High-Temperature Heat Pump Developments in Denmark

IEA HPT ANNEX 58

25.04.2023 – Aarhus

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HEAT PUMPS IN DISTRICT HEATING IN DK

Installed HPs in District Heating in DK
https://varmepumpedata.dk/plants/

- Heat pumps are a preferred solution
- Situation is understood by all involved parties
- Various planning tools available
- Solutions are becoming standardized
- Phase out of biomass still to come
Denmark aims for reducing greenhouse gas emissions by 70% by 2030 compared to 1990.

*Klimarådet* suggests that industry contributes by reductions equivalent to 1.9 mio. tons of CO$_2$ emissions per year. 0.5 mio. tons per year are to be obtained by “Electrification and heat pumps”, mainly implemented between 2025 to 2030.

Source: “Kendte veje og nye spor til 70 procents reduktion – Retning og tiltag for de næste ti års klimainsats i Danmark”, Klimarådet, 03/2020
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

EXPLOITING THE POTENTIAL OF HTHPS

Technology Development
• Component and system development and optimization
• Testing function & performance

Demonstration
• Collecting long-term experiences
• Increasing technology acceptance

Process Integration
• Energy integration methods
• Decarbonization strategies
• Process equipment integration

Sector Integration
• Exploiting synergies through cross-sectoral design and operation
• Testing of system behavior

Business Models
• Cross-sectoral collaboration
• Heat as a service
• Contracting

Dissemination & Education
• Increasing the awareness for the technology and its potentials
• Education of skilled labor

Multi-disciplinary and cross sectoral RD&D effort required
VALUE CHAIN FOR INDUSTRIAL HPs

Component Manufacturers → HP System Manufacturers → Process Equipment Manufacturers

System Integrators

End-users

Consultants
DECARBONIZATION OF INDUSTRIES AT DTI

- Holistic consultancy approach supporting process industries in their decarbonization
- Process Analysis & Target definition
- Conceptualization & Technology Overview
- Roadmap development
- Support during implementation

- Validation of technologies in full scale
- Industrial heat pump lab
- On-site demonstration at end-users

- Component development
- System design and optimization
- Testing function and performance

Technologies
- Heat pumps
- Thermal storage
- Thermal networks
- Biogas & green fuels
- Unit operations
- Electric systems
- Water recovery

Scope
- Energy
- GHG emissions
- Water
- Economy

Collaboration partners
- Technology suppliers (system manufacturers, OEMs, ...)
- Process equipment manufacturers
- End-users from various industries (Food & beverage, Pulp & paper, chemicals, minerals, utilities, industry symbioses, ...)

Decarbonization strategies
Technology development
Test and demonstration
STEAM COMPRESSORS

Turbo compressors based on Rotrex planetary gear

2012 – 2016: Elforsk
• 90 °C → 115 °C
• 260 kW heating
• 90 krpm

2018 – 2022: EUDP
• 85 °C → 105 °C,
• 250 kW for concentrator
• 70 krpm
STEAM COMPRESSORS

Turbo compressors with direct drive

2019 – ongoing: Innobooster
• 80 °C → 110 °C
• 220 kW heating
• 95 krpm

2020 – ongoing: SuPrHeat
• 85 °C → 135 °C
• Two-stage arrangement
• 500 kW for steam production
• 60 krpm
STEAM COMPRESSORS

Spindle Compressor

2020 – 2022: Elforsk
• 105 °C → 230 °C
• 130 kW heating
• 8 krpm
### Motivation
- Increasing focus on electrification
- Increasing competitiveness of HTHPs
- Large heat demand between 100 °C to 200 °C

### Objective
- To facilitate the electrification of industrial process heat supply at up to 200 °C
- To develop and demonstrate a technology portfolio with three prototypes (500 kW)

### Scope
- Technologies: Steam compression, Hydrocarbons, CO₂
- Integration and demonstration in dairy, slaughterhouse, brewery and others

### Project facts
- 09/2020 – 08/2024
- Budget: 61.3 mio. DKK
- [http://suprheat.dk/](http://suprheat.dk/)

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### PARTNERS
PROJECT OUTLINE

- Modular and combinable technologies
- 3 supplementary technologies
- R718 | Hydrocarbons | R744

- Best practice solutions
- Existing facilities
- New process equipment
- Transition strategies for existing sites

- Component development
- System design and optimization
- Testing function and performance

- Demonstration at three sites
- Applications:
  - Dairy
  - Ingredients
  - Slaughterhouses
  - (Brewery)
- Long-term testing
- Increasing trust in technology
HTHP CONCEPTS

Development of a concept that covers the majority of processes at highest performances

**Technologies**

Steam compression
- Low temperature glide
  - Steam production
  - Evaporators
  - ...
- Moderate temperature glide
  - Hot water production
  - Autoclaves
  - ...
- Large temperature glide
  - Spray dryer
  - ...

