Norway - Ongoing activities in the field of high-temperature heat pumps

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• POSITION
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• KEY QUALIFICATIONS
  Heat pumps, Refrigeration, Energy storage, Thermal process engineering, Integrated energy systems, Component development, Lab and pilot scale tests

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Outline

• Update on national HTHP industry
• Overview of national HTHP market and perspectives
• Selected RD&D projects
Is Norway a special Hp country?

- CO2-lean electricity
- Norway is European Champion in HP selling per capita, private and industry
- However, industrial HP and HTHP is often a 1 to 1 decision.
- Energy price difference ??
  - Electricity vs. oil/gas
UPDATE ON NATIONAL HTHP INDUSTRY
Unfortunately, both HEATEN and EPCON did not send any updated information.
Working conditions

• Sink temperatures up to 115 °C @ about 20 bar
• Source temperatures
  A) Ice-water @ 0 °C or water glycol (down to -20°C)
  B) Dry cooler waste heat @ 20°C to 30°C
• High temperature lift (70...120 K) → flexibility

Solution

• Cascade
  • HT circuit with R600 (Butane)
  • LT circuit with R290 (Propane)
• 300kW_{heating} and 150kW_{cooling} HTHP is mounted in
  10 feet shipping container build after EN-NS-378

➤ Pilot installed, available and flexible system (high TRL-level)
**ANEIO - NH₃-MVC – operation range**

- 1.2, 2.5 and 5 MW (10 MW optional)
- Up to 150°C in the form of 5 barA steam
- Ammonia (R717) and Water (R718) cascade
- Piston NH₃ + Centrifugal H₂O
- TRL7-8 (Subsystem are on TRL8-9)

*ANEIO Industry*

business model is Energy as a service

Image courtesy by ANEO Industri AS

Teknologi for et bedre samfunn
ANEO - NH₃-MVC under construction

• Pilot 1 - Animal feed/pellet production Trondheim (ENOVA supported):
  – 1.6 MW steam producing heat pump (2 ton/h supply)
  – Supply pressure 2.6 bar(a), 120°C
  – COP of between 2.5 –3.0
  – Start-up summer 2023

• Pilot 2 - Fish meal factory Pelagia Måløy
  – 4.4 MW steam producing heat pump (7 ton/h supply)
  – Supply pressure 3.6 bar(a), 140°C
  – Utilization of 2 excess heat streams from the fish meal factory
  – Estimated > 7 GWh/year
  – Temperature lift > 100 Kelvin (in parts)
  – Expected Start-up in April 2024

Image courtesy and information provided by ANEO Industri AS
Enerin AS - HoegTemp heat pumps – Sterling

Heating and/or cooling

- Steam or hot water up to 250°C
- Cooling to -100°C
- Industry leading efficiency (COP)
- Helium refrigerant: Zero ODP, Zero GWP
- More than 30,000 hours of operating experience with prototypes
- Unique patented technology
- Low cost of operation
- New generation commercially available 2023 (12m lead time)

Image courtesy and information provided by Enerin AS
Pilot 2023 – Biogas CCS

• Installed at IVAR Biogas facility
  – Generates steam for CO$_2$ removal from biogas (amine process)
  – Recycles heat from the amine cooling
  – 400 kW steam capacity (up to 14 bar$_G$, 200°C)
  – Simulated second-law efficiency approximately 50%
    (as we speak 25.03.2023 the plant is commissioned)

• Energy system
  – Heat source: water circuit from cooling tower, with
    circulation pump and shunting for performance testing at
    lower source temperatures
  – Pressurized hot-water circuit heating a steam generator
  – Feed water from plant system

Image courtesy and information provided by Enerin AS
Enerin AS - R&D plan highlights and upcoming installation

- Pilot at biogas plant
  - From Q2/2023
  - Performance mapping: 5°C < T_L < 40°C, 130°C < T_H < 200°C
- Test unit for extreme temperatures
  - In own lab from Q3/2023 (ultra low temperatures)
  - At KTH lab from 2025 (ultra high temperatures)
  - Accelerated testing, performance mapping, tuning and component qualification
  - Cost of operation
- GE Healthcare Lindesnes
  - First unit Q1/2024
  - Integration in plant energy system and control system
  - COP optimization with real-world operating conditions
- Pelagia
  - First unit Q2/2024
  - Operation in system with varying source and sink temperatures

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- Programme for specific cost, planned for 2023-2025
  - Increased capacity 400kW → 800kW per unit
  - 50% performance increase target
  - 50% production cost reduction target
  - Remove bottlenecks in production, ready for scaling

Image courtesy and information provided by Enerin AS
HIGH TEMPERATURE OPEN-LOOP HEAT PUMP – MVR-400
PLUG & PLAY, COMPACT SOLUTION

Highlights & Specifications

- Using low-temperature waste steam to produce steam at operating temperatures
- Delivered steam mass flow: 500 – 700 kg/h pr. unit
- Modular design - Combining units to increase capacity
- Steam delivery pressure: 1 - 12 bara
- Steam delivery temperature: 100 - 190°C
- Produced steam phase: saturated or superheated
- Dimensions (mm): 5000/2000/2300 (L/W/H)
- Robust two-phase compressor technology handling low-quality waste steam
- Stand-alone system, fully covered and insulated for outdoor/indoor installation

The Tocircle MVR-400 solution can recover waste heat from several industrial processes like drying, frying, distillation...
It can be installed alone to directly compress waste steam from atmospheric pressure (or above), or combined with a bottom cycle to recover waste heat at even lower temperatures.

