme complement/supplement the FAT and SAT test?
How does test and penalty influence the price?
2. Data centre cooling to district heat
Data centre cooling to district heat

Case 2 – example of system integration

Case description
Case 2 is a project where surplus heat from data center cooling was utilized for producing district heat for a local district heating company. The project included a heat pump for transferring the heat.

FAT and SAT test
FAT was carried out according to the contract and was done at the HP contractors own test facility, and the FAT result was found OK/over the tender specification.

Lessons learned
Design failure found during SAT test. Shunt for startup was not includes which challenges the district water system. The failure were covered by the warranty.

The delivery in case 2 was based on conditions according to ABT18, that require a bank guaranty at 10 % of the prices for the first year of service, this is reduced to 2 % after the first year of service and will expire after 5 years. This bank guaranty is made to ensure the coverage of any defects and malfunctions on the scope of delivery for the heat pump.
3. Process cooling to district heat
Process cooling to district heat
Case 3 – example of details in the tender at focus in the test

Case description
Case 3 involves a project where surplus heat from process cooling was utilized for producing district heat to the local district heating company.

FAT and SAT test
The FAT was carried out before shipment of HP at the HP contractor. FAT was carried out during the Corona pandemic and verified in online meetings. SAT was carried out after the installation and commissioning. Results from the SAT was on the limit of the tender specification. This was because of fouling in the heat exchanger to the HP system. The fouling originated from the open cooling tower, that collects dirt in the air, which accumulates as fouling in the heat exchanger. The water loop was equipped with a filter to remove the dirt and avoid fouling. But the fouling could not fully be avoided, so the system ended up with negative deviation on COP and cooling capacity.

Lessons learned
Water systems connected to HP system must be clean and must not cause any fouling. An open water system with an open cooling tower cannot be used directly connected to a HP system without fouling issues. A water filter before the HP system is not a guarantee that there will be no fouling. The issues seen with fouling show it is important to consider this beforehand, both regarding the design of the heat pump system and the verification testing of the heat pump. This issue could be taken into account in the tender material, as this can heavily impact the heat transfer in the heat exchangers, and hence the performance of the heat pump.
4. Process to process
Process to process
Case 4 – example of varying operating conditions

Case description
Case 4 involves a project where surplus heat from process cooling was utilized for process heating in a hot water system. The heat was recovered at a temperature of 35 °C and delivered to the hot water system at a temperature of 65 °C. The system was constructed with a hot water loop with two buffer tanks both to even out the cooling and heating demands.

FAT and SAT test
The COP was adjusted due to the higher sink inlet temperature from 45 °C to 53 °C. COP for this point was calculated by HP-contractor during tender phase, and it was agreed that this point was used as guaranty-point in the SAT.

Lessons learned
Industrial hot water systems, heated by a HP, require a buffer capacity to even out a varying heat consumption to an almost constant heat supply from the HP. In this project the buffer system was well dimensioned, so the system is working well with the varying heat consumers supplied with heat from a HP. Due to the deviating sink inlet temperature, it is recommended to require COP in different operating points, with different sink in temperatures, during the tender phase. This will give more possibilities to get operating conditions that can fulfil a SAT.
Thank you

Fridolin Müller Holm
Phone: 31 76 17 14
fmh@viegandmaagoe.dk
Agenda

• Welcome and introduction
• Introduction to the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
• Introduction to Annex 58 about HTHPs
• Task 1 – High-temperature heat pump technologies
• Task 2 – Integration concepts for heat pump-based process heating
• Short Break
• Task 3 – Applications and transition towards heat pump-based process heating
• Task 4 – Defining and testing HTHP Specifications
• **Outlook and follow-up activities**
From Early Adoption to Mass Adoption

Sources: Rosenow et al. 2015 & IEA, Net Zero by 2050 – A Roadmap for the Global Energy Sector, 2021
Follow-Up Annex in Preparation

- Idea generation and formulation
- Comments and approval by ExCo
- Building the project consortium
- Follow-up Annex on industrial HTHPs 2025 - 2027

Activities:
- Technology Overview (Continuation of Annex 58 – Task 1)
- Demonstration cases (Continuation of Annex 58 – Task 1)
- Elaborated guideline for developing and integrating concepts (Annex 58 – Task 2 & 3)
- Development of education materials
- Sector collaborations
- Open to all participants from countries participating in the HPT TCP
- Announce your interest to Benjamin Zühlsdorf, bez@teknologisk.dk
Thank you for your attention!

Benjamin Zühlsdorf, PhD
Innovation Director
bez@teknologisk.dk
+45 7220 1258