Development and Integration of Steam Producing High-temperature Heat Pump in the Sugar Industry

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Introduction
High-temperature steam-producing heat pumps are emerging as a key technology for decarbonizing the food industry. This presentation focuses on the development, integration, and testing of such a steam-producing heat pump which is being demonstrated as part of the Horizon Europe project “SPIRIT" [1].

The high-temperature heat pump has been developed and built by GEA (the Heating & Refrigeration Technologies department in Berlin). The heat pump is installed and integrated at Tiense Suikerraffinaderij, which is a Belgian sugar factory, where it utilizes low-grade waste vacuum steam at around 75 °C from the sugar evaporation process to deliver process steam at approximately 140 °C with a thermal output of up to 4 MW. This integration demonstrates how high-temperature heat pumps can replace a portion of the fossil-fuel-based steam supply in a highly energy-intensive process, which in this case yields an estimated annual CO_2 saving of 3,500 t/a.

Methods
Figure 1 shows the layout of the heat pump and Figure 2 shows an overall process flow diagram. The natural refrigerant R-601 were chosen as a working fluid, which gives the requirement to the cycle layout for an internal heat exchanger (IHX) to provide sufficient superheating of the suction gas (see point 4 in Figure 2). In addition to this, another “start up” heat exchanger is also included which during start-up shortly creates the possibility of also superheating the suction gas with heat from the steam system until the IHX takes over. The heat from the oil cooling is recovered in the process with an intermediate water circuit (see point 7 and Figure 2).

The screw compressor has a double shaft seal and is driven by a 1.4 MW electrical motor with a frequency drive, and the both the condenser (point 3) and evaporator (point 6) are shell-and-tube heat exchangers, with a width of 9 m and 7 m, respectively.

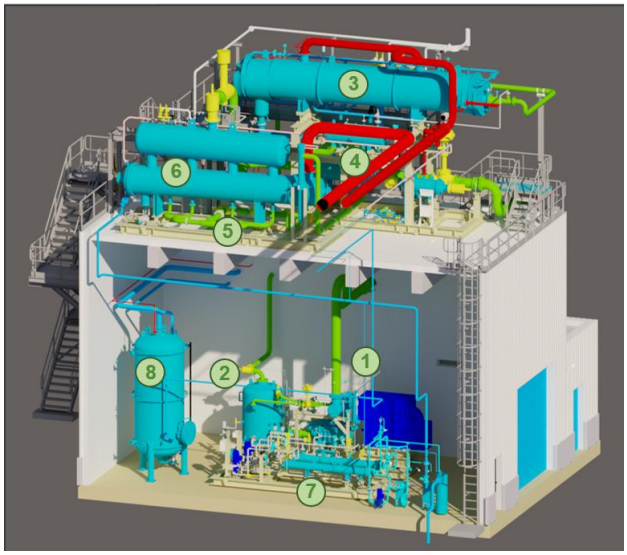

Figure 1: Layout of the heat pump.

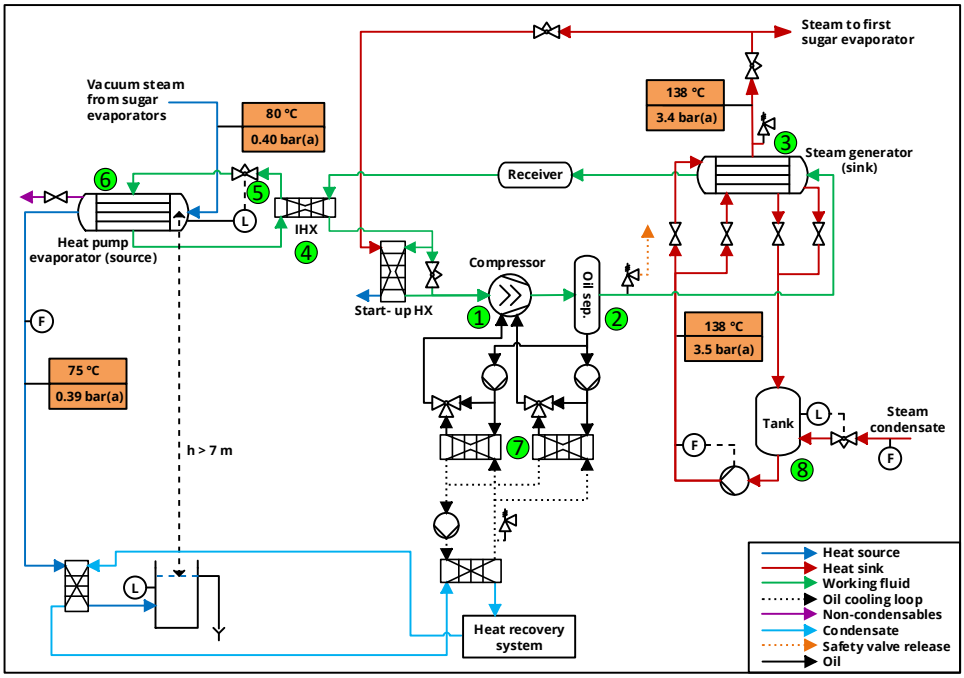

Figure 2: Flow diagram of the heat pump.

