International Workshop on High Temperature Heat Pumps

11. September 2017
Copenhagen, Denmark

\[(EIv^{''})^{''} = q - \rho A\ddot{v}\]

\[\sum \chi^2 = \{2.71\}\]

DANISH TECHNOLOGICAL INSTITUTE

SINTEF

DTU Mechanical Engineering
Department of Mechanical Engineering
Introduction

Modern society moves towards an electrified energy system based on wind, solar and other renewable sources. Utilizing these sources efficiently by heat pumps is highly attractive and a significant potential for improving the energy system by extensive adaptation of heat pumping technology in all fields exists. However, challenges are present for heat pump technology. In particular for high temperature applications like industrial processes and to some extent district heating, heat pumps are not yet commercially available. In some countries the expansion already occurs, but other places the development is much more limited. Some obstacles relate to regulations and boundary conditions which may not be favorable for heat pumps and electrification. But, the level of the technology will probably also improve with regards to temperature limits, efficiency, capacity, and economy, and hence inherently become an attractive alternative to fossil fuels.

The focus on developments for the future is apparent in both industrial and scientific research and development activities at all levels. DTU Technical University of Denmark, Danish Technological Institute and Norwegian SINTEF are all involved in these activities in collaboration with national and international partners.

Based on these common interests and the many exciting activities we decided to invite for a workshop for a broad audience ranging from manufacturers, system suppliers, industrial users, consultants, research institutes, and academia. The meeting attracted more than 60 participants attending the 18 talks and a final panel discussion on the 11. September 2017 in Copenhagen.

The talks were divided in four sessions focusing on

- Market Potential - Developments – Challenges
- Research and Development Projects
- Heat pump developments - Market ready products
- Case studies including realized projects

Altogether the presentations showed significant activity in both the Nordic countries, in Europe, and worldwide. Heat pumps are installed and investigated in various branches and both the foreseen industrial progress and the longer term perspectives indicated by academic research target the challenges and will soon make high temperature heat pumping far more attractive.

The concluding panel discussion involved Andrew J. Marina – Researcher at ECN (Energy Research Centre of the Netherlands), Kim Andre Lovas – Consultant, TINE SA Oslo, Morten Deding – Heat Pump Product Director Johnson Controls, Palle Lemminger – Manager, Innoterm A/S, and Petter Nekså – Chief Scientist, SINTEF. The panelists presented their suggestions on measures that will enhance the utilization of high temperature heat pumps in industry.
The following common conclusions were drawn from the discussion:

- Heat pumps are required for combating climate change
- Avoid wasting excess energy from industry by use of heat recovery
- Technical innovations for achieving lower specific investment costs should be achieved
- Equalize boundary conditions for heat pumps and other technologies
- Broader collaboration and interaction between technology developers and end-users will be beneficial
- Calculation tools may be useful for communicating the potentials to potential users
- Demonstration projects involving all parties including end-users, consultants, manufacturers as well as R&D can constitute a good opportunity to realize the before-mentioned suggestions

As organizers we are grateful to all participants and in particular the speakers for interesting and well-prepared presentations. In the following we present the collection of slides presented at the meeting.

Brian Elmegaard, Technical University of Denmark
Benjamin Zühlsdorf, Technical University of Denmark
Lars Reinholdt, Danish Technological Institute
Michael Bantle, SINTEF
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1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)
• The IEA Technology Collaboration Programme on Heat Pumping Technologies, HPT TCP, and the Heat Pump Centre, the central information activity of the programme.
http://heatpumpingtechnologies.org

• The goal is to accelerate the implementation of heat pumps and related heat pumping technologies. Including air conditioning and refrigeration.

• HPT TCP is member of IEA International Energy Agency (IEA), the programme was founded in 1978.
HPT TCP has been active since almost 40 years.

• There are today 16 member countries: Austria, Belgium, Canada, Denmark, Finland, France, Italy, Germany, Japan, the Netherlands, Norway, South Korea, Sweden, Switzerland, United Kingdom and the United States.

• Annexes = Projects
One of the main activities within the programme is to run collaborative research, development, demonstration and deployment projects. They are called Annexes and they are conducted on a combination of cost sharing and task-sharing basis by the participating countries.

• One person/organization is appointed to manage the Annex, to be the Operating Agent of the Annex.

• http://heatpumpingtechnologies.org/ongoing-annexes/
1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)
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IEA HPP - IETS Annex 35/13: Application of Industrial Heat Pumps

- As a joint venture of the IEA Implementing Agreements Industrial Energy-related Technologies and Systems (IETS) and Heat Pump Programme (HPP)
- 9 IEA countries: A CDN D DK F JAP Korea NL S
- 15 participating organizations
- Operating agent: IZW e.V. Germany
- Start date: 01st May 2010  End date: 30th April 2014
- Report: 31st October 2014  689 pages
  - 39 R&D projects
  - 115 applications
  - 85 publications of the participants

IEA HPP Annex 48: Industrial Heat Pumps, Second Phase

- IEA countries: A CH DK F JAP UK
- Operating agent: IZW e.V. Germany
- Start date: 01st April 2016  End date: 31st March 2019

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<th>CDN</th>
<th>DK</th>
<th>F</th>
<th>D</th>
<th>Jap</th>
<th>Korea</th>
<th>NL</th>
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<td>HP Energy situation, energy use, market overview, barriers for application</td>
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</tbody>
</table>
Task 1:
Heat Pump Energy situation, energy use, market overview, barriers for application
A, CDN, DK, F, D, Japan, Korea, NL, S

Final energy consumption (9,060 PJ) in Germany 2010 by sector /BMWI 2012
Final energy consumption (2,542 PJ) in the Germany industry 2010 by sector /BMWI 2012

Greater market with higher temperature (France)

Market overview
Barriers and Solutions

Challenging Heat & Electricity Prices

- Focus on Countries with favorable Price Ratios:
  - Sweden
  - Finland
  - Bulgaria
  - Netherlands
  - France
  - etc.

- Focus on Rural Areas without Gas Networks

### Electricity/Gas Price Ratio

<table>
<thead>
<tr>
<th>Country</th>
<th>Small Enterprises</th>
<th>Large Enterprises</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>1.2</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Finland</td>
<td>1.8</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>1.9</td>
<td>2.6</td>
<td>2.0</td>
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<tr>
<td>Netherlands</td>
<td>1.5</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>France</td>
<td>1.4</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Slovakia</td>
<td>2.5</td>
<td>2.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Portugal</td>
<td>2.1</td>
<td>2.6</td>
<td>2.4</td>
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<tr>
<td>Estonia</td>
<td>2.5</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Austria</td>
<td>2.8</td>
<td>2.7</td>
<td>2.0</td>
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<tr>
<td>Poland</td>
<td>2.4</td>
<td>2.8</td>
<td>2.4</td>
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<tr>
<td>Lithuania</td>
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<td>3.4</td>
<td>3.2</td>
</tr>
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<td>Croatia</td>
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<td>2.6</td>
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<td>Hungary</td>
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<td>2.4</td>
<td>2.8</td>
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<tr>
<td>Latvia</td>
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<td>2.7</td>
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<tr>
<td>Luxembourg</td>
<td>3.2</td>
<td>2.3</td>
<td>3.6</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1.7</td>
<td>3.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Denmark</td>
<td>4.2</td>
<td>1.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2.2</td>
<td>3.7</td>
<td>2.9</td>
</tr>
<tr>
<td>Spain</td>
<td>2.9</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Greece</td>
<td>2.3</td>
<td>4.0</td>
<td>3.0</td>
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<tr>
<td>Italy</td>
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<td>3.9</td>
<td>3.7</td>
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<td>Romania</td>
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<td>3.0</td>
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<td>Belgium</td>
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<td>4.0</td>
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<tr>
<td>Germany</td>
<td>3.0</td>
<td>4.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Ireland</td>
<td>4.1</td>
<td>3.9</td>
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<td>United Kingdom</td>
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<td>4.2</td>
<td>3.1</td>
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<td>2.4</td>
<td>3.3</td>
<td>3.0</td>
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</tbody>
</table>

Source: IER Stuttgart Stefan Wolf Chillventa CONGRESS 10.10.2016

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Average electricity pricing (2010)

**SELECTED WORLD RESIDENTIAL ELECTRICITY PRICES, 2010**

- **DENMARK**
- **JAPAN**
- **UNITED KINGDOM**
- **FRANCE**
- **UNITED STATES**
- **CANADA**
- **MEXICO**

~ **0.09 US$/kWh**

Cent/kWh

Source: International Energy Agency

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Source: Natural Resources Canada
Heat Pump Energy situation, energy use, market overview, barriers for application

The country reports show that the industrial energy consumption in the participating countries varies between 17 to 58 % with great differences of the manufacturing sectors.

The barriers can be solved, as shown in the results of the Annex:
• short payback periods are possible (less than 2 years),
• high reduction of CO₂-emissionen (up to more than 50%),
• temperatures higher than 100 °C are possible,
• supply temperatures lower than 100 °C are standard.

Task 3: R & D Projects

A, CDN, DK, F, D, Japan, Korea, NL
Company Ochsner offers HPs with new refrigerant ("Öko 1"): non-flammable, not toxic for heat sink temperatures up to 95°C (temp. difference 5 to 10 K).

Two different types:
- IWHSS for a temperature lift from 10 to 95°C
- IHWS for a temperature lift from 40 to 95°C

High-temperature heat pump (Ochsner, 2013)

Closed-cycle mechanical heat pump
- Transcritical CO₂ cycle
- Single-stage compression reverse Rankine cycle
- Two-stage compression reverse Rankine cycle
- Cascade reverse Rankine cycle

Open-cycle hybrid vapor recompression heat pumps
- Hybrid means “mechanical and thermal”
1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)

**Cascade Reverse Rankine Cycle Heat Pump using R410A**

![Diagram of Cascade Reverse Rankine Cycle Heat Pump using R410A](image)

**Specifications of the Heat Pump**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Heating Power (kW)</td>
<td>14.0</td>
</tr>
<tr>
<td>Rated COP*</td>
<td>3.5</td>
</tr>
<tr>
<td>Leaving Temperature Range (°C)</td>
<td>50 to 90</td>
</tr>
<tr>
<td>Ambient air temperature range (°C)</td>
<td>-15 to 43</td>
</tr>
</tbody>
</table>


**Technology**

Choyo Watanabe et al.; IEA HPP Workshop, HPC2014 in Montreal, Canada

---

**Refrigerants on High Temperature HPs 11.9.17 Kobenhavn K**

| Refrigerant | Components | ratio | ODP* | GWP* | NBP* | T_1 | T_2 | P | Safety classification |
|-------------|------------|-------|------|------|------|-----|-----|   |                      |
| R410A       | R22/R125  | 55/50 | 0    | 1730 | -51.6 | 72.6 | 49.0 | A1 |
| R134a       | C,H,F     | 0    | 1300 | -26.1 | 101.0 | 40.6 | A1 |
| R245fa      | C,H,F     | 0    | 950  | 15.3  | 154.0 | 36.4 | B1 |
| R17         | NH3       | 0    | 0    | -33.0 | 133.0 | 114.2 | B2 |
| R244        | CO2       | 0    | 0    | -57.0 | 31.0  | 73.8 | A1 |
| SES98       | R66mfc/PFPE | 65/35 | 0   | 3120 | 35.6  | 177.1 | 28.5 | unknown |
| DR-2        | unknown   | 0    | 9.4  | 33.4  | 171.3 | 29.0 | A1 (expected) |

*) ODP: Ozone Depletion Potential  
GWP: Global Warming Potential  
NBP: Normal Boiling Point

Quellen:

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1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)

**Technology**  
EDF projects to reach temperatures > 100 °C

- **Alter ECO Project**  
  Partnership: Rhodia, Arkema, Danfoss, CIAT, ...
  - VHT HP  
    140°C – 250 kW
  Integrator: CLAUGER

- **Technical Partnership**  
  EDF /Johnson Controls
  - HT/VHT HP  
    100°C/120°C – 700 kW
  Manufacturer: JCI

- **ANR PACO Project**  
  Partnership: Johnson-Control, France Évaporation, CETHIL, AgroParistech, Matmeca ...
  - VHT HP with water  
    140°C – 700 kW
  Manufacturer: JCI/F-Évaporation

---

**Task 4: Case studies**

- A, CDN, DK, F, D, Japan, Korea, NL
### Case Studies

Source: NT Japan Annex 35

<table>
<thead>
<tr>
<th>Application, Industry</th>
<th>Member Country</th>
<th>Year</th>
<th>System</th>
<th>Refrigerant</th>
<th>Cooling</th>
<th>Heating</th>
<th>Drying</th>
<th>Waste</th>
<th>Supply temperature</th>
<th>Payback period</th>
<th>Red CO2</th>
<th>Reduction energy/cost</th>
<th>Report page</th>
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</thead>
<tbody>
<tr>
<td>Food: meat, sausage</td>
<td>A 4ld</td>
<td>2013</td>
<td>Mech Compr</td>
<td>R-134a</td>
<td>W</td>
<td>257 kW</td>
<td>55 °C</td>
<td></td>
<td>75%</td>
<td></td>
<td></td>
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<tr>
<td>Ice rink</td>
<td>A 2013</td>
<td></td>
<td>Mech Compr</td>
<td>R-717</td>
<td>W</td>
<td>413 kW</td>
<td>60 °C</td>
<td></td>
<td>75%</td>
<td></td>
<td></td>
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<tr>
<td>Food: brewery</td>
<td>A 2012</td>
<td></td>
<td>Mech Compr</td>
<td>R-717</td>
<td>W</td>
<td>370 kW</td>
<td>63-77 °C</td>
<td></td>
<td>5.7 a</td>
<td>64,000 €/a</td>
<td>18.3 %</td>
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<tr>
<td>Fish farm</td>
<td>CDN e1d</td>
<td></td>
<td>Mech Compr</td>
<td>R-22</td>
<td>H</td>
<td>109</td>
<td>10-12 °C</td>
<td></td>
<td>1.3 a</td>
<td></td>
<td></td>
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<tr>
<td>Wood drying</td>
<td>CDN e1d</td>
<td></td>
<td>Mech Compr</td>
<td>D</td>
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<td>5.6 kW</td>
<td>n. a.</td>
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<td>21.5%</td>
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<tr>
<td>Wood drying</td>
<td>CDN e1d</td>
<td></td>
<td>Mech Compr</td>
<td>D</td>
<td></td>
<td>2 x 65 kW</td>
<td>up to 100 °C</td>
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<td>Washing metal</td>
<td>DK 2011</td>
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<td>Mech Compr</td>
<td>R-134a</td>
<td>H</td>
<td>25 kW</td>
<td>60 °C</td>
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<td>2.5 a</td>
<td>20 t/a</td>
<td>50%</td>
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<tr>
<td>Food: Slaughter</td>
<td>D 2011</td>
<td></td>
<td>Mech Compr</td>
<td>R-744</td>
<td>C&amp;H</td>
<td>800 kW</td>
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<td>510 t/a</td>
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</tr>
<tr>
<td>house</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Food: Dairy</td>
<td>D 2011</td>
<td></td>
<td>Mech Compr</td>
<td>R-717</td>
<td>W</td>
<td>3.45 MW</td>
<td>58 °C</td>
<td></td>
<td>30-40%</td>
<td></td>
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</tbody>
</table>

---

1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)
### Case studies

#### Some applications in Austria

**Company:**

![Mohrenbrauerei](https://www.mohrenbrauerei.at)

