HTHP for Simultaneous Process Cooling and Heating - SkaleUP

Figure 1: SkaleUP cascade HTHP installed in 10 feet container, Trondheim Norway

Picture: SINTEF Energi AS, Christian Schlemminger

Summary of demonstration case

The SkaleUP Cascade HTHP is a unit developed for a) simultaneous ice- and process hot water production or b) utilization and upgrade of low temperature waste heat, i.e. from dry-cooler circuits. The HTHP is placed in a 10 feet shipping container serving as a machinery room, having ventilation and gas detection. SkaleUP is integrated as a retrofit for existing boilers at a dairy of TINE SA located in Trondheim Norway. Here, both operation modes are under validation.

The dairy is producing about 75 million liter milk products per annum. It´s process cold and heat supply is simplified depicted in Figure 2. The process cold is supplied by NH_3-chillers 80%, a CO_2 heat pump 10% and the SkaleUP cascade HTHP 10%. Process heat is supplied by electric boiler 90% and the HTHP 10%. Fresh water heating, mainly used for cleaning in place (CIP), is covered by the CO_2 heat pump working in transcritical operation. District heating and oil-fired boilers are serving as backup for the heat supply.

The SkaleUP cascade HTHP uses natural working fluids and it´s design comprised of:

- Classical cascade cycle with direct cascade heat exchanger and internal heat exchangers
- Working fluids low-temperature cycle R290, high-temperature cycle R600
- Heat source: a) ice water 5°C → 0,5°C, secondary water/glycol circuit 3 °C → -1 °C supplies heat to R290 evaporator, b) Water/glycol from existing dry cooler circuit 20°C → 12°C, secondary water/glycol circuit 18 °C → 10 °C supplies heat to R290 evaporator
- Heat sink side direct exchange to pressurized process hot water 95 °C → 115°C, 300kW_{th}

The HTHP development started in 2015 under the umbrella of the HeatUP-project (Grand NFR-243679) and HighEFF (Centre for Environment-friendly Energy Research, 257632/E20) analyzing the needs of sustainable heat supply different industrial processes and developing a laboratory scale HTHP system with 30 kW_{th} condenser capacity lifting form 0 °C to 115 °C. In 2019 the project consortium (Skala Fabrikk AS, TINE SA, Cadio AS and Officine Mario Dorin S.p.A and SINTEF) teamed up supported by The Research Council of Norway (Grand NFR-296374) to develop an industrial HTHP system and demonstrate the technology at a dairy of TINE SA.

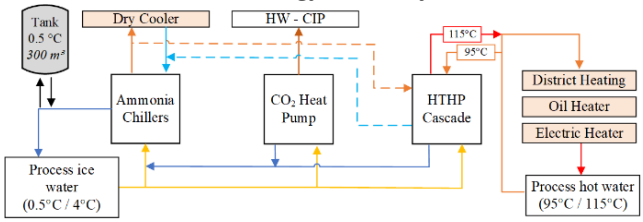

Figure 2: Simplified integration of the SkaleUP cascade HTHP

Operating experiences

The analysis carried out during full operation of the dairy and covers the ice water operation mode. The load profiles of the process heat and cold indicate a simultaneous demand, with peak shift of up to two hours.

Peak loads are 1.6 MW_{th} process heat and 1 MW_{th} cold. Minimum demand is in both cases about 200 kW_{th}. The $COP_{combined}$, where both heat sink and heat source are considered, is the best KPI for heat source and sink utilization with small temperature glides with less than 30 K. A comparison of the $COP_{combined}$ and $COP_{heating}$ is depicted over the temperature lift in Figure 3. Thus, the $COP_{heating}$ is used to predict the operation using the dry cooler circuit as heat source.

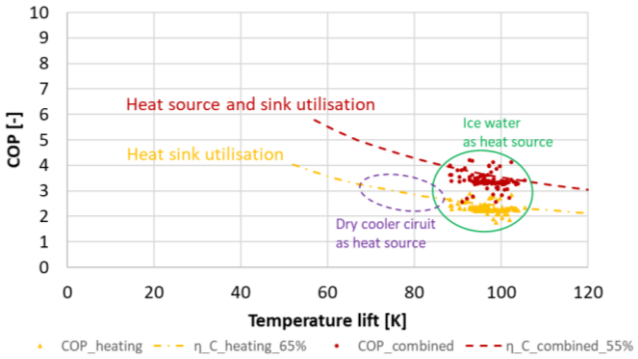

Figure 3: Performance of SkaleUP cascade HTHP

For a 100 K temperature lift the COP combined is in the order of 3.4, giving a Carnot-efficiency of 54%. The COP heating is about 2.3 at the same conditions resulting in a Carnot-efficiency of 65%. The analysis conducted allows a projection of the low temperature waste heat utilization from, i.e. dry coolers to a $COP_{heating}$ in the range of 2.5 to 3.3 for a temperature lift in the range of 85 K to 70 K.

Considering a typical production week, where all the thermal process heat of 117 MWh_{th} is supplied with the SkaleUP cascade and operation of the transcritical CO_2 heat pump results in a remaining ice water cooling demand of 5.9MWh_{th}. Considering a $COP_{cooling}$ of 4.5 for the remaining ice water production, results in a reduced primary energy consumption from 126 kWh to 58 kWh or 53%. Secondary effects, of the HTHP integration is the reduced peak load of the electric grid compared to electric boilers as well as reduction of CO_2 emissions of up to 94 %, compared with a natural gas based heat supply.

Special learnings

A continuous work on the HTHP topic and the awareness of the potential allowed the end-user to tune the production process i.e. reducing the supply temperature in the existing dairy. Further, reduction potential can be utilized by designing new processes and plants optimized for HTHP integration, as conducted in the dairy TINE Bergen, Norway.

FACTS ABOUT THE CASE

Intallation year: 2021
Operating hours: 6500 hours/a
Working fluid used: R290, R600
Compressor technology: piston (semihermetic),
System manufacturer: Skala Fabrikk AS
Performance in design point:

- **Heat source:**
  - Ice water mode 5 °C → 0 °C, water
  - Waste heat mode i.e. 20 °C → 12 °C, water/glycole
- **Heat sink:** 95 °C → 115 °C, pressurized water
- **Heat supply capacity:** 0.3 MW_{heat} + 0.15 MW_{coold}
- **COP:** (Measured at seconday side close to HTHP)
  - Ice water mode 3.4 ±0.3, T_{lift} 95K ±10K
  - Dry cooler mode estimated 2.5 to 3.2

Investment cost: 500 €/kW to 700 €/kW thermal supply capacity (sink + source)
Savings: up to 62% primary energy
Estimated annual CO_2 savings: up to 94 %
Link to webpage or report: Schlemminger et al.: HTHP mit natürlichen Kältemitteln, DKV-Tagung 2021 Dresden, Germany

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All information were provided by the supplier without third-party validation. The infomation was provided as an indicative basis and may be different in final installations depending on application specific parameters.