For the integration of the heat pump a new machine room building (full Atex inside) were constructed, see Figure 3. This consists of compressor room in the bottom (left side) where also the oil coolers, oil separator and a condensate tank are located. On the top floor the large heat exchangers are located in ambient conditions (right side of figure). The elevated height with the Pentane evaporator on the top floor is an advantage in order to avoid issues with NSPH for the condensed vacuum steam.

Figure 3: Heat pump building.

The heat source with vacuum steam is in general dependent on the sugar production process, hence careful operation is needed to ensure optimal and stable operation for the heat pump, as well as for other consumers that is part of this large steam network. Several preventative measures has been taken to avoid air or condensed water being trapped in the vacuum steam line for the heat source of the heat pump. Other improvements and investigations were also made during commissioning, e.g. adding more trace heating to selected places, installing a motorized valve, and adding plates in the heat exchanger for the oil cooling loop. And in general finetuning of the control and start-up sequences has been made.

Results and discussion

Selected results from the operation of the heat pump are shown in this section. In Figure 4 the temperatures during a start-up sequence is shown. The discharge temperatures (blue line) are close to 165 °C, while the saturation temperature of R-601 (orange line) is 143 °C. The temperature of the steam produced (red curve) is 138 °C, while the measured temperature of the vacuum steam used as heat source here is around 73 °C, and the evaporation temperature is around 67 °C. The open-type compressor without high requirements to suction gas cooling allows for relative high suction temperatures, in this case around 112 °C.

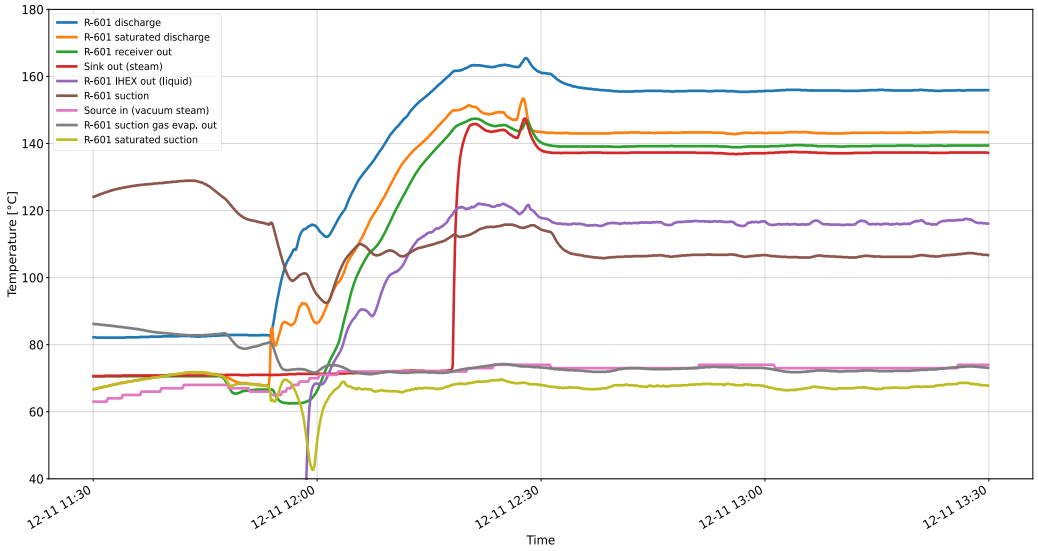

Figure 4: Temperatures during start-up sequence.

The discharge pressure and suction pressure for R-601 were in steady-state 14 bar(a) and 2.6 bar(a), respectively after the start-up period, and in this case with full compressor speed at 3600 RPM around 3.0 MW of steam was made with a COP of 2.9 and a η_{Lorenz} of 46 %.

In Figure 5 and Figure 6 the change in temperature and pressure are shown in a case where during full load conditions at 19:30 a change in the steam valve after the condenser was changed from full open to 14 % open, and then changed back to full open at 03:00.