**Case studies**


<table>
<thead>
<tr>
<th>Application, Industry</th>
<th>Member Country</th>
<th>Year</th>
<th>System</th>
<th>Refrigerant</th>
<th>Cooling Capacity</th>
<th>Heating Capacity</th>
<th>Supply temperature</th>
<th>Pay back period</th>
<th>Reduction CO₂</th>
<th>Reduction energy/cost</th>
<th>Report page</th>
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<tbody>
<tr>
<td>Food: Dairy</td>
<td>D</td>
<td>2011</td>
<td>Mech Compr</td>
<td>R-717</td>
<td>W</td>
<td>3.45 MW</td>
<td>58 °C</td>
<td>30-40%</td>
<td>506</td>
<td>25%</td>
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<tr>
<td>Coating Powder</td>
<td>D</td>
<td>2012</td>
<td>Mech Compr</td>
<td>R-717</td>
<td>D</td>
<td>240 kW</td>
<td>45 °C</td>
<td>5 a</td>
<td>531</td>
<td>33%</td>
<td>547</td>
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<tr>
<td>Food: Malt production</td>
<td>D</td>
<td>2010</td>
<td>Mech Compr</td>
<td>R-717</td>
<td>D</td>
<td>3,250 kW</td>
<td>35 °C</td>
<td></td>
<td>546</td>
<td>25%</td>
<td>557</td>
</tr>
<tr>
<td>Food: Brewery</td>
<td>D</td>
<td>2012</td>
<td>Mech Compr</td>
<td>R-134a</td>
<td>H</td>
<td>77 kW</td>
<td>55 °C</td>
<td>&lt; 6 a</td>
<td>547</td>
<td>25%</td>
<td>557</td>
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<tr>
<td>Transformer casing (painting)</td>
<td>Jap</td>
<td>2009</td>
<td>Mech Compr</td>
<td>R-744 trans.</td>
<td>D</td>
<td>110 kW</td>
<td>80–120 °C</td>
<td>13%</td>
<td>565</td>
<td>56%</td>
<td>569</td>
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<tr>
<td>Automotive (painting)</td>
<td>Jap</td>
<td>2009</td>
<td>Mech Compr</td>
<td>R-407E</td>
<td>D</td>
<td>566 kW</td>
<td>n. a.</td>
<td>3 – 4 a</td>
<td>569</td>
<td>63%</td>
<td>575</td>
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<tr>
<td>Automotive – Washing process</td>
<td>Jap</td>
<td>2009</td>
<td>Mech Compr</td>
<td>R-134a</td>
<td>C &amp; H</td>
<td>8 x 45.3 kW</td>
<td>65 °C</td>
<td>86%</td>
<td>575</td>
<td>73%</td>
<td>575</td>
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<tr>
<td>Greenhouse</td>
<td>Jap</td>
<td>2010</td>
<td>Mech Compr</td>
<td>R-410A</td>
<td>6 x 18 kW</td>
<td>20 °C</td>
<td>63%</td>
<td>50%</td>
<td>580</td>
<td>50%</td>
<td>580</td>
</tr>
<tr>
<td>Food: Drying of french fries</td>
<td>NL</td>
<td>2012</td>
<td>Mech Compr</td>
<td>R-717</td>
<td>C&amp;H</td>
<td>880 kW</td>
<td>70 °C</td>
<td>4 a</td>
<td>580</td>
<td>70%</td>
<td>NL-06</td>
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<td>Greenhouse Tomatoes</td>
<td>NL</td>
<td>2003</td>
<td>Mech Compr</td>
<td>R-134a</td>
<td>C&amp;H</td>
<td>3 x 1.25 MW</td>
<td>42-50 °C</td>
<td>&gt; 10 a</td>
<td>580</td>
<td>40-60%</td>
<td>NL-27</td>
</tr>
</tbody>
</table>

**Compression heat pump in in a brewery:**

- NH₃ Compression HP (COFELY)
- 370 kW heating capacity
- Waste heat from:
  - air compressor
  - chillers
- Heat upgrade from ca. 40 to 77 °C
- Space and process water heating
- ROI: 5.7a

Source: klima:aktiv

Source: klima:aktiv, 2012

---

1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)
Fish farm heat recovery

Overall system COP: 7.9
Payback period: 1.28 year

Heat pump-assisted drying

Industrial high-temperature HP for softwood drying (354 m³)

- 2 HPs – total 130 kW
- HFC-236fa
- Split HPs with remote condensers

- > 19 300 Liters of water removed/cycle
- SMER: 1.46 to 2.52 kg Water/kWh (compressors + blowers)
- Energy savings: 27 to 57 % vs. oil

Source: 27

Case studies
Selected applications of industrial heat pumps in Germany - Size

Collection of 18 heat pump applications in the German industry:
- 13 use waste heat to provide space heating
- 5 use waste heat to provide process heat

Selected applications of industrial heat pumps in Germany - Temperatures

Collection of 18 heat pump applications in the German industry:
- 13 use waste heat to provide space heating
- 5 use waste heat to provide process heat
Temperature ranges and types of heat used in industries

<table>
<thead>
<tr>
<th>Type of industry</th>
<th>Process</th>
<th>Temp. used [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>General machinery and tools</td>
<td>Drying</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Washing</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Degreasing</td>
<td>80</td>
</tr>
<tr>
<td>Electronic components and devices</td>
<td>Drying</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Washing</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Degreasing</td>
<td>80</td>
</tr>
<tr>
<td>Transportation machinery</td>
<td>Drying</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Washing</td>
<td>80</td>
</tr>
<tr>
<td>Food</td>
<td>Sterilization</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Washing</td>
<td>80</td>
</tr>
<tr>
<td>Beverage</td>
<td>Sterilization</td>
<td>80</td>
</tr>
</tbody>
</table>


Temperature Applied for IHP Source: NT Japan Annex 48

<table>
<thead>
<tr>
<th>Industry</th>
<th>Industrial process</th>
<th>Temp. [°C]</th>
<th>Industry</th>
<th>Industrial process</th>
<th>Temp. [°C]</th>
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</thead>
<tbody>
<tr>
<td>Food production</td>
<td>Freezing foods</td>
<td>-60 ~ -30</td>
<td>Lumber dehumidifier</td>
<td>40 ~ 60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling of chicken</td>
<td>-20 ~ 5</td>
<td>Freezing exhibit case</td>
<td>-20 ~ -10</td>
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<tr>
<td></td>
<td>Cooling of noodle</td>
<td>1 ~ 3</td>
<td>Cooling vehicle</td>
<td>-10 ~ 0</td>
<td></td>
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<tr>
<td></td>
<td>Sterilization and cooling of milk</td>
<td>3 ~ 5, 70 ~ 75</td>
<td>Hot water supply for cooking room</td>
<td>60 ~ 80</td>
<td></td>
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<tr>
<td></td>
<td>Ham production</td>
<td>2 ~ 80</td>
<td>Heating for indoor pool water</td>
<td>~ 35</td>
<td></td>
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<tr>
<td></td>
<td>Retort pouch</td>
<td>3 ~ 5, 70 ~ 75</td>
<td>Heating for hot spring</td>
<td>~ 60</td>
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<tr>
<td></td>
<td>Fermentation of Japanese sake</td>
<td>14 ~ 15</td>
<td>Hot water supply for bathhouse</td>
<td>50 ~ 65</td>
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<td></td>
<td>Fermentation and temperature control of wine</td>
<td>18 ~ 20</td>
<td>Dry cleaning</td>
<td>20 ~ 30</td>
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<tr>
<td></td>
<td>Seaweed drying</td>
<td>20 ~ 30</td>
<td>Cloth drying</td>
<td>60 ~ 80</td>
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<tr>
<td></td>
<td>Temperature control of yeasts and bread</td>
<td>22 ~ 30</td>
<td>Drying heating</td>
<td>90</td>
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<tr>
<td></td>
<td>Fermentation of miso and shoyu</td>
<td>27 ~ 28, 38 ~ 40</td>
<td>Towel drying</td>
<td>~ 100</td>
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<td>Rice koji drying</td>
<td>35</td>
<td>Drying of furniture and musical instr.</td>
<td>38 ~ 60</td>
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<tr>
<td>Agriculture</td>
<td>Low temperature storage</td>
<td>1 ~ 6</td>
<td>Drying of paper and pulp</td>
<td>80 ~ 130</td>
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<tr>
<td></td>
<td>Pre-cooling</td>
<td>3 ~ 5</td>
<td></td>
<td></td>
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<td></td>
<td>Cooling &amp; washing for milking process</td>
<td>0 ~ 4, 40 ~ 60</td>
<td>Concentration of medicine</td>
<td>20 ~ 80</td>
<td></td>
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<td></td>
<td>Mushroom cultivation</td>
<td>13 ~ 20</td>
<td>Dehumidifying of incense stick</td>
<td>25 ~ 30</td>
<td></td>
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<tr>
<td></td>
<td>Temperature control for slop culture</td>
<td>15 ~ 25</td>
<td>Separation and synthesis of petro.</td>
<td>60 ~ 120</td>
<td></td>
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<tr>
<td></td>
<td>Greenhouse cultivation</td>
<td>18 ~ 32</td>
<td>Petroleum refinery</td>
<td>60 ~ 180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dehumidifier cultivation</td>
<td>20 ~ 23</td>
<td>Distillation of chemicals</td>
<td>80 ~ 170</td>
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<tr>
<td></td>
<td>Heating for stock breeding</td>
<td>20 ~ 30</td>
<td>Waste burning</td>
<td>~ 60</td>
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<tr>
<td></td>
<td>Egg incubation</td>
<td>36 ~ 38</td>
<td></td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>
Problems of Practical Heat Usage in Factory

- **A large amount of low temperature heat is wasted.**
  Processes in a factory generate exhausted heat in different forms. All input energy in a factory is finally wasted as low level of heat.

- **Low effective use of steam boiler system**
  Practical steam supply system has nearly 50% of heat loss generated in processes of boiler, piping and drain.

- **Constant temperature of heat supply**
  Heat in a factory is used for heating, drying, washing, etc. at different heat levels. However, heat of constant temperature is supplied for those purposes.

- **Separate heat supply for heating and cooling**
  It is required for both heating and cooling in production processes. Different technologies are separately adopted for heating and cooling.

Source: Guide of IHP application, JEHC, 2017
1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)

<table>
<thead>
<tr>
<th>N</th>
<th>Industry</th>
<th>Food</th>
<th>Machinery</th>
<th>Chemicals</th>
<th>Food</th>
<th>Machinery</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Process applied</td>
<td>Heating/cooling</td>
<td>Heating/cooling</td>
<td>Distillation/concentration</td>
<td>Distillation/concentration</td>
<td>Heating</td>
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<td>Location</td>
<td>Hyogo</td>
<td>Aichi</td>
<td>Hokkaido</td>
<td>Kochi</td>
<td>Mie</td>
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<td>Year of installation</td>
<td>2010</td>
<td>2010</td>
<td>-</td>
<td>2015</td>
<td>2013</td>
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<tr>
<td>HP manufacturer</td>
<td>MAYEKAWA MFG. Ltd</td>
<td>General HP Industries, Ltd.</td>
<td>KOBE STEEL, Ltd</td>
<td>Sasakura Engineering Ltd</td>
<td>Fuji Electric co.Ltd.</td>
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<td>HP system</td>
<td>Water-source hot water supply HP</td>
<td>Water-source HP chiller</td>
<td>Water-source steam supply HP</td>
<td>Mechanical vapor recompression</td>
<td>Water-source steam supply HP</td>
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<tr>
<td>Refrigerant</td>
<td>CO₂</td>
<td>R134a</td>
<td>R245fa</td>
<td>steam</td>
<td>R245fa</td>
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<tr>
<td>Compressor type</td>
<td>reciprocate</td>
<td>scroll</td>
<td>screw</td>
<td>roots</td>
<td>reciprocate</td>
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<tr>
<td>Heating/cooling capacity (kW)</td>
<td>828</td>
<td>66</td>
<td>9,250</td>
<td>-</td>
<td>30</td>
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<tr>
<td>Supply temperature (°C)</td>
<td>90</td>
<td>65</td>
<td>120</td>
<td>70</td>
<td>120</td>
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<tr>
<td>Heat source/heat sink</td>
<td>Simultaneous heating/cooling</td>
<td>Simultaneous heating/cooling</td>
<td>Exhausted heat of cooling tower</td>
<td>Exhausted steam</td>
<td>Exhausted cooling water of cogeneration</td>
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<tr>
<td>Savings energy (%)</td>
<td>-</td>
<td>84</td>
<td>40</td>
<td>79</td>
<td>46</td>
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<tr>
<td>Savings CO₂ emissions (%)</td>
<td>87</td>
<td>80</td>
<td>43</td>
<td>79</td>
<td>40</td>
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<tr>
<td>Savings energy cost (%)</td>
<td>80</td>
<td>79</td>
<td>54</td>
<td>78</td>
<td>55</td>
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<tr>
<td>Evaluation</td>
<td>c, d, f, g</td>
<td>d, e, f, g</td>
<td>a, b, d, g</td>
<td>c, d, e, f, g</td>
<td>a, d, g</td>
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</table>

Source: NT Japan
Annex 48

**Best Practice 2 Outline**

<table>
<thead>
<tr>
<th>ID</th>
<th>#21</th>
<th>Annex 35</th>
<th>Installed Year 2010</th>
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<tbody>
<tr>
<td>Industry</td>
<td>Machinery (Automobile Parts Production)</td>
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<tr>
<td>Processes</td>
<td>Cutting, Washing</td>
<td></td>
<td></td>
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<tr>
<td>Application</td>
<td>Simultaneous Hot Water (65°C) and Cold Water (15°C) Supply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purposes</td>
<td>Reduction of Boiler Steam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td>Water-to-Water and Air-to-Water Heat Pumps (6+8=14 units) Refrigerant: R134a Heating Capacity: 22kW/unit (6 units), 43kW/unit (8 units)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effects</td>
<td>CO₂ Reduction: 80%, Energy Cost Reduction: 79% Payback Period: within 5 years (estimated)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)

**Best Practice 2 System**

**Before**

- Cutting Process
  - Cutting Liquid: 20°C
  - Chiller: 15°C
- Washing Process
  - Washing Liquid: 60°C
  - Boiler: 30°C
  - Steam: 30°C

**After**

- Cutting Process
  - Cutting Liquid: 20°C
- Washing Process
  - Washing Liquid: 60°C
  - Heat Pump: 65°C

- Simultaneous heating & cooling heat pump was installed for heating of washing liquid and cooling of cutting liquid.
- Heating COP: 3, Cooling COP: 2, Total COP: 5
- Installing heat pump near process can reduce heat loss from piping.

**Best Practice 2 Operation**

- **Simultaneous Heating & Cooling Operation Mode**
  - 10°C
  - 15°C
  - 60°C

- **Cooling Operation Mode**
  - 10°C
  - 15°C

- **Heating Operation Mode**
  - 50°C
  - 65°C

Switching operation modes can cope with unbalance between heating and cooling demands.
1.1. IEA HPT TP Annex 48: Heat Pump Application in commercial and industrial processes, Dr.-Ing. Rainer Jakobs (Information Centre on Heat Pumps and Refrigeration)

### Best Practice 1

**Outline**

<table>
<thead>
<tr>
<th>ID</th>
<th>#2</th>
<th>Annex</th>
<th>Installed Year</th>
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</thead>
<tbody>
<tr>
<td>Industry</td>
<td>Food (Freeze-Dried Foods Production)</td>
<td></td>
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<tr>
<td>Processes</td>
<td>Food Processing, Sterilization, Washing, Building Air-Conditioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>Simultaneous <em>Hot Water</em> (90°C) and <em>Cold Water</em> (10°C) Supply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purposes</td>
<td>Renewal of Facilities, Energy Saving, Energy Cost Reduction</td>
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<tr>
<td>System</td>
<td><em>Water-to-Water Heat Pumps</em> (3 units)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refrigerant: CO₂ (Trans-critical Cycle), Heating Capacity: 80kW/unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effects</td>
<td>CO₂ Reduction: 87%, Energy Cost Reduction: 80%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Payback Period: within 5 years (estimated)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Case studies**

- Freeze-Dried Foods (ex. Instant Soups)
- External Appearance of Installed Heat Pumps

---

**Best Practice 2**

**Effects**

- **CO₂ Emission**
  - 80% reduced
  - 1,094 tons/year reduced

- **Primary Energy Consumption**
  - 84% reduced
  - 437 kL/year reduction (Fuel oil equivalent)

- **Energy Cost**
  - 79% reduced
  - 26 million JPY/year

- **Payback Period**
  - 3.5 years
Applying Heat Pump Technology to Agricultural Production *

<table>
<thead>
<tr>
<th>Industry</th>
<th>Fruit Cultivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Green House Air-conditioning</td>
</tr>
<tr>
<td>Application</td>
<td>Space Heating in Winter and Space Cooling in Summer</td>
</tr>
<tr>
<td>Purpose</td>
<td>Reduction of Fuel Heavy Oil in Winter and Air-conditioning in Summer</td>
</tr>
<tr>
<td>System overview</td>
<td>Air-to-Air Inverter-controlled Greenhouse Heat Pumps using R410A (7 Units) with Heating Capacity 18 kW (20 °C) and Cooling Capacity 16 kW (27 °C). Twin Type 6 Sets and Single Type 1 Set</td>
</tr>
</tbody>
</table>
| Effect            | Primary energy consumption was reduced by 49%.