Hydrocarbons

CO₂

**Matching**

Promising match

Possible match
A BREWERY, PRODUCTION OF HOT WATER

Wort boiling with hot water system using R-601a from heat recovery tank

A brewery uses 2.4 MW of hot water at 145 °C for wort boiling distributed several temporarily offset batches in parallel. The remaining processes are covered by the heat recovery tank.

Water returns from the high-temperature processes at 90 °C which is heated back up to 145 °C by the heat pump keeping the conventional gas boiler as a back-up.

90 °C hot water from the heat recovery tank supplies the heat pump and returns at 80 °C.

The tank is supplied by a ammonia heat pump and recovered process heat.

<table>
<thead>
<tr>
<th>Heating COP</th>
<th>4.93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating capacity</td>
<td>2.4 MW</td>
</tr>
<tr>
<td>Sink</td>
<td>90 °C</td>
</tr>
<tr>
<td>Source</td>
<td>145 °C</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>Isopentane, R-601a</td>
</tr>
<tr>
<td>Important remarks</td>
<td>COP of 2.49 w. bottom HP ATEX required</td>
</tr>
</tbody>
</table>
8 BAR STEAM FROM DISTRICT HEATING

Steam production at 8 bar at culture production facility

- The dairy culture production facility consumes 10.5 t/hr of 8 bar steam at maximum capacity covering all processes.
- The steam condensate returns from the process at 90 °C to the feed water tank. The water is pressurized before being evaporated in the heat pump sink exiting as saturated steam at 170 °C.
- The local 70 °C district heating network, which already supplies the facility with space heating, is used as the heat source of the heat pump returning at 50 °C.

<table>
<thead>
<tr>
<th>Heating COP</th>
<th>2.31</th>
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<tbody>
<tr>
<td>Heating capacity</td>
<td>6 MW</td>
</tr>
<tr>
<td>Sink</td>
<td>Source</td>
</tr>
<tr>
<td>R-601A</td>
<td>90 °C 170 °C</td>
</tr>
<tr>
<td>R-718</td>
<td>70 °C</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>Isopentane and water</td>
</tr>
<tr>
<td>Important remarks</td>
<td>ATEX required, Cascade heat pump</td>
</tr>
</tbody>
</table>
SPRAY DRYER ELECTRIFICATION

Drying of fish food at 280 °C in spray dryers using R-744 brayton heat pump

- A protein rich substance is dried in several parallel spray dryers using 15,000 kg/hr of dry air heated to 280 °C.

- Ambient air is heated from 30 °C to 190 °C in a heat exchanger connected to the heat pump by a secondary water loop before an electric heater raises the temperature to 280 °C w. a total COP of 1.77.

- The exhaust air comes out at 90 °C at 12 % relative humidity which is used as the source of the heat pump.

| Heating COP | 2.02 |
| Heating capacity | 0.8 MW |
| Sink | Source |
| Refrigerant | Carbon dioxide, R-744 |
| Important remarks | High pressures 150 bar, Compact cycle |
HTHP TECHNOLOGIES

Steam compression system
- Spindle compressor: High pressure ratio and $T_{\text{lift}}$
- 2-stage turbo compressor: high flows and $T_{\text{lift}}$ up to 50 K
- Full-scale test: 2023
- On-site demo: 2024

Hydrocarbon system
- Butane (R600) $\rightarrow$ 120 °C
- Isopentane (R601a) $\rightarrow$ 160 °C
- Bock piston compressors
- Full-scale test: 04/2023
- On-site demo: Early 2024

CO$_2$ system
- CO$_2$ (R744) $\rightarrow$ 180 °C
- Bock piston compressors
- Single-stage with ejectors
- Full-scale test: 2023
- On-site demo: Early 2024
NEXT STEP: TESTING THE HYDROCARBON SYSTEM
InterHeat – Demonstration of HTHPs at different integration levels

<table>
<thead>
<tr>
<th>Motivation</th>
<th>Objective</th>
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<tbody>
<tr>
<td>• To demonstrate HTHPs in industrial applications</td>
<td>• To develop and demonstrate HTP solutions for hot water at 140 °C and steam at 160 °C</td>
</tr>
<tr>
<td>• To increase the competitiveness of HTHPs</td>
<td>• To analyze different level of integration</td>
</tr>
<tr>
<td>• To increase the technology availability</td>
<td>• To demonstrate different business models</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scope</th>
<th>Project facts</th>
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</thead>
<tbody>
<tr>
<td>• Hydrocarbon + Steam compression</td>
<td>• 02/2022 – 08/2025</td>
</tr>
<tr>
<td>• Commercial semi-hermetic compressors and open industrial compressors</td>
<td>• Budget: 50 mio. DKK</td>
</tr>
<tr>
<td>• Demonstrating two solutions</td>
<td>• 11 partners</td>
</tr>
<tr>
<td></td>
<td>• <a href="https://interheat.dk/">https://interheat.dk/</a></td>
</tr>
</tbody>
</table>