Image courtesy and information provided by toCircle Industries AS

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TOCIRCLE COMPRESSOR MEETING INDUSTRY REQUIREMENTS

DELIVERY TEMPERATURES UP TO 220°C

OIL-FREE MACHINE

TWO-PHASE FLOW HANDLING

HIGH COMPRESSION RATIO 1:5

WATER INJECTION IN THE COMPRESSION CHAMBER TO KEEP WORKING MEDIA ON SATURATION LINE

ROBUST & EFFICIENT TECHNOLOGY

Image courtesy and information provided by toCircle Industries AS
Pilot project: Leveraging Tocircle’s proprietary MVR solution to increase energy efficiency while drying biomass.

Moisture evaporating from biomass while drying is captured and compressed and returned back to the process. Temperature lift from 100°C (1bara) to 155°C (5bara)

The MVR becomes the only heat source, replacing the diesel generator.

**ENERGY SAVING:**
67 % with today’s technology
75 % with next technology version (target)

**CO₂ EMISSIONS CUT* (ton/year):**
ca. 800 (pilot)
ca.1.600 (aim)

(*) 7,500 hours (operation time), from diesel to green electricity.

**DRYING PROCESSES ACCOUNT FOR 10-25% OF TOTAL INDUSTRIAL ENERGY CONSUMPTION**

Image courtesy and information provided by toCircle Industries AS

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• Unfortunately, both HEATEN and EPCON did not send any updated information
High Temperature Heat Pumps

NH₃/H₂O hybrid technology

Image courtesy and information provided by Johnson Controls Plc

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2 new hybrid heat pumps at 100°C+ in operation

- Successfully commissioned and hand-over to client

Fruit processing
- GreenPAC-R / 1.9MW (1-stage)
- Source outlet: 57°C
- Sink: 100°C
- COP: 5.0

Dairy
- HyPAC-R / 1.5MW (2-stages)
- Source outlet: 80°C
- Sink: 102°C
- COP: 4.4

Image courtesy and information provided by Johnson Controls Plc
Hybrid heat pumps to be produced at Johnson Controls Sabroe factory

- **Background:** In January 2023, Johnson Controls acquired Hybrid Energy

- As a direct consequence, all production of hybrid heat pumps has been moved to Johnson Controls Sabroe factory in Aarhus, Denmark

- Improved quality of delivery will be the main focus

- This will continue and strengthen the standardization process

- End of line test bench will be performed (EFAT)
OVERVIEW OF NATIONAL HTHP MARKET POTENTIAL
ENOVA commissioned an evaluation of the potential for excess heat utilisation within the Norwegian industry:

- Performed by Norsk Energi and NEPAS, published in 2009 ("Utnyttelse av spillvarme fra norsk industry")

- Data averaged from 72 participating Norwegian industries
  - About 63% (ca. 53 TWh/year) of the Norwegian industry energy use

- Total reported waste heat resources not utilised in 2008:
  - By nature: water/waste water, steam and exhaust gas,
  - By T range: 25-40°C, 40-60°C, 60-140°C and > 140°C.
Excess heat inventory in Norway

Ref: ENOVA / Norsk Energi / NEPAS, Utnyttelse av spillvarme fra norsk industry. 2009
Identification of relevant industrial processes by T range

- Estimates of distribution adapted to Norway by total energy use (2015)


Based on total energy use, not total heat demand => Slightly over-estimated
Identification of relevant industrial processes by T range

- Estimates of distribution adapted to Norway by total energy use (2015)

Based on total energy use, not total heat demand
=> Slightly over-estimated

SELECTED R&D PROJECTS
DryFiciency: Industrial Demonstration

High temperature heat pumps up to 160ºC

Closed loop heat pump
- Brick drying
  - Wienerberger AG
    - Uttendorf (AT)

Starch drying
- AGRANA Stärke GmbH
  - Pischelsdorf (AT)

Open loop heat pump
- Bio sludge drying
  - Scanship A/S
    - Drammen (NO)

The project has received funding from the European Union’s Horizon 2020 programme for energy efficiency and innovation action under grant agreement No. 723576.