<table>
<thead>
<tr>
<th>Type</th>
<th>Twin</th>
<th>Single</th>
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</thead>
<tbody>
<tr>
<td>Number of Indoor Units</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Cooling (Standard) COP</td>
<td>5.48</td>
<td>3.86</td>
</tr>
<tr>
<td>Heating (Standard) COP</td>
<td>5.50</td>
<td>4.90</td>
</tr>
<tr>
<td>Heating (Cold climate) COP</td>
<td>3.77</td>
<td>3.20</td>
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</tbody>
</table>

Cross sectional view of a greenhouse

CO₂ Heat Pump Air Heater for Drying Process *

<table>
<thead>
<tr>
<th>Industry</th>
<th>Laminate Printing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Drying, Cooling</td>
</tr>
<tr>
<td>Application</td>
<td>Hot Air Supply to Drying Zone and Cool Water Supply to Cooling Roller</td>
</tr>
<tr>
<td>Purpose</td>
<td>Reduction of Steam (Fuel Gas)</td>
</tr>
<tr>
<td>System Overview</td>
<td>Water-source Heat Pump Using CO₂ Refrigerant (1 Unit) for Hot Air Supply with Heating Capacity 110 kW, Operating Range of Hot Air Leaving Temperature 80 to 120 °C and That of Heat Source Water Entering Temperature 5 to 32 °C, COP</td>
</tr>
</tbody>
</table>
| Effect            | Primary energy consumption was reduced by 46%.

Reciprocating-type compressor

Heating air: from 20 to 100 °C
Heating Capacity: 110 kW
Heating COP: 3.4

Cooling water: from 30 to 25 °C
Cooling Capacity: 81 kW, Cooling COP: 2.5
Total COP: 5.9

Case studies Choyu WATANABE et al.; IEA HPP Workshop, HPC2014 in Montreal, Canada
Summary

- Heat pumps can provide high temperatures up to 100 °C at large heating capacities (several MW).
- Industrial heat pump systems reach payback times between 2 and 7 years.
- Heat pumps become especially economical feasible, when both hot and cold side are used.
- Heat pumps are ready for the industry!

Barriers and threats:

- Insufficient knowledge about industrial processes among HVAC planners.
- Rising electricity prices (e.g. in Germany), while gas and oil prices remain stable or decrease.

Outlook

- Main Goal of the new HPT-Annex 48 is to overcome difficulties and barriers for the market introduction of industrial heat pumps.
- Collected cases studies of industrial branches with a large potential, should be analyzed.
- Development of a web based information platform for heat pumps in industrial and commercial application.
- Creating information material for IHP (training) courses.
- The IHP potential for more efficient use of energy and reduction of greenhouse gas emission should be prepared for policy makers.
Many thanks for your kind attention

Herzlichen Dank für Ihre freundliche Aufmerksamkeit
Presentation Outline

- Industrial Energy use in the Netherlands
- Requirement for active heat recovery technologies (heat pumps) in industrial processes
- Results of industrial heat pump market study
- Challenges in implementing heat pumps in practice
1.2 High temperature heat pumps in Dutch industry: Market potential and challenges in implementation, A. J. Marina (ECN)

Introduction

- Requirement for a transition to a sustainable energy system
  - Move away from our reliance on fossil fuels
- Sustainable energy system can be achieved through a combined approach:
  - Transition to renewable energy sources - Wind, solar, etc.
  - Reductions in final energy consumption (FEC) through energy efficiency measures

80% of the final industrial energy use is used for heating purposes.

![Industrial Energy Usage & Case for Heat Pumps](image-url)
1.2 High temperature heat pumps in Dutch industry: Market potential and challenges in implementation, A. J. Marina (ECN)

**Dutch Industry**

- **Final energy consumption**
  - 597 PJ

- **Energy use dominated by selected sectors**
  - Chemical and petrochemical
  - Iron and steel
  - Food and beverage

- **Refinery sector is the additional piece of the pie**
  - Similar processes to the chemical sector

- **Total combined energy consumption**
  - 744 PJ

**Transitioning to Sustainable Energy Sources**

**Current Industrial Energy Mix (Incl. Refinery)**

- Share of renewables in electricity system growing at greater rate than heating system
- Increasing shares of renewable electricity enable alternate heating technologies
Utilising Waste Heat in Industry

- Heat is the primary driver for a number of industrial processes
  - Low temperature after use in the process → heat is discarded to ambient
- Waste heat is an untapped energy source
  - Recovery can lead to large reductions in primary energy consumption

- Technologies for waste heat recovery – Active or Passive:
  - Passive: Heat is reused directly in the process
  - Active: Heat is converted to a higher temperature or another form of energy (electricity, cold)
- Limits to the amount of passive heat recovery
  - Industrial processes designed for passive reuse of waste heat
  - Elaborate heat exchanger networks
- Integration of active technologies is essential to fully exploit the potential for waste heat in industry

Heat Pumps in Industrial Processes

- Heat pump is an active technology able to upgrade the temperature of a waste heat source with electrical energy input
  - Performance limited by thermodynamic laws:
    \[
    \text{COP}_{\text{THEORETICAL}} = \frac{\frac{T_{\text{SINK}}(K)}{T_{\text{SINK}}(K) - T_{\text{SOURCE}}(K)} - \frac{\dot{Q}_{\text{SINK}}}{W_{\text{IN}}}}
    \]

- Growing drivers for the implementation for heat pumps
  - Take advantage of renewable electricity and waste heat
  - Electrical input a factor of 2 – 5 lower than process heat output
  - Falling CAPEX
  - Increases in technology development
  - Ability to operate a high temperatures
  - Low payback times
Heat Pump in Industrial Process

• Assumptions → 8000 hr/y, PEF 2.5
  – Reduction in FEC – 122 TJ
  – Reduction in PEC – 68 TJ
• Further assumptions → Steam price 20 €/tonne, Elec. price 50 €/MWhr
  – Reduction in OPEX costs – 0.7 M€/y

Process Heat Demand

Dutch Industry

• Heat pumps well suited to deliver process heat temperature below 200°C
  – Paper and pulp industry (25 PJ)
  – Food and beverage industry (83 PJ)
  – Chemical industry (282 PJ)
  – Refinery industry (147 PJ)
• Focus on these sectors within market studies
  – 72% of the industrial energy usage
  – Heat <200°C accounts for approximately 194 PJ
  – 36% of energy consumption in these sectors, 26% of total industrial consumption
Determining the Heat Pump Market
Methodology

- Bottom up approach for determining the heat pump market
- Focus on sectors which have high heating requirements at T < 200°C
- Collate generalized information from processes within these industries
  - Partial process heat and waste heat information
  - Temperature levels
  - Heat quantities
  - Media contained
  - Focus on heat streams suitable for heat pump utilization
  - Determine typical production rates and operating hours for processes
- Couple with production statistics from PRODCOM or industry bodies
- Verification utilizing top down approach
  - Energy usage statistics - EUROSTAT

Case Study – Heat Pump Assisted Distillation Column

- Production of Styrene through the dehydrogenation of ethylbenzene
  - Energy usage of approx. 11 PJ in NL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reboiler Temperature</td>
<td>102°C</td>
</tr>
<tr>
<td>Condenser Temperature</td>
<td>45°C</td>
</tr>
<tr>
<td>Pinch Temperature</td>
<td>90°C</td>
</tr>
<tr>
<td>Reboiler Duty</td>
<td>2.2 GJ/tonne</td>
</tr>
<tr>
<td>Condenser Duty</td>
<td>1.7 GJ/tonne</td>
</tr>
<tr>
<td>Typical Plant Capacity</td>
<td>200 kT/a</td>
</tr>
<tr>
<td>Columns in NL</td>
<td>5</td>
</tr>
</tbody>
</table>

- Calculation of the thermal performance through
  - Estimation based on Carnot limitations

\[
\text{COP}_{\text{THEORETICAL}} = 0.5 \frac{T_{\text{LINK}}(K)}{T_{\text{SOURCE}}(K)} - \frac{Q_{\text{LINK}}}{W_{\text{IN}}}
\]

<table>
<thead>
<tr>
<th>COP</th>
<th>Reduction in FEC (PJ)</th>
<th>Reduction in PEC (PJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>1.62</td>
<td>0.56</td>
</tr>
</tbody>
</table>

- Total in database - 57 distillation columns in chemical industry covering manufacture of 19 chemical products
Overview of the NL industrial heat pump market can be achieved through use waste heat and process heat signatures and quantities.

Key parameters:
- HP evaporator (source) temperature
- HP condenser (sink) temperature
- HP thermal output power

Key figures:
- Total cumulative potential: 2.4 GW
- Number of individual applications: 108
- Total possible heat pump installations: 340
- Average condenser power: 7.0 MW
- Reduction in FEC/PEC: 45 PJ / 15 PJ

Challenges in Implementation

Challenges in Implementation
Challenging Economics

- Low cost of energy as well as process utility equipment makes economics for heat pumps challenging
  - Cost target of <200 €/kWth for heat pumps to be competitive
- Previous example:
  - 5 MWth
  - Cost saving 0.7 M€/year
  - Payback time of 3 years → CAPEX = 210 €/kWth
- Differing temperature conditions and thermal powers lead to differing business cases
  - Average condenser power of 7 MW
  - Higher frequency of occurrences of lower power machines → More challenging economics
- What about integration costs?
  - Limited electrical infrastructure on-site
  - No standard method for integration

Other Challenges

- Perceived risks as emerging technology
- Coupling to existing heat integrated plants
- Conservative energy efficiency targets
  - Limited subsidies for energy efficiency compared to renewable energy
  - Focus on process equipment or process techniques
- Energy is not the core business
  - But... changing due to customer demands
- Competing technological options
  - Government intervention
Summary

- **Large industrial sector in the Netherlands**
  - Energy use dominated by chemical, iron and steel, food and beverage and refinery sectors

- **Growing driver for heat pumps in industry**
  - Take advantage of renewable electricity generation and waste heat from processes
  - Suitable for delivering process heat temperatures up to 200°C

- **Utilized a bottom up approach to determine the industrial heat pump market in NL**
  - Potential 2.4 GW installed capacity over 340 installations

- **Industrial heat pumps face a number of challenges preventing implementation**
  - High capital costs combined with low energy prices
  - Perceived technology risk and conservative energy efficiency targets

Contact

**Andrew Marina**
Thermal Systems Researcher
E: marina@ecn.nl
T: +31 88 515 4408

**ECN**
Westerduinweg 3, 1755 LE, Petten, 1755 ZG, Petten, The Netherlands

www.ecn.nl
1.3. Energy demand in the Norwegian industry and possibilities for high temperature heat pumps, Michael Bantle (SINTEF)
1. What is a high temperature for an industrial heat pump?

Non-representative questionnaires:

- Condensation at 80°C → TRL 8 – 9
- Condensation at 100°C → TRL 6 – 8
- Condensation at 120°C → TRL 6 – 7
- Condensation at 150°C → TRL 4 – 6

Conclusion (for today): heat sink temperature above 100°C can be considered as high temperature heat pumps (higher as industrial standard)

1. What is a high temperature for an industrial heat pump?

1. A HTHP also requires a relative high temperature heat source (< 100 °C)
   → valuable heat from downstream processes
2. A industrial HTHP is a system integration in one or more processes and creates dependencies
2. Energy Demand in Norway

Overall energy use and cost for Norwegian industry

Industry locations well distributed all over Norway
Industry often located in places without high external heat demand

Location and name of the largest energy-intensive industries in Norway per 2012

(Ref: Energiintensiv industri - En beskrivelse og økonomisk analyse av energiintensiv industri i Norge. NVE - Norges vassdrags- og energidirektorat; 2013)
1.3. Energy demand in the Norwegian industry and possibilities for high temperature heat pumps, Michael Bantle (SINTEF)
2. Energy Demand in Norway

The energy above 100°C is quite often supplied in the form of steam

Based on total energy use, not total heat demand
=> 10 000 GWh

2. Steam based energy demand in USA

International Workshop on High Temperature Heat Pumps
3. Excess heat inventory in Norway

- Reported energy use (TWh/year): 0.5
- Reported waste heat: 14.4%
- Waste heat as steam: 18%
- Waste heat as steam vs. energy use: 13/2.6%

Manufacture of food products, beverages

- Reported energy use (TWh/year): 11.2
- Reported waste heat: 44.2%
- Waste heat as steam: 4%
- Waste heat as steam vs. energy use: 198/1.8%

Wood, wood products and paper products

- Reported energy use (TWh/year): 1.9
- Reported waste heat: 45.4%
- Waste heat as steam: 0%
- Waste heat as steam vs. energy use: 0/0.0%

Cement and building block processing

- Reported energy use (TWh/year): 2
- Reported waste heat: 158.1%
- Waste heat as steam: 6%
- Waste heat as steam vs. energy use: 190/9.5%

Chemistry

- Reported energy use (TWh/year): 18.5
- Reported waste heat: 12.0%
- Waste heat as steam: 0%
- Waste heat as steam vs. energy use: 0/0.0%

Aluminium

- Reported energy use (TWh/year): 8.3
- Reported waste heat: 57.8%
- Waste heat as steam: 3%
- Waste heat as steam vs. energy use: 144/1.7%

Basic metals

- Reported energy use (TWh/year): 100
- Reported waste heat: 93.7%
- Waste heat as steam: 24.1%
- Waste heat as steam vs. energy use: 190/9.5%

Based on an average steam price of 0.29 NOK/kWh (SSB, 2008) and the total reported waste heat as steam (545 GWh in 2008)

- Reported waste heat as steam represents a loss of about 158 MNOK for the 72 participating Norwegian industries.
- 158 MNOK is ~10 % of the district heating sales incomes in Norway in 2008

Generally underestimated:
- Not all Norwegian Industry
- Steam waste heat may be condensed and not reported
4. Process most suited for HTHP
(Heat sink and source in the same process)

Chemical industry
- Distillation
- Compression
- Thickening

Food and Beverages
- Evaporation
- Cooking
- Pasteurisation
- Sterilisation
- Drying

Paper and Paper Products
- Bleaching
- Cooking
- Drying

Iron, Steel, Non-Ferrous / Fabricated metal
- Drying

4. Processes suited for HTHP

Assumptions
- Excess steam: 100°C and 1 bar
- Isentropic efficiency: 0.7
- Pressure ratio limitation: 2.5

Graphs showing COP and condensing temperature for 1, 2, and 3 steps.
5. Return of Investment

<table>
<thead>
<tr>
<th></th>
<th>Case 1 Germany</th>
<th>Case 1 Norway</th>
<th>Case 2 Germany</th>
<th>Case 2 Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Sink °C</td>
<td>150</td>
<td>150</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Heat Source °C</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Pressure Outlet</td>
<td>Bar A</td>
<td>5.0</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Steam Flow Rate</td>
<td>kg/h</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Electrical Power</td>
<td>kW</td>
<td>304</td>
<td>304</td>
<td>461</td>
</tr>
<tr>
<td>Heat Recovered</td>
<td>kWh</td>
<td>1,430</td>
<td>1,430</td>
<td>1,552</td>
</tr>
<tr>
<td>COP</td>
<td>W/W</td>
<td>4.70</td>
<td>4.70</td>
<td>3.36</td>
</tr>
<tr>
<td>ROI</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Case 1: MVR to 150°C
Case 2: MVR to 180°C

Based on:
- Electricity
  - Germany: 0.15€/kWh
  - Norway: 0.07€/kWh
- Gas
  - Germany: 0.04€/kWh
  - Norway: 0.06€/kWh

15.