**PARTNERS**
DIN FORSYNING DEMONSTRATOR

Source, fjernvarme
HC skrue kompressor
Vanddamp kompressor
Indsprøjtning
Kaskade
HEX
Konden-
sator
Under-
køler
Intern
HEX
Sink, 
procesdamp
Sink
Vand
Butan
Source

Expected COPs:

<table>
<thead>
<tr>
<th>Source</th>
<th>Sink</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 °C → 40 °C</td>
<td>160 °C</td>
<td>1.8</td>
</tr>
<tr>
<td>70 °C → 40 °C</td>
<td>140 °C</td>
<td>2.0</td>
</tr>
<tr>
<td>80 °C → 70 °C</td>
<td>160 °C</td>
<td>2.4</td>
</tr>
<tr>
<td>80 °C → 70 °C</td>
<td>140 °C</td>
<td>2.8</td>
</tr>
</tbody>
</table>
BOTTOM CYCLE: BUTANE

- Supplier: SRM
- Upgraded screw compressor package
- Supply temperatures: up to 120 °C
- Experiences from commercially available applications at lower temperatures
TOP CYCLE: STEAM

- Supplier: SRM
- Novel steam screw compressor
- Supply temperatures: up to 160 °C
- Experiences from prototype tests
- Ongoing full-scale test
DRYING OF PROTEIN POWDER

- Approx. 500 kW of heat is supplied for a protein powder drying process. The warm, most exhaust air is used as source. Both source and sink are provided with a safety water circuit.

- The heat pump is a 2-stage system, using isobutane in the low stage and isopentane in the high stage.

- A very large fraction of the heat comes from subcooling the refrigerants; only 1/3 is from condensation.

- Compressors by Frascold
Heat pumps as the reference low carbon technology for industrial heat supply <160°C by 2030

Demonstration sectors require 63% of industrial process heat <160°C

Reducing CO₂ emissions by 56 Mt/a

Total process heat in industry

Contributing to the electrification of the heat supply in industry

Reducing final energy consumption by 150 TWh/a -7.5%

Process heat <160°C in industry by sector

Food and beverage 15%
Paper and pulp 22%
Chemical 41%
Other 22%

Modular design concepts
Increasing application potential and lowering capital expenses

In multiple industry sectors with multiple heat pump technologies

Heat pump demonstration

Business models and contractual agreements
Reducing barriers for market uptake

Creating awareness of industrial heat pumps
Disseminating and communicating project results

Performance optimization
Reducing energy use and operational costs

TRL6 → TRL8

Reducing 640 MT CO₂ and 1687 TWh of Final Energy Consumption in Europe by 2050

https://spirit-heat.eu/
HTHP TECHNOLOGIES – FURTHER DEVELOPMENT AND DEMONSTRATION ACTIVITIES

**HC cascade system**
- Iso-Butane (R600a) → 120 °C
- Iso-Pentane (R601a) → 160 °C
- Frascold screw compressors
- 500 kW in drying process
- Full-scale test: 2023
- On-site demo: 2024

**HC & steam system**
- Butane (R600) → 120 °C
- Water (R718) → 160 °C (steam)
- SRM screw compressors
- 1 MW process heat (source DH)
- Full-scale test: 2023
- On-site demo: 2024

**Pentane system**
- Pentane (R601) → 145 °C (steam)
- GEA screw compressors
- Single-stage
- 4 MW for sugar production
- On-site demo: 2024
HTHP SYMPOSIUM

• Focus on:
  • Potential and demand
  • Successful case studies
  • Available technologies
  • Developments and trends
  • Good feedback and growing interest

• Save the date:
  23rd & 24th of January 2024

• http://hthp-symposium.org/
CONCLUSIONS AND OUTLOOK

**Conclusions**
- High-temperature heat pumps have a considerable potential.
- Rapid technology uptake expected for 2025 towards 2030 → maybe earlier?
- Variety of technologies and manufacturers required to provide competitive solutions.
- Process integration and decarbonization strategies are key to optimal performances.
- Multi-disciplinary and cross sectoral RD&D required for exploiting the technology's potential.

**Outlook**
- Large up-take of heat pumps in district heating < 100 °C.
- Establishing HTHPs as reference technology for heat supply up to 150/160 °C.
- Advancing the state of the art for technologies >150 °C.
- Creating awareness at variety of stakeholders.