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Open loop steam compression demo for dryer application: Scanship

- 500kW Heat pump
- Steam compression from 1 bar_a to 4.5 bar_a
- COP 4.3
- Large dimensions due to accurate flow measurement
Implementation Project - Dairy

Case 1 – RETROFIT : Tine dairy Trondheim (Norway)

- Annual production: 75 mio. liter milk
- Cold supply:
  - 4 NH₃-condensing units (2700 kWth, -1.5 °C / 33 °C)
- Process heat supply:
  - Hot water transcritical CO₂-Heat pump 160 kWth, 0 °C / 10 °C bis 75 °C
  - Process electrical heat 3000 kWth 95 °C/115 °C
  - District heating and oil burner as 100% Backup

Case 2 – NEW (2019): Tine dairy Bergen (Norway)

- Annual production: 43,4 mio. liter Liter milk products
- Photo voltaic : 6 000 m²
- Completely integrated process cold (-1,5°C) and hat supply (snow smelting 20°C to Pasteurisation 95°C)

Sources: https://www.tine.no

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RETRoFIT – HTHP for combined cold and heat supply - SkaleUP

Simplified process diagram – Process ice water and process hot water

HTHP-is connected in series with existing chillers and boilers → 100% Backup

Aim:
• Utilisation of available waste heat
• Reduction of energy consumption
• Reduction of CO₂ Emissions
SkaleUP is a success story! From the IDEA to the INDUSTRIAL SCALE

Central for this development was long-term perspective of TINE SA the support of Forskningsrådet

R&D focus on system level

2016 HighEFF

2019 IPN-SkaleUP 2022

Supply of HE to SkaleUP

2015 KPN- HeatUP 2018

R&D focus on component level RA2
Input from SkaleUP to RA3 and RA6

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NEW dairy - Fully heat pumps based system

Simplified process diagram

All dairy processes are integrated with each other.

The system design has focus on maximal waste heat utilisation. 95% waste heat utilisation were documented.
Summary and conclusions

- Simultaneous utilisation of evaporator and condenser/gas cooler is key
- New dairy:
  - Reduced process temperature requirements from 120 °C to 95°C
  - Optimal thermal storage temperature level and size
  - Energy savings up to 65%
  - CO₂-Reduction 95% (compared to gas + NH₃-chiller)
- Dairy retrofit:
  - High Temperature lift (>110K) Cascade required --> high flexibility
  - Industrial pilot R290/R600 300kWth @ 110°C to 115 °C integrated and in full operation
  - Energy saving potential 62%, CO₂-Reduction potential 94%
  - Energy saving potential at Trondheim site 54%

➢ Chillers, HP und HTHP with natural working fluids are favourable for sustainable and efficient food production
➢ Using natural refrigerants can prevent the uncertainty of future restrictions and ensure future-proof operation
ENOUGH
European food chain supply to reduce GHG-emissions by 2050

NTNU – Trondheim
Norwegian University of Science and Technology

HighEFFLab

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement Nº 101036588
Absorption-Compression Heat Pump (ACHP)

The ACHP prototype in the NTNU lab

Flow diagram of the ACHP prototype in the NTNU lab
Absorption-Compression Heat Pump (ACHP)

The following challenges were identified to further improve the application range and system efficiency → 150°C target

1. Efficient and cost-effective absorber and desorber design
2. Efficient liquid-vapor mixing and distribution process
3. Reduction of compressor discharge temperature
4. Selection of suitable compressor lubrication
5. Realization of oil-free system operation
6. Cavitation protection of the solution pump
R&D Project Friendship – HTHP for integration of Solar Energy

• FRIENDSHIP - Forthcoming Research and Industry for European and National Development of SHIP (Solar Energy in Industrial Processes)

• HTHP focus is on test of water steam centrifugal compressors at elevated pressures towards 200°C

• Development of concepts for 300°C (theoretical)

Source: D31INI1.pdf (friendship-project.eu)
R&D Project TRINFLEX – HTHP for CCS

- The overall objective of TRINFLEX is to drive the decisive evolution of process industries towards the net-zero goals for 2050.
- Total 28 partners
- HTHP focus on enabling Renewable and energy efficient CCS (Carbone Capture and Storage)
R&D Project TRINFLEX – HTHP for CCS

• The overall objective of TRINFLEX is to drive the decisive evolution of process industries towards the net-zero goals for 2050.
• CCS – Carbone Capture and Storage
• Study effects of different solvents and operation parameters
• Lab scale development and integration of steam producing HTHP

– SINTEF (2 departments)
– Svalin Solar
Summary, Discussion and Questions

→ HTHP need? Yes, please, best already yesterday!
→ HTHPs available?
  Yes, but not many.
→ Only natural refrigerants are considered as safe long-term investment
→ R&D trends towards implementation of new applications (lab scale), Industrial piloting for established process
→ The end-user need to gain confidence in the technology
Technology for a better society