5. Return of Investment

<table>
<thead>
<tr>
<th>High Temperature Heat Pump</th>
<th>Investment 120 000 €</th>
<th>Investment 1 200 000 €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>1300 kW</td>
<td></td>
</tr>
<tr>
<td>Steam flow</td>
<td>2000 kg / h</td>
<td></td>
</tr>
<tr>
<td>COP (W/W)</td>
<td>4.25</td>
<td></td>
</tr>
<tr>
<td>Net savings</td>
<td>8.48 GWh</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Germany</td>
<td>Norway</td>
</tr>
<tr>
<td>Net savings**</td>
<td>52 275 €</td>
<td>482 885 €</td>
</tr>
<tr>
<td>ROI</td>
<td>2.5 year</td>
<td>2.5 year</td>
</tr>
</tbody>
</table>

** Based on:
- Electricity 0.15€/kWh Germany, 0.07€/kWh Norway;
- Gas 0.04€/kWh Germany, 0.06 €/kWh Norway
Conclusion

1. High temperature heat pumps start at heat sink temperature of 100°C
   a. Technical limitations above 200°C
2. Food, Paper, Chemical and Metal industry have energy demands within this temperature limits
   a. Potential for Norway: estimated 10 TWh could be supplied by HTHP
   b. Reasonable to assume that 20% of this potential is feasible
3. Currently this energy is primarily supplied by steam (produced by fossil fuel)
   a. HTHP are benchmarked against fossil fuel prices
4. HTHP should supply heat sink in the form of steam
   a. Interesting technology for several industries which are using steam as energy carrier
5. Available excess heat is not completely monitored and "missing"
6. Identified some "ideal" processes for HTHP where heat sink and heat source are from one process
7. CAPEX and Return of investment give requirements for COP and costs:
   a. COP > 4 (→ challenging in many ways, depending on energy prices)
   b. Investment < 100-200 €/kWinstalled (at least have the potential at TRL 8-9)

Thank you for your attention
1.3. Energy demand in the Norwegian industry and possibilities for high temperature heat pumps, Michael Bantle (SINTEF)
Industrial energy demand and excess heat in Denmark

Fabian Bühler, Benjamin Zühlsdorf and Brian Elmegaard

International Workshop on High Temperature Heat Pumps
September 2017 in Copenhagen, Denmark

Introduction

Motivation
Process heat requirements in the industry and availability of excess heat for the internal and external recovery (using heat pumps).

Approach
• Energy use in Denmark
• Energy saving obligations in Denmark
• Process heat demand in the manufacturing industry
• Profile and availability of industrial excess heat
• Some conclusions for (high temperature) heat pumps
1.4. Energy demand and excess heat of industrial processes in Denmark, Fabian Bühler (DTU)

**Energy use in the Denmark**

- **Trade and transport etc.:** 30.39%
- **Households, Services and Public:** 21.05%
- **Utility services:** 30.30%
- **Construction:** 1.28%
- **Mining and quarrying:** 1.61%
- **Agriculture, forestry and fishing:** 2.34%

**Energy Savings in Denmark**

Since 2006: Network and distribution companies have obligation to realize energy saving projects at end users

Last agreement: 10.1 PJ/year in the period 2016-2020

Since 2017: Heat pumps for district heating included

In 2015: 43% of the savings obtained in manufacturing industry
1.4. Energy demand and excess heat of industrial processes in Denmark, Fabian Bühler (DTU)

### Energy and exergy analysis

Exergy flows [TJ] for thermal process heating in the Danish industry

- **Facility (Thermal & Electric)**
- **Industrial Processes (Thermal & Machines)**
- **Utility System**
- **Fuel**
- **Heat**
- **Electricity**
- **Product**

### Energy Losses

- **System Efficiency**
- **Site Efficiency**
- **Exergy Losses**

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### Heating demand in Denmark

- **Total energy use 108.7 PJ/year**
- **District Heating Demand of 96 PJ/year**
  - 2.6 PJ covered by excess heat
  - > 4.9 PJ coverable by industrial excess heat

---

Heating demand [PJ/year] for various industries in Denmark.
1.4. Energy demand and excess heat of industrial processes in Denmark, Fabian Bührer (DTU)

**Industrial excess heat in Denmark**

- Total of 212 PJ of excess heat per year
- 23% of excess heat from industry and 28% from utility
- Total excess heat in manufacturing industry 22.6 PJ/year

**Evaluation of utilization pathways**

- Drying, Evaporation and refrigeration main excess heat sources
- Highest temperatures from furnaces, boilers and melting operation

Process and excess heat in Denmark

- Process Heat [TJ year⁻¹]
- Excess Heat [TJ year⁻¹]

<table>
<thead>
<tr>
<th>Temperature Range [°C]</th>
<th>Food &amp; Drink</th>
<th>Pulp &amp; Paper</th>
<th>Chemical</th>
<th>Building</th>
<th>Metal</th>
<th>Electrical</th>
<th>Machines</th>
<th>Petrochemical</th>
<th>Other</th>
<th>WWT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-20</td>
<td>20-30</td>
<td>30-40</td>
<td>40-50</td>
<td>60-70</td>
<td>80-90</td>
<td>100-110</td>
<td>120-130</td>
<td>140-150</td>
<td>160-170</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>2500</td>
<td>5000</td>
<td>7500</td>
<td>10000</td>
<td></td>
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</tbody>
</table>

1.4. Energy demand and excess heat of industrial processes in Denmark, Fabian Bühler (DTU)
1.4. Energy demand and excess heat of industrial processes in Denmark, Fabian Bühler (DTU)

Identifying heating symbiosis

- Excess heat potential from
  - Industry (2500)
  - Power plants (1200)
  - Waste water treatment (100)
- Heating demand in District heating areas (222) and industry
High Temperature Heat Pumps

Internal vs. external utilization
- Potential to use excess heat in district heating
- Internal recovery potential in industries requires more detailed site-specific process knowledge

Demand and Excess heat mapping
- Potential for heat pumps in district heating
- Temperature profiles of heating demand and excess heat indicate potential for HTHP
- Excess heat size on site level suggests large potential in HP 10-50 kW

More research on potentials required
- Which part of heating demand is covered by steam/water/direct heat?
- Recovery potential in the different processes itself?

Thank you for your attention!

Fabian Bühler
PhD Student
DTU Mechanical Engineering

Email fabuhl@mek.dtu.dk
Phone +45 22471020
2 Research and Development Projects

2.1 Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

2.2 High temperature heat pump development at AIT, Michael Lauermann (AIT)

2.3 Generic fist assessment tool and high temperature heat pump development at DTI, Lars Reinholdt (DTI)

2.4 Development of a Propane-Butane cascade high temperature heat pump, Opeyemi Bamigbetan (NTNU)

2.5 Working fluids for high temperature heat pumps, Benjamin Zühlsdorf (DTU)
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

Outline

1. Market overview of commercially available industrial HTHP systems
   - Cycles, refrigerants, application limits, efficiencies
2. Research status
   - Screening of research activity
   - Experimental and theoretical studies, cycles, refrigerants, supply temperatures, operating ranges
3. Refrigerants
   - Selection criteria, properties, GWP, price, efficiency, safety
4. Conclusions
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

Classification of heat pumps (focus on compression heat pumps)
Development of temperature levels

adapted from Nellissen and Wolf (2015)

Potential for high temperature heat pumps – Process heat in industry

Theoretical potential for HTHPs in Switzerland

Technical potential of process heat in Europe accessible with industrial heat pumps

Data from BFE (2016), Pulfer and Spirig (2015)

Based on Eurostat data from 2012 of 33 countries, Nellissen and Wolf (2015)
2.1. Review on high temperature heat pumps - Market overview and research status, Cordin Arpagaus (NTB Buch)

Overview of processes in different industrial sectors
Temperature levels and technology readiness level

<table>
<thead>
<tr>
<th>Sector</th>
<th>Process</th>
<th>Technology levels</th>
<th>Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>Drying</td>
<td>90-240</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bleaching</td>
<td>40-140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>De-inking</td>
<td>20-70</td>
<td></td>
</tr>
<tr>
<td>Food &amp; beverages</td>
<td>Drying</td>
<td>40-200</td>
<td></td>
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<tr>
<td></td>
<td>Conveying</td>
<td>40-120</td>
<td></td>
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<tr>
<td></td>
<td>Pasteurization</td>
<td>60-120</td>
<td>50-130</td>
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<tr>
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<td>Sterilization</td>
<td>120-140</td>
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<td>Cooking</td>
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<td>Heating</td>
<td>40-100</td>
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<td>Blending</td>
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<td>Concentration</td>
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<tr>
<td></td>
<td>De-inking</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drying</td>
<td>80-120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blending</td>
<td>50-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sealing</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filling</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emulsifying</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filtrating</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling</td>
<td>20-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>20-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blending</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>De-inking</td>
<td>30-90</td>
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</tr>
<tr>
<td></td>
<td>Drying</td>
<td>30-90</td>
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</tr>
<tr>
<td></td>
<td>De-inking</td>
<td>30-90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drying</td>
<td>30-90</td>
<td></td>
</tr>
</tbody>
</table>


Selection of industrial HTHPs with supply temperatures > 90°C

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Refrigerant</th>
<th>Max. supply temperature</th>
<th>Heating capacity</th>
<th>Compressor type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobelco</td>
<td>SGH 185</td>
<td>R134a/R225fla</td>
<td>160°C</td>
<td>70 – 660 kW</td>
<td>Double screw</td>
</tr>
<tr>
<td></td>
<td>SGH 120</td>
<td>R245fa</td>
<td>120°C</td>
<td>70 – 370 kW</td>
<td>Double screw</td>
</tr>
<tr>
<td></td>
<td>HEM-HR90, HEM-90A</td>
<td>R134a/R225fla</td>
<td>100°C</td>
<td>70 – 230 kW</td>
<td>Double screw</td>
</tr>
<tr>
<td>Vicking Heating Engines AS</td>
<td>HeatBooster</td>
<td>R1336mz(T)</td>
<td>150°C</td>
<td>28 – 188 kW</td>
<td>Piston</td>
</tr>
<tr>
<td>Ochsner</td>
<td>IWDDS</td>
<td>R134a/OK01</td>
<td>130°C</td>
<td>170 – 750 kW</td>
<td>Screw</td>
</tr>
<tr>
<td></td>
<td>IWDS 330 ER3</td>
<td>R245fa</td>
<td>105°C</td>
<td>100 – 125 kW</td>
<td>Screw</td>
</tr>
<tr>
<td></td>
<td>IWHS ER3</td>
<td>R245fa</td>
<td>95°C</td>
<td>100 – 10 kW</td>
<td>Screw</td>
</tr>
<tr>
<td>Hybrid Energy</td>
<td>Hybrid Heat Pump</td>
<td>R717</td>
<td>120°C</td>
<td>25 – 25.5 kW</td>
<td>Piston</td>
</tr>
<tr>
<td>Mayekawa</td>
<td>Eco-Scover</td>
<td>R744(CO2)</td>
<td>120°C</td>
<td>55 – 60 kW</td>
<td>Piston</td>
</tr>
<tr>
<td></td>
<td>Eco-Cute Unico</td>
<td>R744(CO2)</td>
<td>90°C</td>
<td>45 – 110 kW</td>
<td>Screw</td>
</tr>
<tr>
<td>Dürtherma</td>
<td>thermoco2</td>
<td>R744(CO2)</td>
<td>110°C</td>
<td>45 – 220 kW</td>
<td>Piston</td>
</tr>
<tr>
<td>Combitherm</td>
<td>Sonderanforderung</td>
<td>R245fa</td>
<td>100°C</td>
<td>20 – 300 kW</td>
<td>Piston</td>
</tr>
<tr>
<td>Fritscher</td>
<td>Unitop 20</td>
<td>R134a</td>
<td>50°C</td>
<td>2 – 8 kW</td>
<td>Turbo (2-stage)</td>
</tr>
<tr>
<td>Star Refrigeration</td>
<td>Neopump</td>
<td>R134a</td>
<td>90°C</td>
<td>326 – 1434 kW</td>
<td>Piston</td>
</tr>
<tr>
<td>GEA Refrigeration</td>
<td>GEA Grasso FX P 63 bar</td>
<td>RT17</td>
<td>90°C</td>
<td>326 – 1434 kW</td>
<td>Double screw</td>
</tr>
<tr>
<td>Johnson Controls</td>
<td>HeatPAC HPX</td>
<td>RT17</td>
<td>90°C</td>
<td>230 – 1315 kW</td>
<td>Piston</td>
</tr>
<tr>
<td></td>
<td>HeatPAC Screw</td>
<td>RT17</td>
<td>90°C</td>
<td>230 – 1315 kW</td>
<td>Screw</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>ETV-L</td>
<td>R134a</td>
<td>90°C</td>
<td>340 – 600 kW</td>
<td>Turbo (2-stage)</td>
</tr>
<tr>
<td>Viessmann</td>
<td>Vitocal 350-HT Pro</td>
<td>R134a</td>
<td>90°C</td>
<td>148 – 223 kW</td>
<td>Piston (2-3 stages)</td>
</tr>
</tbody>
</table>
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)
### 2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

#### Commercial HTHPs – cycles, COPs and pictures

<table>
<thead>
<tr>
<th>Model</th>
<th>COP (Min)</th>
<th>COP (Max)</th>
<th>COP (Average)</th>
<th>COP (Std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial HTHPs</td>
<td></td>
<td></td>
<td>3.9 ± 0.8</td>
<td></td>
</tr>
<tr>
<td>Stirling Refrigeration</td>
<td></td>
<td></td>
<td>3.4 ± 4</td>
<td></td>
</tr>
<tr>
<td>Star Refrigeration</td>
<td></td>
<td></td>
<td>3.6 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>Gaia Gigant FX P Heat Pump</td>
<td></td>
<td></td>
<td>3.7 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>Johnson Controls SABROE</td>
<td></td>
<td></td>
<td>3.8 ± 1</td>
<td></td>
</tr>
<tr>
<td>Mitsubishi ETH-L Heat Pump</td>
<td></td>
<td></td>
<td>3.9 ± 1.5</td>
<td></td>
</tr>
</tbody>
</table>

#### Research status on HTHPs – Publications, projects, cycles, operating ranges

**Publications**

- Which laboratory setups already exist?

**Research projects**

- COP vs. supply temperature

**Cycles**

- COP vs. temperature lift for various commercial HTWPs

Average values:

- \( \text{COP} = 3.9 ± 0.8 \)
- \( \Delta T_{\text{lift}} = 57 ± 15 \text{ K} \)
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpaga (NTB Buch)

Research activity on HTHPs –
Number of publications

![Graph showing number of publications with search key word «high temperature heat pump» in databases SCOPUS (www.scopus.com) and Web of Science (www.webofknowledge.com)]

Experimental research projects on HTHPs

<table>
<thead>
<tr>
<th>Organisation, Project partners</th>
<th>Cycle</th>
<th>Compressor type</th>
<th>Refrigerant</th>
<th>Source and supply temperatures [°C]</th>
<th>Heating capacity [kW]</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austrian Institute of Technology (ATI), WIEN, CHEMnns, Bitter</td>
<td>1-stage</td>
<td>piston</td>
<td>R134a</td>
<td>20-60</td>
<td>10</td>
<td>(Heininger et al., 2016)</td>
</tr>
<tr>
<td>Austrian Institute of Technology (ATI), WIEN, CHEMnns, Bitter</td>
<td>1-stage</td>
<td>piston</td>
<td>R134a</td>
<td>20-60</td>
<td>10</td>
<td>(Faccio et al., 2015a, 2015b)</td>
</tr>
<tr>
<td>PACO, University Lyon, EDF ELECTRICITE DE FRANCE</td>
<td>flash tank</td>
<td>double screw</td>
<td>R245Ca, R410a</td>
<td>300</td>
<td>10</td>
<td>(Chamoun et al., 2014, 2013, 2012a, 2012b)</td>
</tr>
<tr>
<td>Institut für Luft-und Kältetechnik (LkK), Dresden</td>
<td>1-stage</td>
<td>n.a.</td>
<td>HT125</td>
<td>12</td>
<td>10</td>
<td>(Noack, 2015)</td>
</tr>
<tr>
<td>Friedrich-Alexander Universität Erlangen-Nürnberg, Siemens</td>
<td>1-stage</td>
<td>piston</td>
<td>R134a</td>
<td>12</td>
<td>10</td>
<td>(Reiser, 2013, Reiser et al., 2013a, 2013b)</td>
</tr>
<tr>
<td>Alstom ECO</td>
<td>1-stage</td>
<td>sodium</td>
<td>NaK</td>
<td>50-200</td>
<td>150-400</td>
<td>(Yamaoka and Kubo, 1985)</td>
</tr>
<tr>
<td>Tokyo Electric Power Company, Japan</td>
<td>1-stage</td>
<td>screw</td>
<td>R601</td>
<td>150-400</td>
<td></td>
<td>(Bohn et al., 2012, IEA, 2014)</td>
</tr>
<tr>
<td>Austrian Institute of Technology (ATI), WIEN, Echtl, October</td>
<td>1-stage</td>
<td>screw</td>
<td>R245Ca, R410a</td>
<td>250-400</td>
<td>1.8</td>
<td>(Fukuda et al., 2014)</td>
</tr>
<tr>
<td>Kyushu University, Fukuoka, Japan</td>
<td>1-stage</td>
<td>double screw (2-stage)</td>
<td>R1234zei</td>
<td>300-500</td>
<td>900-1200</td>
<td>(IEA, 2014)</td>
</tr>
<tr>
<td>Johnson Controls, EDF Electricité de France</td>
<td>1-stage</td>
<td>double screw centrifugal</td>
<td>R245Ca, R410a</td>
<td></td>
<td></td>
<td>(IEA, 2014)</td>
</tr>
</tbody>
</table>
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