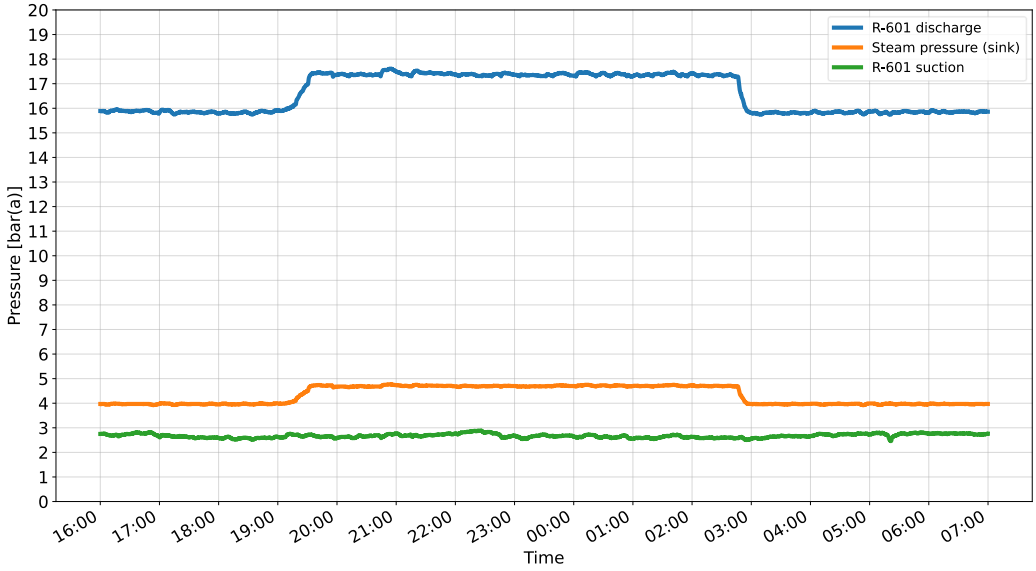

Figure 5: Change in pressures during change of steam valve after the condenser.

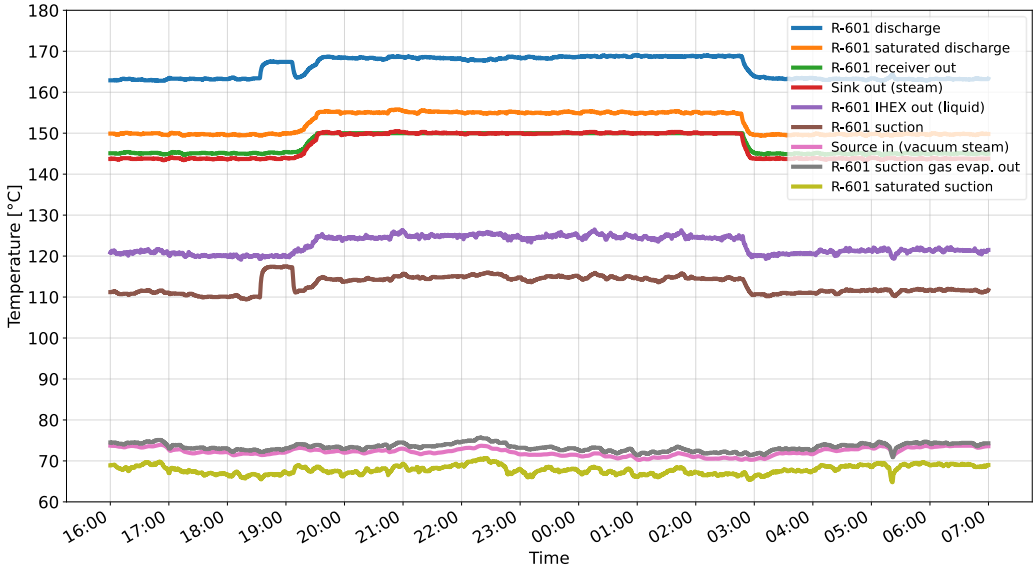

Figure 6: Change in temperatures during change of steam valve after the condenser.

This changed the steam pressure from 4.0 bar(a) (144 °C sat.) to 4.8 bar(a) (150 °C sat.) and the pentane discharge pressures from 16.0 bar(a) to 17.3 bar(a), causing a change in thermal steam capacity from around 2.5 MW to 2.3 MW.

Conclusion and perspectives

The project underlines the potential for enhancing energy efficiency and accelerating industrial decarbonization by using advanced heat pump solutions, which is here demonstrated in a real industrial environment. The project hence serves as a concrete example of the applicability and benefits of steam-producing high-temperature heat pumps in the food industry, supporting the broader transition towards climate-neutral process heat in Europe.

Successful and stable operation with the steam producing heat pump has been demonstrated at steam temperatures up to 150 °C. Further long-term testing is planned to continue in upcoming sugar production campaigns. There is a continuous focus on system optimization such as flooded/spray mode for the steam generator and control/influence of variations of source boundary conditions.

Acknowledgements

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References

[1] “SPIRIT - Fostering the decarbonisation of industry through high-temperature heat pumps,” 2026. https://spirit-heat.eu/