Achieved COPs of experimental research projects vs. supply temperature at constant temperature lifts ($\Delta T_{lift}$) 

Refrigerants for HTHPs

Selection criteria

- Which refrigerants are suitable for HTHPs?
- Price
- Efficiency
- Refrigerant properties
- Safety

Critical temperature vs. GWP

Efficiency

Safety
Refrigerants – selection criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Required properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal suitability</td>
<td>High critical temperature, low critical pressure</td>
</tr>
<tr>
<td>Environmental</td>
<td>ODP = 0, low GWP, short atmospheric life</td>
</tr>
<tr>
<td>Safety</td>
<td>Non-toxic, non-combustible (safety group A1)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>High COP, low pressure ratio, minimal overheat to prevent fluid compression, high volumetric capacity</td>
</tr>
<tr>
<td>Availability</td>
<td>Available on the market, low price</td>
</tr>
<tr>
<td>Other factors</td>
<td>Good solubility in oil, thermal stability of the refrigerant-oil mixture, lubricating properties at high temperatures, material compatibility with steel and copper</td>
</tr>
</tbody>
</table>

Critical temperature vs. GWP

- GWP < 50
- 50 < GWP < 1'000
- GWP > 1'000

Critical temperature [°C] vs. GWP [100]
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

Theoretical studies – Efficiency range for 1-stage cycles with different refrigerants

- $\Delta T_{\text{lift}}$: temperature lift
- $\Delta T_{\text{sh}}$: superheating
- $\Delta T_{\text{sc}}$: subcooling
- $\eta_{\text{comp}}$: isentropic compressor efficiency

<table>
<thead>
<tr>
<th>Reference</th>
<th>$\Delta T_{\text{lift}}$</th>
<th>$\Delta T_{\text{sh}}$</th>
<th>$\Delta T_{\text{sc}}$</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fukuda et al. (2014)</td>
<td>3</td>
<td>20</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>Krontmagnis (2014)</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>40</td>
</tr>
<tr>
<td>EIA (2014), Krontmagnis (2018, 2019)</td>
<td>10</td>
<td>5</td>
<td>75</td>
<td>45</td>
</tr>
<tr>
<td>Ductus et al. (2014)</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>50</td>
</tr>
<tr>
<td>Reiliger (2015)</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>50</td>
</tr>
<tr>
<td>Reiliger et al. (2017)</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>50</td>
</tr>
<tr>
<td>EIA (2014), Krontmagnis (2018, 2019)</td>
<td>20</td>
<td>5</td>
<td>9</td>
<td>70</td>
</tr>
<tr>
<td>Krontmagnis and Koyama (2018)</td>
<td>5</td>
<td>60</td>
<td>1</td>
<td>60</td>
</tr>
</tbody>
</table>

Possible concept for a HTHP laboratory prototype

**HFO refrigerants**

- R1336mzz(Z)
- R1233zd(E)
- R1234ze(Z)
- R1234ze(E)
- R1234yf

**Cycle**

- 1-stage with IHX

- 80-150°C
- 30-90°C

**Decision criteria:**

1. Thermodynamic suitability ($T_{\text{crit}} > 150°C$, allows subcritical, good efficiency at high temperatures)
2. Environmental compatibility (GWP <10, ODP = 0, future-proof according to F-Gas regulation)
3. Safety (no or only low flammability)
4. Natural refrigerants R600 and R600a excluded due to flammability (A3), other refrigerants due to lack of information and availability
Conclusions – Market overview

- **More than 20 HTHP models** identified with supply temperatures > 90°C from 13 manufacturers (e.g. Vicking HeatBooster with 150°C, Ochsner IWWDS with 130°C, Kobelco SGH120, Mayekawa Eco Sirocco, and Hybrid Energy Heat Pump with 120°C)
- **Heat source**: water, brine, waste heat (17 to 65°C)
- **COP**: 2.4 to 5.8 at a temperature lift of 40 to 95 K
- **Heating capacity**: from about 20 kW to 20 MW
- **Refrigerants**: R245fa, R717 (NH3), R744 (CO2), R134a, R1234ze(E)
- **Compressors**: 1- and 2-shaft screws, 2-stage turbo, pistons (parallel)
- **Cycles**: usually 1-stage, optimization by IHX, parallel compressors, economizer, intermediate injection, 2-stage cascade (R134a/R245fa) or with a flash economizer

Conclusions – Research status

- **Highest supply temperature of 160°C** at AIT (Vienna), 1-stage cycle with IHX and R1336mzz(Z)
- **At least 10 research projects** reached > 100°C
- **Heating capacity**: lab scale 12 kW, larger prototypes >100 kW
- **COPs** (at 120°C supply temperature): 5.7 to 6.5 (30 K temperature lift), 2.2 to 2.8 (70 K)
- **Cycles all 1-stage**: partly with IHX and/or economizer with intermediate injection
- **Refrigerants**: R1336mzz(Z), R718 (H2O), R245fa, R1234ze (Z), R601, LG6 (Siemens), ÖKO1 (contains R245fa, Ochsner), ECO3 (R245fa, Alter ECO), HT125 (ILK, Dresden)
- **Compressors**: piston in lab systems
- **HFO refrigerants**: thermodynamic suitable, good efficiency, GWP <10, ODP = 0, safe, future-proof according to F-Gas regulation
2.1. Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)
Barriers to the wider spread of industrial HTHPs

- **Low level of awareness** about the technical possibilities and application potentials among main actors
- **Lack of knowledge** about the integration into processes
- **Requirements of low payback times** (< 3 years)
- **Competing technologies** generating high temperatures using fossil fuels at low energy prices
- **Lack of available refrigerants** in the high temperature range with low GWP
- **Lack of pilot and demonstration systems**

HIGH TEMPERATURE HEAT PUMP DEVELOPMENT
at Austrian Institute of Technology GmbH

MICHAEL LAUERMANN
Research Engineer
Energy Department
Sustainable Thermal Energy Systems

Giefinggasse 2 | 1210 Vienna | Austria
T +43 50550-6414 | M +43 664 88390714 | F +43 50550-6679
michael.lauermann@ait.ac.at | http://www.ait.ac.at

AIT RESEARCH AREAS

Energy
• Sustainable Thermal Energy Systems
• Electric Energy Systems
• Sustainable Buildings and Glass
• Photovoltaic Systems
• Environmental Resources & Technologies

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• Bioresources
• Molecular Diagnostics
• Biomedical Systems
• Digital Health Information Systems

Digital Safety & Security
• Security & Communication Technologies
• Visual Surveillance and Insight
• Smart Sensor Solutions
• Dependable Systems Engineering
• Information Management

Vision, Automation & Control
• High-Performance Image Processing
• Autonomous Systems
• Complex Dynamical Systems

Mobility Systems
• Transportation Infrastructure Technologies
• Dynamic Transportation Systems

Low-Emission Transport
• Electric Drive Technologies
• Light Metals Technologies Ranshofen

Technology Experience
• Capturing / Measuring Experience
• Future Interface Paradigms
• Experience Orientated Thinking

Innovation Systems & Policy
• Digital Innovation
• Foresight & Institutional Change
• Policies for Change
MARKET TRENDS AND DEVELOPMENT NEEDS

- General Framework
  - Energy efficiency directive
  - Load flexibilisation
  - Reduction of energy requirements and CO₂ emissions
  - F-Gas regulation

- Industrial heat pump as market chance for Europe
  - 45% of industrial heat demand lower than 150°C
  - Relevant sectors: Food, Chemical, Pulp & Paper, Non metal mineral, Metals
  - Relevant processes: Pre-heating, Drying, Distillation, Evaporation, Cooking, Sterilisation, etc.
2.2 High temperature heat pump development at AIT, Michael Lauermann (AIT)
2.2. High temperature heat pump development at AIT, Michael Lauermann (AIT)
2.2 High temperature heat pump development at AIT, Michael Lauermann (AIT)
HIGHBUTANE
Concept of a new butane high temperature heat pump

Motivation
- Industrial heating processes account for 25 % of Austria’s final energy demand. An industrial heat pump lifting waste heat beyond 100 °C is needed to realize more efficient processes, thus reduce energy demand and CO2 emissions.

Aim
- Butane shall be used in a single-stage heat pump process to lift industrial waste heat from 60 °C to 130 °C. Heat exchangers will be evaluated with respect to the charge and system configurations of use cases will be developed and experimentally validated.

Highlights
- Identifying suitable processes
- Validated Dymola model
- Ejector utilisation
- CFD-heat & mass transfer
- Experimental

Results
- Performance increase with Ejector
- CFD model is being validated
- Potential cost saving of 300.000 EUR per year

2.2. High temperature heat pump development at AIT, Michael Lauermann (AIT)
Motivation
- Industrial heating consumes a significant fraction of the energy consumed globally. Heating at temperatures higher than about 100 °C is predominantly provided through combustion of fossil fuels with uncertain prices and well recognized environmental impacts. A significant fraction of industrial input energy is lost as low temperature waste heat that could be lifted by high temperature heat pumps to process relevant temperatures.

Aim
- Validation of a novel high temperature refrigerant (DR-2) in process heat pumps with condensation temperatures up to 160 °C.

Highlights
- Novel high temperature refrigerant (DR-2)
- Lab scale heat pump
- Experimental analysis with condensation temperatures up to 155 °C
- Energetic and economic evaluation

Results
- Short term operation of a lab scale machine with a heating capacity of around 12kW.
- Experimental investigation of the coefficient of performance (COP) at different temperature levels.
- Economic evaluation including the CO2 savings potential for selected industrial applications.
DRYPUMP
Efficient drying with heat pumps

Aim
- To solve substantial industrial research issues in the context of using compression heat pumps for industrial drying
- To achieve energy savings up to 80 %, CO₂ emission savings up to 68 % and primary energy savings up to 65 % in the medium term

Highlights
- Large industrial applications
- Useful temperature up to 170 °C
- Heating capacity up to 350 kW
- Energy savings up to 80 %

Results
- Development of technical viable concepts
- Experimental proof of concept of three heat pump installations
- Optimized discontinuous drying process

Efficient drying with heat pumps

11.09.2017
2.2 High temperature heat pump development at AIT, Michael Lauermann (AIT)

DRYFICIENCY
Efficient drying with heat pumps on industrial scale

- Overall objective: to lead energy-intensive sectors of the European manufacturing industry to high energy efficiency and a reduction of fossil carbon emissions by means of waste heat recovery
- Aim: consortium will elaborate technically and economically viable heat pump solutions for upgrading idle waste heat streams to process heat streams at higher temperature levels up to 180 °C and will demonstrate them in three industrial drying processes (brick, pet care/feed and food industry)
- Consortium:
  - RTOs: AIT (Michael Hartl); Lead, SINTEF
  - Technology providers and integrators: Rotrex, Bitzer Kühlmaschinenbau, Chemours Fluorchemicals, Fuchs Europe Schmierstoffe, EPCON
  - Demonstration partners: Wienerberger, Agrana, Mars Petcare
  - Dissemination exploitation partners: RTDS, EHPA
- Project volume: € 6,5 Mio. (EC Funding: € 5 Mio.)

SUMMARY

- Heat Pumps are a mature technology. Carefully integrated, they are highly reliable and lifetime up to 40 years is proven.
- Heat Pumps for Industrial applications are still widely unknown
- AIT works together with technology providers to bring high temperature heat pumps to the industry.
- DRYficiency will demonstrate high temperature heat pump solutions for drying processes.
2.2. High temperature heat pump development at AIT, Michael Lauermann (AIT)
Generic first assessment tool

Motivation

Postulate: Heat pumps are just “nice to have”
- The only purpose is heat supply in a more appropriate way (like cost (incl. taxes), CO₂ footprint, CSR, …)
- They do not solve technical problems
  It is “all” about COP...
  (….and first cost, maintenance…)

- Many heat pump solutions exist
- A way to first assessment is needed...???
2.3.2. Generic fist assessment tool and high temperature heat pump development at DTI, Lars Reinholdt (DTI)

Heat pump COP and system design calculations

Theoretical limit: Carnot cycle \[ \text{COP}_{\text{HP,Car}} = \frac{T_H}{T_H - T_L} \] (T in K)

Constant temperature source and sink: 15/90°C > COP\(_C\) = 4.84

Higher COP by splitting up

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Higher COP by splitting up

<table>
<thead>
<tr>
<th>Process</th>
<th>$T_L$ [°C]</th>
<th>$T_H$ [°C]</th>
<th>COP$_{HP, Cu}$ [-]</th>
<th>$Q_H$ [kW]</th>
<th>$P$ [kW]</th>
</tr>
</thead>
<tbody>
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<td><strong>Total</strong></td>
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<td></td>
<td><strong>6,62</strong></td>
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</table>

COP = 6,62 (+37%)

Lorenz COP

$$COP_{HP, Lor} = \frac{T_{lm,H}}{T_{lm,H} - T_{lm,L}}$$

(+ 51%)

<table>
<thead>
<tr>
<th>No.</th>
<th>Heat source (°C)</th>
<th>Heat sink (°C)</th>
<th>COP$_C$</th>
<th>COP$_L$</th>
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<tr>
<td>Ex.</td>
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<tr>
<td>A</td>
<td>40 &gt; 15</td>
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<td>B</td>
<td>40 &gt; 15</td>
<td>60 &gt; 95</td>
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<td>7,3</td>
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<tr>
<td>C</td>
<td>25 &gt; 20</td>
<td>70 &gt; 110</td>
<td>4,3</td>
<td>5,4</td>
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<tr>
<td>D</td>
<td>80 &gt; 20</td>
<td>85 &gt; 90</td>
<td>5,2</td>
<td>9,4</td>
</tr>
</tbody>
</table>

Theoretical maximum COP

![Graph showing COP vs. Source outlet temperature](image)
(First) system design calculation

Theoretical COP can be used for first assessment analysis of system design without knowing the heat pump technology.

Carnot and Lorenz efficiency:
- How good a real heat pump system is compared to theoretical maximum

\[
\eta_{Car} = \frac{COP_{HP}}{COP_{HP,Car}} \quad \eta_{Lor} = \frac{COP_{HP}}{COP_{HP,Lor}}
\]

(First) system design calculation

- In the best industrial refrigeration systems 60% of COP$_C$ have been realized, so high COP can also be expected by heat pumps...

\[
COP_{HP} = COP_{HP,Lor} \eta_{Lor} \quad > \quad COP_{HP,Lor} = \frac{COP_{HP}}{\eta_{Lor}}
\]

Example:
- System requirement to the heat supply: 150°C
- Based on the precalculations (energy cost etc.) COP = 3.0 is needed.
- Using $\eta_{Lor} = 60\%$ > $COP_{HP,Lor} = \frac{3.0}{0.6} = 5$
Fundamental process analysis

Case:
- Sink: Heating from 35 to 80°C
- Source: Cooling from 25 to 15°C

- COP_C = 5.4, COP_L = 8.9

Pinch temperature 1K
- COP_C = 5.3 > -2.7%
- COP_L = 8.5 > -4.8%
Industrial heat pump development at DTI

- Flexible Energy Optimized Split Condenser Ammonia Heat Pump - Foscap
- Mixed Refrigerant Heat Pump - MiReHP
- Ultra-high temperature hybrid heat pump for process application - HighHeat
- Development of Rotrex turbocompressor for steam compression
- Experimental Development of Electric Heat Pumps in Greater Copenhagen District Heating System – SVAF 2
- Direct contact heat exchangers (water vapor, heat uptake at freezing)
- Projects on COP optimization of heat pump cycles
- Heat pumps and storage (hot and/or cold)

Development of ultra-high temperature hybrid heat pump for process application - HighHeat

Objective

- to increase the operating limits of the hybrid process by using the new standard components for higher pressures.
- demonstrate that it is possible to develop an efficient and reliable heat pump process for high temperatures up to 180-250°C.
- Investigation of possible implementation into the processes at the end users in the consortium and the conduction of a general market survey.
- Demonstration at an end user in the consortium.

Funded by the Danish EUDP program no. 64011-0351. Ends Dec 2018.
2.3. Generic first assessment tool and high temperature heat pump development at DTI, Lars Reinholdt (DTI)
2.3. Generic fist assessment tool and high temperature heat pump development at DTI,
Lars Reinholdt (DTI)
800kW three-stage system in sewage treatment plant

\[ T_{L,i} = 22.5^\circ C, \ T_{L,o} = 19.4^\circ C, \ T_{H,i} = 79.1^\circ C, \ T_{H,o} = 108.4^\circ C, \]
\[ Q_H = 540 \ kW, \ P_{tot} = 198 \ kW. \]
\[ \text{COP}_{HP} = 2.72, \ \eta_{Car} = 63\%, \ \eta_{Lor} = 54\% \]

Summing up

- It is suggested to use COP\textsubscript{Lor} for comparing actual heat pump performance ($\eta_{Lor}$)
- It is suggested to use COP\textsubscript{Lor} and $\eta_{Lor}$ as base for system analysis including economics

Question:
- Is (first assessment) tools needed?
2.3. Generic fist assessment tool and high temperature heat pump development at DTI, Lars Reinholdt (DTI)

Thank you

Lars Reinholdt
Danish Technological Institute
lre@teknologisk.dk
Phone: +45 7220 1270
Development of Propane-Butane cascade high temperature heat pump
Early test rig results

Opeyemi Bamigbetan
Trygve M. Eikevik
Petter Nekså
Michael Bantle

Research motivation

- Industrial processes with heat demand between 110 – 150 °C
  - Process water, Pasteurization, Sterilization, Cleaning, Drying, Distillation

- Industrial processes with excess heat between 30 – 100 °C
  - Eg. Heat at condensers of ammonia refrigeration unit
Research motivation, current solution

- Industrial processes with excess heat between 30 – 100 °C
  - E.g. Heat from condensers of ammonia refrigeration unit

- Industrial processes with heat demand between 100 – 150 °C
  - Process water, Pasteurization, Sterilization, Cleaning, Drying, Distillation

- Boilers

- Cooling towers, Dry coolers

Research motivation, HTHP

- Industrial processes with heat demand between 100 – 150 °C
  - Process water, Pasteurization, Sterilization, Cleaning, Drying, Distillation

- Industrial processes with excess heat between 30 – 100 °C
  - E.g. Heat from condensers of ammonia refrigeration unit
2.4. Development of a Propane-Butane cascade high temperature heat pump, Opeyemi Bamigbetan (NTNU)
2.4. Development of a Propane-Butane cascade high temperature heat pump, Opeyemi Bamigbetan (NTNU)
Parameters and performance results

HTC Compressor Temperatures

2.4. Development of a Propane-Butane cascade high temperature heat pump, Opeyemi Bamigbetan (NTNU)
Summary

- Operating conditions are still random, unable to accurately and independently adjust the inlet temperatures.
- Simple modification required
- Results are not sufficient for proper evaluation
- High temperature heat delivery up to 115 °C from a heat source at 30 °C
- High temperature difference at heat sink from 35 °C to 115 °C
- Stable operation of prototype compressor with an average total compressor efficiency of 70%
2.5. Working fluids for high temperature heat pumps, Benjamin Zühlsdorf (DTU)

**Working fluids for high temperature heat pumps**

International Workshop on High Temperature Heat Pumps  
11.09.2017 - Copenhagen

Benjamin Zühlsdorf, Brian Elmegaard

Section of Thermal Energy  
Email: bezuhls@mek.dtu.dk  
Tlf.: +45 452 54103

DTU Mechanical Engineering  
Department of Mechanical Engineering

**Agenda**

- Motivation
- Screening Method
- Case I: Heat recovery at spray dryer (Arla)
- Case II: Excess heat to DH
- Conclusions
2.5. Working fluids for high temperature heat pumps, Benjamin Zühlisdorf (DTU)

Motivation

Heat Pump:
Heat Source: 100 °C → 70 °C
Heat Sink: 100 °C → 130 °C

Butane

COP = 4.12, p\text{evap} = 7.2 \text{ bar}, p\text{cond} = 27.7 \text{ bar}

Exergetic Efficiency = 62%

Exergy Product 62%
Exergy Destruction 38%

Exergy Destruction
38%

Exergy Product
62%

Compressor 12%
TV 9%
Condenser 7%
Evaporator 10%

Exergetic Efficiency = 62%

Exergy Destruction
38%

Exergy Product
62%

Compressor 12%
TV 9%
Condenser 7%
Evaporator 10%
Motivation

Heat Pump:
- Heat Source: 100 °C → 70 °C
- Heat Sink: 100 °C → 130 °C

- Butane: COP = 4.12, p\textsubscript{evap} = 7.2 bar, p\textsubscript{cond} = 27.7 bar
- 60% Butane / 40% Hexane: COP = 5.49, p\textsubscript{evap} = 4.34 bar, p\textsubscript{cond} = 13.5 bar
- 50% DME / 50% Pentane: COP = 5.56, p\textsubscript{evap} = 9.36 bar, p\textsubscript{cond} = 25 bar

Working Fluid Screening: Thermodynamic Model

→ Simulation of all possible binary mixtures, considering 14 HCs + 4 HFOs
2.5. Working fluids for high temperature heat pumps, Benjamin Zühlsdorf (DTU)

Working Fluid Screening: Results (5K SH)

Working Fluid Screening: Results (no SH)
Case I:
Heat recovery at spray dryer (Arla)

<table>
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<th></th>
<th>( T ) [°C]</th>
<th>( \dot{m} ) [kg/s]</th>
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<td>15</td>
<td>43.7</td>
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<tr>
<td>2</td>
<td>70</td>
<td>43.7</td>
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<tr>
<td>3</td>
<td>125</td>
<td>43.7</td>
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<tr>
<td>4</td>
<td>210</td>
<td>43.7</td>
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<tr>
<td>Excess Air</td>
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<td></td>
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<tr>
<td>5</td>
<td>70</td>
<td>61.5</td>
</tr>
<tr>
<td>6</td>
<td>\approx45</td>
<td>61.5</td>
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<td>Secondary Cycle Source</td>
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<tr>
<td>7</td>
<td>65</td>
<td>14.8</td>
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<tr>
<td>8</td>
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<td>Secondary Cycle Sink</td>
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<tr>
<td>9</td>
<td>75</td>
<td>10.6</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>10.6</td>
</tr>
</tbody>
</table>
**Case I:**
Heat recovery at spray dryer (Arla)

Heat Pump:
- **Heat Source:** 65 °C → 40 °C, excess heat
- **Heat Sink:** 75 °C → 130 °C, air preheating, $\dot{Q}_{\text{sink}} = 2.25 \text{ MW}$

- **Ammonia**
  - COP = 4.07, $V_{\text{flow,Comp,in}} = 410.6 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 8.57 \text{ bar, } p_{\text{cond}} = 42.6 \text{ bar}$
- **Butane**
  - COP = 2.88, $V_{\text{flow,Comp,in}} = 3415 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 2.83 \text{ bar, } p_{\text{cond}} = 29.5 \text{ bar}$
- **60% DME / 40% Pentane**
  - COP = 3.28, $V_{\text{flow,Comp,in}} = 2135 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 4.57 \text{ bar, } p_{\text{cond}} = 31.7 \text{ bar}$
- **50% R1234YF / 50% R1233ZDE**
  - COP = 4.61, $V_{\text{flow,Comp,in}} = 1212 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 3.32 \text{ bar, } p_{\text{cond}} = 14.9 \text{ bar}$
- **60% DME / 40% Isopentane**
  - COP = 4.72, $V_{\text{flow,Comp,in}} = 1136 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 3.55 \text{ bar, } p_{\text{cond}} = 14.6 \text{ bar}$

**Case II:**
Excess heat to DH

Heat Pump:
- **Heat Source:** 40 °C → 25 °C, e.g. excess heat from air liquefaction process
- **Heat Sink:** 50 °C → 85 °C, e.g. district heating (DH), $\dot{Q}_{\text{sink}} = 1 \text{ MW}$

- **Ammonia**
  - COP = 4.07, $V_{\text{flow,Comp,in}} = 410.6 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 8.57 \text{ bar, } p_{\text{cond}} = 42.6 \text{ bar}$
- **60% DME / 40% Isopentane**
  - COP = 4.72, $V_{\text{flow,Comp,in}} = 1136 \text{ m}^3/\text{h}$
  - $p_{\text{evap}} = 3.55 \text{ bar, } p_{\text{cond}} = 14.6 \text{ bar}$
2.5. Working fluids for high temperature heat pumps, Benjamin Zühlsdorf (DTU)

Case II: Excess heat to DH

Heat Pump:

Heat Source: 40 °C → 25 °C, e.g. excess heat from air liquefaction process
Heat Sink: 50 °C → 85 °C, e.g. district heating (DH), $\dot{Q}_{\text{sink}} = 1$ MW

- **Ammonia**
  - COP = 4.07, $V_{\text{flow, Comp, in}} = 410.6$ m$^3$/h
  - $p_{\text{evap}} = 8.57$ bar, $p_{\text{cond}} = 42.6$ bar

- **50% R1234YF / 50% R1233ZDE**
  - COP = 4.61, $V_{\text{flow, Comp, in}} = 1212$ m$^3$/h
  - $p_{\text{evap}} = 3.32$ bar, $p_{\text{cond}} = 14.9$ bar

Conclusions

- Utilization of mixtures:
  - Enhances range of applications for limited set of fluids
  - Possibility of matching temperature glides
  - Glide matching in evaporator has dominating influence
  - Reduction of superheating improves the glide match
  - Significant performance increase possible by use of mixtures
    - Case in introduction: COP = 4.12 → 5.49 (+33 %)
    - Case I (Spray Dryer): COP = 2.86/2.99 → 3.28 (+10/15 %)
    - Case II (DH): COP = 4.07 → 4.72 (+16 %)

- Future work:
  - Experimental validation at DTI: ThermCyc/MIREHP
3 Heat pump developments – Market ready products

3.1 Industrial heat pumps: Present and in the future, Morten Deding (Johnson Controls)

3.2 Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)

3.3 16 years with high temperature hybrid heat pumps, Bjarne Horntvedt (Hybrid Energy)

3.4 Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

3.5 Development and testing of HeatBooster, Mattias Nilsson (Viking Heat Engines)
3.1. Industrial heat pumps: Present and in the future, Morten Deding (Johnson Controls)
Present portfolio

Present products trends
Split in technology towards segment

• Traditional refrigeration segments
  • Single stage products on reciprocating compressors
  • Capacity <2MW and temperature 55-75-90°C
  • ROI/CAPEX is often the barrier
  • Heat pumps is not primary heat supply

• District heating segment
  • Large capacity above 10MW screws or centrifugal
  • Small capacity below 10MW two-stage reciprocating
  • 3-5 years project cycle from feasibility study to order
  • Temperature 72-85°C
  • Multiple running conditions
  • FAT +SAT test
  • Strict terms and conditions
Kalundborg fjernvarme

Production of heating from cold sewage water:
6 pcs Dual PAC SMC108/HPX716 two-stage heat pumps

Design specifications
Cold side = +13° C / +3° C
Hot side = +52° C / +82° C
Cooling capacity = 7.380 kW
Heating capacity = 10.000 kW
Power consumption = 2622 kW
COP_{heat} = 3.24

OM TURBO MASTER – Heat Pump

Industrial HP (combined chilling and heating)
Heating capacity 11.3 MW 800 m3/h from 77.5°C to 90°C
Cooling capacity 7.3 MW 780 m3/h from 12°C to 4°C
Absorbed Power 4.2 MW
COP: 4.4 (11.3 + 7.3) / 4.2

• York Multi stage compressor: M 438 (4 stages compression)
• Motor: 4.5 MW - 6KV - 1450 rpm – Soft starter
• Gear Box: 1 450 to 5 400 rpm
• 3 Interstages cooling for thermodynamic cycle efficiency
• Integrated sub cooler
• Shell & Tube condenser (CS plain tubes)
• Shell & Tubes evaporator (enhanced copper tubes)

• Weight: Empty 90 T  Operating 113 T
• MWP water side 23 barg Refrigerant side 41.3 barg

– ENERTHERM Heat Pump Case
District heating / cooling application in Paris La Defense

International Workshop on High Temperature Heat Pumps
ENERTHERM Heat Pump Case
District heating / cooling application in Paris La Defense

Vestmanner Iceland

Production of heating from cold seawater:
4 stk. Twin Heat PAC 193S single-stage heat pumps Sabroe
Single stage cycle with economizer

Design specifications
Cold side = +6/+2°C
Hot side = +38/+77°C
Cooling capacity = 7,370 kW
Heating capacity = 10,370 kW
Power consumption = 3,190 kW
COP_{heat} = 3,24
Future products trends

- Traditional refrigeration segments
  - Bring down running cost and improve service life
  - Lot of heating demands at 100-150 °C
  - Steam re-compression
  - Reduce charge

- District heating segment
  - Waste heat from industry
  - Low GWP and Natural refrigerants preferable
  - Low charge
  - High temperatures for transmission circuits >85° C
Refrigerants for all temperature levels

- Evaporation up to 110°C
- Condensation up to 125°C
- Capacity: 800kW to 10MW
- R245fa

... Technology based on YMC²

« Valenthin » project

- Evaporation up to 110°C
- Condensation up to 125°C
- Capacity: 800kW to 10MW
- R245fa

... Technology based on YMC²
3.1. Industrial heat pumps: Present and in the future, Morten Deding (Johnson Controls)

PACO2 project
Steam re-compression

- Evaporation 90 - 110°C
- Condensation up to ~150°C
- 25K per stage
- Capacity: 1000kW to 3MW

... Technology based on YK R718 PACO2 project
Steam re-compression

Screw compressors next generation
HPSH 2709+2712

Business Opportunity
- Heat pumps for Europe – ammonia refrigerant
- Fuel gas booster compressor feeding natural gas to power generation turbines
- Process gas compression for higher pressures
- District heating Europe or Asia

Product Description
- High pressure screw compressor with 273 mm rotor diameter
- Max water temp ~ 195 °F / (95 °C)
- Targeting 1300 psi (90bar) discharge / 1000 psi (69bar) suction
3.1. Industrial heat pumps: Present and in the future, Morten Deding (Johnson Controls)
3.1. Industrial heat pumps: Present and in the future, Morten Deding (Johnson Controls)

Heat pump Losses and Tolerances

\[
\text{COP}_{\text{Heat}} = \frac{P_{\text{heat}}}{P_{\text{line}}}
\]

\[
P_{\text{heat}} = f(\text{Fouling}_{\text{hot}}; \text{Fouling}_{\text{cold}}; \text{Pressure loss}_{\text{suction}}; \text{Pressure loss}_{\text{discharge}}; P_{\text{RC}}; \text{Pressure loss}_{\text{Eco}}; P_{\text{cooling}} \pm 5\%)
\]

\[
P_{\text{line}} = f(\text{Eta}_{\text{motor}}; P_{\text{motor}} \pm 0.5\%; P_{\text{RC}}; P_{\text{shaft}} \pm 5\%)
\]

Heat pump Losses and Tolerances

Capacity and Performance

Heat capacity: 4800 kW

COP Heat

Water inlet temperature: 15°C

Water outlet temperature: 50°C

International Workshop on High Temperature Heat Pumps 113 of 174
3.2. Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)

Why do we need heat pumps in district heating

- Why burn gas at 600°C to create 21°C in your home – Waste of exergy
- Decarbonisation of electricity grid makes heat pumps a zero carbon heat source
- Heat pumps is the most efficient use on natural energy source.
- Sustainable biomass only harness 1% of the solar energy
- Using seawater, sewage water, waste water, ground source water, cooling tower water etc, gives high efficient heating all year, independent on ambient temperature.
- Proven technology, competitive investment
- District heating / District cooling is key to improved energy optimisation for carbon neutral EU by 2050
- District heating converting from steam to water based system across Europe
- Temperatures of network at getting reduced each year.
3.2 Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)
Old PED limitations when using ammonia screw compressors

- For 52 bar ammonia heat pump PED describes that a 10% margin is required

\[
\begin{align*}
52 \text{ bar } -10\% & = 46.8 \text{ bar (86.7°C)} \text{ – set point for safety valve} \\
45.8 \text{ bar (85.7°C)} & \text{ Internal safety valve} \\
45.3 \text{ bar (85.2°C)} & \text{ alarm} \\
44.3 \text{ bar (84.1°C)} & \text{ compressor limiting} \\
= \text{ Maximum design point: 83°C condensing pressure} \\
= \text{ 80 - 82°C hot water from heat pump}
\end{align*}
\]

New PED limitations when using ammonia screw compressors

- For 52 bar ammonia heat pump PED describes that a less than 10% margin is required by applying good safety device

\[
\begin{align*}
52 \text{ bar } -10\% & = 50.5 \text{ bar (90.3°C)} \text{ – set point for safety valve} \\
49.0 \text{ bar (88.8°C)} & \text{ Internal safety valve} \\
48.5 \text{ bar (88.4°C)} & \text{ alarm} \\
48.0 \text{ bar (87.9°C)} & \text{ compressor limiting} \\
= \text{ Maximum design point: 87°C condensing pressure} \\
= \text{ 85°C hot water from heat pump}
\end{align*}
\]

Commercial range of ammonia heat pumps have now increased to supply temperature of 85°C
Small district heating schemes

GEA M-screw compressor

- Greatly improved efficiency in part load and full load
- New valves with lower pressure drop
- Wider speed range enables 1000 - 4500 rpm screw packages
- Larger Vi range enables higher efficiency
- 5 – 7% efficiency improvement

Now in 52 bar design
3.2. Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)

### Standard M-screw compressor based heat pumps

**GEA RedASTRUM Concept**

<table>
<thead>
<tr>
<th>Type</th>
<th>Compressor Model</th>
<th>Cooling capacity [kW] at +40°C/+35°C</th>
<th>Heating capacity [kW]</th>
<th>Heating water [°C]</th>
<th>Shaft power [kW] at compressor shaft</th>
<th>COP$\text{_{He}}$ at 3600rpm</th>
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<tr>
<td>1000</td>
<td>HR-G21T-52</td>
<td>1045</td>
<td>1255</td>
<td>+50/+70</td>
<td>215</td>
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<td>+60/+70</td>
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<td>+80/+80</td>
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<td>MR-H24T-52</td>
<td>1550</td>
<td>2010</td>
<td>+60/+80</td>
<td>465</td>
<td>4.32</td>
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<td></td>
<td>MR-H24T-52</td>
<td>1410</td>
<td>1875</td>
<td>+70/+80</td>
<td>465</td>
<td>4.03</td>
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<td>6.05</td>
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<td>MR-L20T-52</td>
<td>1815</td>
<td>2200</td>
<td>+60/+70</td>
<td>390</td>
<td>5.65</td>
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<tr>
<td></td>
<td>MR-L27T-52</td>
<td>1795</td>
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<td>+60/+80</td>
<td>520 (^{R})</td>
<td>4.44</td>
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<tr>
<td></td>
<td>MR-L27T-52</td>
<td>1635</td>
<td>2155</td>
<td>+70/+80</td>
<td>520 (^{R})</td>
<td>4.14</td>
</tr>
</tbody>
</table>

**GEA** 

**RedASTRUM** 

**Concept**

**Coolant +40°C/+35°C**

**200 kW**

**Supply:**

**Ammonia charge**

**Water/water or Cascade**

**Large district heating schemes**

International Workshop on High Temperature Heat Pumps 

118 of 174
3.2 Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)
3.2. Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)

### Ground source heat pump for a hotel (Denmark)

**Copenhagen Towers**

- Heat pump and heat exchangers
- Boiler
- Control-system
- Well

- 10-18°C Cooling
- 30-60°C Heating

Peak chilling duty is 4.1 MW
Peak heating duty is 2.9 MW
Chilled water system is designed for 10°C/18°C
Heating water system is designed for 60°C/30°C
Heating COP 3.9, Cooling COP 40

### 40 MW Ammonia Heat Pump (Sweden)

**4 off XD compressors**

- Heat sink: district heating water 57 °C to 66 °C
- Heating COP >3.50
- Shell and tube evaporator
- Plate and shell condenser
- Heat source: Sewage water 14 °C to 8 °C
3.2 Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)
Conclusion

1. Heat pumps only need a little electrical energy to raise the temperature of the waste heat to useful level.
2. By using heat pumps the decarbonisation of the electricity grid will ensure future reduction in CO₂ emissions.
3. Using water based heating system instead of steam makes implementation of heat pumps cheaper and improve efficiency.
4. It is now possible to achieve 85°C water with a 52bar design heat pump
5. Large heat pumps in the building services sector can help communities reach their zero emission targets

GEA Heat pumps 2017
Our Challenge at the start

Selling expensive, unfamiliar technology, replacing an existing energy solution in a field of business often characterized by optimistic, half-baked technologies.
The Company: History

- Founded in 2004
- Institute for Energy Technology (IFE) in Norway
- Commissioned plants in dairies, slaughter houses, fish feed producers, bio gas production plants, district heating and process industries
- More than 400,000 hours economic running in industry – equal to 46 years continues running

The Technology: What is a Hybrid Heat Pump?

- Natural working medium (50/50 water and ammonia)
- Uses Standard refrigeration equipment for ammonia
- Can deliver 120 °C at low pressure (25 bar)
- Offers unique flexibility after commissioning (by changing mixing ratio and circulation number)
- Yields exceptional COP’s, especially with large glides (Δt’s) on hot and cold side
The Technology: COP – Carnot vs. Lorenz

Experiences: Commercial Challenges

• Significant CAPEX
• Elaborate and complex procurement and decision making processes
• Technological skepticism
• Small company
Experiences: Solutions

- Holistic approach to the total energy system
- Tailor made solutions
- Project ownership & user commitment
- High commercial focus, strong sales organization
- Bold and competent partners

16 years, where are we?

- Hybrid Energy have most experience by tailor fitting high temperature heat pumps into industrial processes.
- Generation 3 hybrid heatpump with water/ammonia optimizes COP at different running conditions.
- Just delivered largest ever hybrid heat pump unit commissioned in Norway in 2017 at Borregaard (2 MW).
- First installation in the French dairy market will be commissioned this fall (2017) in cooperation with our strategic partner Engie Axima in France.
- Green shift offers new possibilities
- Increased environmental commitments in blue-chip companies
- Increased awareness among consultants about existing well proven and market ready solutions for high temperature heat pumps.
Steam compression and the development of a cost effective turbo compressor
PSO project “Water vapor compressor based on Rotrex gear”

Lars Reinholdt

Water as working fluid

- As ‘green’ as it gets
- As safe as it gets

- No global warming effect
- Cheap and easily available
- Non toxic
- Non flamable
- No break-down product
- Relative low pressure
Water as working fluid

Physical properties
- Low working pressure
  - 60°C: 0.2 bar a
  - 85°C: 0.6 bar a
  - 100°C: 1 bar a
  - 120°C: 2 bar a
  - 180°C: 10 bar a
- High heat of evaporation
  - ~2200 kJ/kg @ 100°C

Water Vapor Compressor

- Two types of prototype turbocompressors developed
  - Axial (chiller)
  - Centrifugal (HP)
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

**Turbo compressor: Design base**

![Graph showing temperature lift and tip speed](image)

Different optimal design for different application

**Cost effective radial air compressor**

Rotrex planetary gear

How it works:

Programme:

- C8: 240.000 rpm - 5 kW input power
- C15: 200.000 rpm - 15 kW input power
- C30: 120.000 rpm - 30 kW input power
- C38: 90.000 rpm - 50 kW input power
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

Compressor design

PSO project no. 344-009 “Water vapor compressor based on Rotrex gear”
- DTI, Rotrex, Weel & Sandvig, Spirax Sarco, Xvaporator, Union Engineering, Johnson Controls Denmark

Specifications by the project group:

<table>
<thead>
<tr>
<th>Type of user</th>
<th>Inlet conditions</th>
<th>Capacity</th>
<th>Temperature difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump Unit supplier</td>
<td>65 – 85°C</td>
<td>100 – 1000 kW</td>
<td>20 – 30</td>
</tr>
<tr>
<td>Steam system supplier</td>
<td>65 – 144°C</td>
<td>500 – 1000 kg/h</td>
<td>15 – 20</td>
</tr>
<tr>
<td>Process Industry</td>
<td>90 - 110</td>
<td>100 – 1200 kW</td>
<td>15 – 35</td>
</tr>
<tr>
<td>Waste recovery, concentration</td>
<td>85 - 110</td>
<td>500 – 1000 kg/h</td>
<td>15 – 20</td>
</tr>
<tr>
<td>Process Consultants</td>
<td>65 - 150</td>
<td>0.4 – 3 MW</td>
<td>15 – 30</td>
</tr>
<tr>
<td>Drying consultants</td>
<td>30 - 130</td>
<td>200 – 2500 kg/h</td>
<td>5 – 30</td>
</tr>
</tbody>
</table>

Compressor design

Specifications is a trade between
- Efficiency
- Pressure ration (temperature lift)
- Capacity (maximum load on gear and material)
- Lifetime

Specification:
- Speed 90,000 RPM
- PRts 2.6
- ΔT 25°C
- Efficiency h_
- Volume flow 0.45 m³/s
- Capacity (at 90°C inlet) 360 kW
Compressor design

- Design specification based on high end design tool

Final compressor and testrig
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

Compressor design

- Test results
- Efficiency documented
- Gear oil temperature little higher than expected > lower max. RPM

Application examples

Steam generation... concentration... recompression... Drying...

Heat exchanger / evaporator
compressor
Steam at 110 °C
Liquid at 100 °C
Liquid at 60 °C
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

Thank you

Lars Reinholdt
Danish Technological Institute
lre@teknologisk.dk
Phone: +45 7220 1270
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

### Boundary conditions for steam dryer (full scale)

<table>
<thead>
<tr>
<th>Product</th>
<th>Mass flow in: ( \dot{m}_\text{in} )</th>
<th>Moisture content in: ( \text{MC}_\text{in} )</th>
<th>Mass flow out, ( \dot{m}_\text{out} )</th>
<th>Moisture content out, ( \text{MC}_\text{out} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>10000 kg/h</td>
<td>25%</td>
<td>7895 kg/h</td>
<td>5%</td>
</tr>
<tr>
<td>Drying agent (process steam)</td>
<td>Mass flow: ( \dot{m}_\text{DA} )</td>
<td>Temperature in: ( T_{\text{DA}} )</td>
<td>Mass flow out: ( \dot{m}_\text{DA} )</td>
<td>Temperature out: ( T_{\text{DA}} )</td>
</tr>
<tr>
<td></td>
<td>65684 kg/h</td>
<td>155±5°C</td>
<td>67789 kg/h</td>
<td>110°C</td>
</tr>
<tr>
<td>Mechanical vapor recompression (MVR)</td>
<td>Mass flow: ( \dot{m}_\text{MVR} )</td>
<td>Temperature in: ( T_{\text{MVR}} )</td>
<td>Pressure in: ( P_{\text{in}} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2105 kg/h</td>
<td>110°C</td>
<td>1 bar</td>
<td></td>
</tr>
<tr>
<td>Water out</td>
<td>Mass flow: ( \dot{m}_\text{water} )</td>
<td>Temperature: ( T_{\text{water}} )</td>
<td>Pressure: ( P_{\text{water}} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2105 kg/h</td>
<td>&lt;100°C</td>
<td>1 bar</td>
<td></td>
</tr>
</tbody>
</table>

Drying process (MC 25% → 5% at 155±5°C)

\[ f(\dot{m}_\text{in}, \text{MC}_\text{in}, \dot{m}_\text{DA}, T_{\text{DA}}) = 0.2105 \text{ kg water/kg product} \]

SEC = 0.78 kWh/kg
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)
2 stage setup

Outlet of stage 2:
- Super heated water vapor
- 250 °C
- 6.5 bar (abs)
- Mass flow 800 kg/hr (0.222 kg/s)

Inlet of stage 2:
- Super heated water vapor
- 145 °C
- 3.2 bar (abs)
- Mass flow 800 kg/hr (0.222 kg/s)

Water spray cooling:
- 120 °C
- Flow: 0.026 kg/s

* Water spray cooling system not included in deliverables

WP2: Deliverables
3.4. Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

De-Supeheating

- Requires a certain pipe-length (=residue time for the water to evaporate)
- Pipe diameter is smaller than we would like to have it
  - Increase pressure loss for our compressors
    - Loss if efficiency
    - Start-up procedure?
- Evaluated as necessary
  - between stage 1 and stage 2
  - after stage 2 and before MVR-condenser

Heat Pump Demonstration Unit
Conclusions and Discussion Open Loop

- Overall: good progress on the development
- Currently building together the prototype unit
- Until end of October testing in single stage
- From November 2017 testing in multistage (target 2000 hours)
- Questions ? Comments ?
3.5. Development and testing of HeatBooster, Mattias Nilsson (Viking Heat Engines)

Product Platform

CraftEngine™ produces electricity from waste heat

HeatBooster produces high-temperature heat by adding electricity
The Product Plan

<table>
<thead>
<tr>
<th>Market Size in kWh</th>
<th>1st Generation:</th>
<th>2nd Generation:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CraftEngine™</td>
<td>HEATBOOSTER S4</td>
</tr>
<tr>
<td></td>
<td>Demo</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 kW&lt;sub&gt;e&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>10 – 40 kW&lt;sub&gt;e&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 kW&lt;sub&gt;th&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CraftEngine™ 10 &amp; 40</td>
<td>HEATBOOSTER Large-series</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HEATBOOSTER X-series</td>
</tr>
</tbody>
</table>

Future...

How It Works

The HeatBooster is a high-temperature heat pump, which uses electricity to raise the temperature of a heat source in an efficient way.

**Q<sub>in</sub>** = 150 kW<sub>th</sub>
Process or waste heat

Input temperature range:
30 – 120 °C

**Q<sub>out</sub>** = 200 kW<sub>th</sub>
Useful heat at a higher temperature level

Output temperature range:
80 – 160 °C

**COP** = 2 to 7

*Coefficient of Performance* indicates the ratio of output heat divided by electrical input added to the reciprocating compressor. The ratio depends strongly on the temperature lift.

Input temperature range:
30 – 120 °C

Output temperature range:
80 – 160 °C
In this case, the HeatBooster consumes one (1) part of electricity to lift five (5) parts of heat to a 30°C higher temperature.

**Performance examples of different working fluids:**

**HeatBooster (COP=6)**

<table>
<thead>
<tr>
<th>Energy source</th>
<th>CO₂ emissions</th>
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</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>280 kg CO₂ per MWh*</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>270 kg CO₂ per MWh*</td>
</tr>
<tr>
<td>Natural gas</td>
<td>260 kg CO₂ per MWh*</td>
</tr>
<tr>
<td>Direct electricity</td>
<td>60 kg CO₂ per MWh**</td>
</tr>
</tbody>
</table>

Sources:

*Tech4B/Regenerative Energiesysteme and UBA
**EU-28 average power grid

Example, see above (blue mark): A 90°C heat source and 120°C heat sink result in a COP of 5
Possible Applications

The industry needs large amounts of process heat
▪ Coal, oil, gas or electric heaters are usually used for this purpose
▪ These kinds of heaters can be replaced by the HeatBooster

Industrial heat pumps increase energy efficiency
▪ Costs and emissions can be reduced
▪ Payback periods of 1 to 3 years are possible

HeatBooster reaches the highest temperatures (> 150 °C)
▪ Commercial HTHPs generally reach < 90 °C
▪ HeatBooster uses gas compression
▪ Flexible integration with regards to temperature change in water loops and possibilities for steam production

Installation Example

The HeatBooster S4 constitutes a complete heat pump system with compressors, process components, electronics, software and so on.

The given values are example values
### Installation Example - Multistage

COP_{combined} = \frac{Q_{out}}{Q_{in} + Q_{el}} = \frac{200}{37.5 + 50} = 2.29

The given values are example values.

### Installation Example – Cascade

The cascade connection allows for a temperature lift of 45°C. Comparatively, you'd get a temperature lift of 60°C with one large system, which results in a lower COP.

The given values are example values.
Our Key Partners

**AVL**
- Collaborated since 2011
- World's largest independent engine design company
- > 8,000 employees and revenue of € 1.3 Billion (2015)
- AVL has invested in Viking Heat Engines

**The Chemours Company**
- Collaborated since 2015
- Large chemical company developing and producing environmentally friendly working fluids / refrigerants and more

**GWK**
- Supplier of high-quality cooling and heating technology products
- Current manufacturer of CraftEngine/HeatBooster process modules

Unique High-Temp. Heat Pump Technology

**The future is electric**
- The HeatBooster can reduce electricity consumption from 50 to 85%
- The COP of the HeatBooster is typically around 50% of the Carnot limit
- The HeatBooster can power a process without any CO₂ emissions

**A potent, durable and highly flexible piston engine technology**
- Used as a reciprocating piston expander in the CraftEngine™ and compressor in the HeatBooster
- Runs at 20-100% load without significant efficiency penalty
- Durability of 80,000 hours
- Low maintenance requirements
- Can reach 160°C with current working fluids
- Suitable with environmentally friendly working fluids and thus part of a new technology generation

**About Viking Heat Engines**
- Over 40 employees in three locations around the world
- Highly qualified and experienced sales and development team
- €50 Million Technology (research, development, testing, commercialization, etc.)
3.5. Development and testing of HeatBooster, Mattias Nilsson (Viking Heat Engines)
4 Case studies – Realized and not realized projects – Experiences – Economics

4.1 5 years of strategic sale of large heat pumps to the industry, Palle Lemminger (Innoterm)

4.2 TINE’s road to get the (high temperature) heat pump, Kim Andre Lovas (TINE)

4.3 Integration of high temperature heat pumps in industry, Fridolin Müller Holm (Viegand Maagøe) & Søren Gram (Svedan Industri Køleanlæg)

4.4 Steam Generation from district heating, Stefano Vittor (Olvondo Technology)
4.1. 5 years of strategic sale of large heat pumps to the industry, Palle Lemminger (Innoterm)

"5 years of strategic sale of large heat pumps to the industry"

Palle Lemminger – Innoterm A/S
Owner & CEO

In 2010-2012 consulting engineers concluded:
250-300 industrial high temperature heat pumps needed and wanted in Denmark.

Technically: Innoterm moves the sensor from the cold to the warm side.
Same materials and personnel for the heat pumps.
4.1. 5 years of strategic sale of large heat pumps to the industry, Palle Lemminger (Innoterm)

High temperature heat pump references:
- Arla Arinco, milk powder production in Videbæk
- Danish Crown, slaughterhouse in Holsted
- Tican, slaughterhouse in Thisted
- TDC, heat recovery from datacenter in Slet
- Løgumkloster district heating
- Dronninglund district heating
- Ringkøbing district heating
- Tønder district heating

Reference plant: 1200 kW heat pump, Arla Arinco, Videbæk, 2012

Two-step hybrid heat pump:
- Cooling capacity: 950 kW
- Heating capacity: 1200 kW
- Source temp.: 45 °C / 22 °C
- Outlet temp.: 55 °C / 85 °C
- COP(heat): 4.5

Equipped with:
- 1 Sabroe SMC 116L piston compressor
- 1 Sabroe SMC 108L piston compressor
- Refrigerant: R717 / R718

On the 1st of September 2017, the heat pump has been running for 33,500 hours, and delivered 35,400 MWh heat with an average COP of 4.57.

This project is supported by EUDP.
4.1 5 years of strategic sale of large heat pumps to the industry, Palle Lemminger (Innoterm)

Reference plant: 988 kW heat pump, Danish Crown, Holsted, 2013

Supercharge heat pump:
- Heating capacity: 988 kW
- Evaporator temp.: 28 °C
- Condensing temp.: 61 °C
- COP(heat): 8

Equipped with:
- 2 Grasso 65HP piston compressors
- Refrigerant: R717

The heat pump is integrated in a 4.5 MW ammonia refrigeration plant built by Innoterm. The plant refrigerates the 120 cattle being slaughtered at the slaughterhouse every hour.

Reference plant: 1350 kW heat pump, TDC district heating, Slet, 2015

Two-step heat pump:
- Heating capacity: 1350 kW
- Source temp.: 16/9 °C
- Outlet temp.: 45/78 °C
- COP(heat): 4.0

Equipped with:
- 3 GEA piston compressors
- Refrigerant: R717

The heat pump is projected and built on-site in Slet, by Innoterm. The heat from rooms and server cooling is raised in temperature and used for heating and/or sale for the district heating. The heat pump supplements and replaces existing district heating as well as the existing cooling plant.
4.1. 5 years of strategic sale of large heat pumps to the industry, Palle Lemminger (Innoterm)

Reference plant: 1100 kW heat pump, Løgumkloster district heating, 2015

Two-step hybrid heat pump:
- Cooling capacity: 844-1005 kW
- Heating capacity: 1089 - 1207 kW
- Source temp.: 23 °C/17 °C
- Outlet temp.: 35 °C/60-85 °C
- COP(heat): 4.0 - 5.3

Equipped with:
- 1 Sabroe SMC 116L piston compressor
- 1 Sabroe SMC 112S piston compressor
- Refrigerant: R717 / R718

This heat pump is used for either direct heating the district or to move energy around in the plant between storage, sunpanels or return water.

This project is supported by EUDP.

Reference plant: 4,5 mW air to water heat pump, Ringkøbing district heating and Tønder district heating

Two-step heat pumps:
- Heating capacity: 3,360/4500 kW
- Source temp.: Varying outdoor air
- Outlet temp.: 35/70 °C
- COP(heat): 4.5

Air is cooled in air cooler area, and the district heating is heated by both condensation- and motor heat.

The heat pump supplements the existing district heating.

Equipped with:
- 4 Sabroe piston compressors in 2 parallel two-step plants
- The compressors can be driven by gasmotors or electrical motors
- Kølemiddel: R717
Overview: wants and reality

- 5 different ministers since 2010
- Several different studies (Universities, consulting engineers, technical institutes), EUDP, VE, Rejseholdet, etc.
- Funding added / funding removed
- A lot of ‘talk’ on re-using the energy for district heating and electricity from windmills for HTHP
- Reality is different with taxes and fees, removing focus from the visions
- Today: most of the HTHP supported by EUDP or other funding
- If Denmark needs to be fossil free in 2050, we need to motivate the industry and district heating plants to invest in HTHP!

Questions?
4.2 TINE's road to get the (high temperature) heat pump, Kim Andre Lovas (TINE)

The TINE Group 2015

- Liquid products
- Solid products
- Special products
- Central warehouses/terminals

Good profit performance in 2015
- Revenues of NOK 22,2 billion
- Operating income NOK 1678 million
- Profit before tax NOK 1579 million

Industry
- 31 dairies
- 2 central warehouses
- 2 terminals
- Wholly and partly owned subsidiaries

Employees
- 5362

Owners
- 12,092 farmers (cows and goats)

Raw materials delivered (cows’ and goats’ milk)
- 1474 million litres
TINE's climate objectives: Reduce greenhouse gas emissions by 30 per cent by 2020 (compared with the 2007 level)
• Conversion to bioenergy and district heating
• Energy efficiency
• Transport
• Food waste

Greenhouse Gases TINE

Overview of Greenhouse Gases 2015

Production 31 %
Transport 63 %
Other 6 %
Our success depends on efficient transport, logistics and distribution

- Extreme requirements for quick processing, quality and hygiene when the raw material is fresh milk
- Collection of milk from 220,000 cows and 30,000 goats from about 10,000 locations, followed by delivery to 24,000 stores and delivery sites within a geographical area corresponding to Oslo–Rome
- Secure the consumers’ requirements and expectations of Norwegian dairy products

On the road to Climate Neutral transport by 2020
The environment

TINE 2014

Total: 503 GWh
Heat: 305 GWh

Large demand for heat in the temperature range 90°C to 180°C
Large amounts of surplus heat available in the temperature range 30°C to 45°C

New Dairy Bergen
18.000 m²
Capacity 300.000 liter milk/daily
Will be completed in 2019

Shall be the most efficient, future-oriented and profitable plant in the Nordic region
Challenges

- Relative small Dairy
- Operational stability
- Innovation/Technology readiness level

Utilities in the New Dairy

105 °C
Hot water distribution

Boiler

Room heating
67 °C

Waste heat

40 °C
30-50 °C
30-50 °C

Cooling plant
40 °C

Ice water to process
(hot) Ice water back from process

*CIP=Clean in place

4.2. TINE’s road to get the (high temperature) heat pump, Kim Andre Lovas (TINE)
Goals

- First Dairy in Norway completely supplied by heat pumps
- Specific energy from 0,24 kWh/liter to 0,15 kWh/liter product
- 30 % reduction in energy use compared to existing Dairy in Bergen
4.2 TINE’s road to get the (high temperature) heat pump, Kim Andre Lovas (TINE)

Key Success Factors

• Research projects like HighEff/HeatUp
• State Aid ENOVA
• Research partners like SINTEF
• Good Suppliers
4.3. Integration of high temperature heat pumps in industry, Fridolin Müller Holm (Viegand Maagøe) & Søren Gram (Svedan Industri Køleanlæg)
4.3. Integration of high temperature heat pumps in industry, Fridolin Müller Holm (Viegand Maagøe) & Søren Gram (Svedan Industri Keleanlæg)

BACKGROUND

History 2013-2017

- Energy symbiose Køge spring 2014: VEKS - CP KELCO, Sun Chemical, Fef Chemicals and Junckers
- VEKS is expanding the district heating grid in the Køge region.
- CP Kelco produces ingrediencies for the food sector. As a part of the production substantial amount of heat needs to be cooled, which is today done primarily by cooling towers.
- CP Kelco is very focused on reducing the environmental load and is constantly optimizing there production in order to become more efficient

What makes this project flying?

- Expansion of the district heat grid
- High temperature surplus heat
- Huge interest from both CP Kelco and VEKS
- Energy saving subsidy
- Government support
- A number of similar business cases
- ...

PROJECT DEVELOPMENT

Initial design phase

- Energy Symbiose Køge
- Substituting one cooling tower
- Increasing the heat recovery system temperature
- Extending the system with an additional cooling tower
- Designing a buffer system
- Optimizing system efficiency
- ...

Production

- Condenser redesign
- Integration with existing recovery systems
- Integration with existing systems and piping
- Working on flow and pressure issues
- Securing sufficient redundancy

District heat

- Expansion of the system
- Temperature demands
- Pipe routing – ownership of property
- Agreement between VEKS and CP Kelco

Technology

- Heat pumps
- Heat storages
- Condenser type and design

Integration

- Integration with the district heating system – balancing supply and demand
4.3. Integration of high temperature heat pumps in industry, Fridolin Müller Holm (Viegand Maagøe) & Søren Gram (Svedan Industri Køleanlæg)

**PROJECT DEVELOPMENT**

![Diagram of heat pump system]

- **Power**: 4-7 MJ/s
- **Energy**: 140 TJ/year (38,700 MWh/year)
- **System COP**: 18.5

**INTEGRATION OF DISCIPLINES**

**Authorities**
- Municipality
- Project proposal
- Application for dispensation
- Application for construction
- Binding answer from the tax authorities
- Danish Working Environment Authority

**Client**
- In house engineering
- Maintenance
- Production
- Procurement
- Management
- EHS

**Suppliers**
- Mechanical
- Electrical
- Building
- Civil
- HEAT PUMP

**District heat**
- Management
- In house engineering
- Subcontractors

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HEAT PUMP DESIGN

High process water temperatures

- High process water temperatures: 75 / 60°C
- Small lift with hot water temperatures: 72 / 85°C
- Variable water flow both sides: 100 – 50%
- Small or no sub cooling and super heating
- Two units for flexibility and optimum efficiency
- Need for suction pressure protection
- Need for closing off to compressor during stand still

HEAT PUMP PERFORMANCE DATA

<table>
<thead>
<tr>
<th>UNIT No. 1 MAYEKAWA N4HS</th>
<th>UNIT No. 2 MAYEKAWA N4HS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td><strong>Capacity</strong></td>
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<tr>
<td>[kW] 1.510</td>
<td>[kW] 1.504</td>
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<tr>
<td><strong>ABSORBED POWER</strong></td>
<td><strong>ABSORBED POWER</strong></td>
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<tr>
<td>[kW] 176</td>
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<td><strong>SPEED</strong></td>
<td><strong>SPEED</strong></td>
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<tr>
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<td>[min^-1] 1.235</td>
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<tr>
<td><strong>LOAD</strong></td>
<td><strong>LOAD</strong></td>
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<tr>
<td>[%] 100</td>
<td>[%] 100</td>
</tr>
<tr>
<td><strong>PROCESS WATER TEMP. IN/OUT</strong></td>
<td><strong>PROCESS WATER TEMP. IN/OUT</strong></td>
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<tr>
<td>[degC] 75/67.5</td>
<td>[degC] 67.5/60</td>
</tr>
<tr>
<td><strong>DISTRICT HEATING WATER TEMP. IN/OUT</strong></td>
<td><strong>DISTRICT HEATING WATER TEMP. IN/OUT</strong></td>
</tr>
<tr>
<td>[degC] 78.5/85</td>
<td>[degC] 72/78.5</td>
</tr>
<tr>
<td><strong>HEATING CAPACITY</strong></td>
<td><strong>HEATING CAPACITY</strong></td>
</tr>
<tr>
<td>[kW] 1.676</td>
<td>[kW] 1.658</td>
</tr>
<tr>
<td><strong>COPh electricity</strong></td>
<td><strong>COPh electricity</strong></td>
</tr>
<tr>
<td>[-] 9.0</td>
<td>[-] 9.6</td>
</tr>
</tbody>
</table>
4.4. Steam Generation from district heating, Stefano Vittor (Olvondo Technology)

The issue

- District heating operators are looking for new revenue streams within their footprint
- Industrial customers offer an attractive demand for energy, but often at temperatures above district heating grid level
- Commercial available high temperature heatpumps can be used to meet industrial customers demand for temperatures up to 200°C enabling district heating operators to tap into new revenue streams
Steam Production from District Heating – Case study

City of Ålesund - Northwest cost of Norway

Tafjord Kraftvarme – District heating operator

Tine Meierier - Diary

Business model

- Tafjord Kraftvarme supplies district heating to Olvondo technology
- Olvondo Technology uses district heating as source for steam production, lifting the temperature from 85°C to 184°C using its own SPP HighLift Heatpump technology
- Tine Meierier purchases the steam produced by the Olvondo Technology heatpumps
- Long term fixed energy supply contract
  - 10y duration
  - Fixed energy prices
  - Remote operatered steam production

4.4. Steam Generation from district heating, Stefano Vittor (Olvondo Technology)
Facts & Figures:
- 12 GWh/y steam consumption (natural gas)
- Steam temperature 184 °C (10 bar)
- Constant consumption 51 weeks per year
- Heat pump energy supply up to 9,6 GWh/y
- Energy sourced from District Heating up to 5,2 GWh/y
- District heating temperature 85°C
- 3x SPP HighLift 104-6 Heat pumps

Steam Production from District Heating – Case study

![Image of SPP HighLift heat pumps installed at AstaZeneca in Mölndal, Sweden]

Basic system principle

International Workshop on High Temperature Heat Pumps
4.4. Steam Generation from district heating, Stefano Vittor (Olvondo Technology)

Steam Production from District Heating – Case study

**Deliverables**
- Increased energy consumption in the district heating grid of Tafjord Kraftvarme
- Reduced energy cost for steam production at Tine Meierier
- Significantly reduced carbon emissions from the diary by 1.800 t/y less CO₂, counting for 60% of total CO₂ emissions from the diary

The heatpump project with Tine in Ålesund is under construction and will be in operation from Q4'2017

Tine Ålesund in a District Heating Perspective

**Assumptions:**
- Energy consumption residential subscriber of 20,000 kWh per year
- Rough estimate of monthly distribution
4.4. Steam Generation from district heating, Stefano Vittor (Olvondo Technology)

SPP HighLift Heatpump

- Stirling principle
- Helium (R704) refrigerant
- Temperature lift > 100°C
- Source temperatures in the range 0 - 100°C
- Sink temperatures up to 200°C
- 500 kW heat + 250 kW cooling in the same process
5  Plenary Discussion: "What measures will enhance the utilization of (high temperature) heat pumps in industry?"

4.1 What measures will enhance the utilisation of HTHPs in industry, Petter Nekså (SINTEF)
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Measures to enhance utilisation of HTHPs

- Select good cases for industrial demonstration
- Reliable technology concepts
- Utilise desire to reduce emissions of GHGs (incl HFCs)
- Acceptable temperature lift (COP/ROI)
- Utilise long term acceptable refrigerants (natural refr)
- Consider industrial clusters/thermal storage and networks