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DECARBONISATION THROUGH INNOVATION

Demonstration of a steam producing high-temperature heat pump in the sugar industry

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Abstract

Steam-producing heat pumps is a key technology for decarbonizing the food industry. This paper 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". The heat pump has a single screw compressor and is based on Pentane (R-601) as a working fluid. It is installed in a sugar factory, where it utilizes low-grade waste steam from the sugar evaporation process to deliver process steam at approximately 140 °C with a thermal output up to 4 MW.

Recent results from the demonstration test period, and practical experiences with the integration of the heat pump into the existing factory processes, will be presented. Hence, this paper highlights 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.

Keywords: High-temperature heat pumps, steam production, industrial decarbonization, demonstration

1. Introduction

High-temperature heat pumps (HTHPs) is recognized as an essential technology in the transition to sustainable industrial process heating, for instance reflected in the International Energy Agency's Net Zero by 2050 Roadmap, which calls for HTHPs to cover 15 % of low/medium-temperature industrial heat demand by 2030 and 30 % by 2050 [1]. The R&D project SPIRIT under the Horizon Europe Framework Programme supports the development and demonstration of high-temperature heat pumps to produce steam for process heating in energy-intensive processes [2].

The core of the "SPIRIT" project is three industrial demonstrations, where one case is the development and demonstration of a high-temperature heat pump developed by GEA Refrigeration Germany, which is integrated into the energy supply of steam for process heating in an energy-intensive sugar refining process at Tiense Suikerraffinaderij, which is a sugar factory operated by Tiense Suiker and located in Tienen, Belgium. In this diffusion process, sugar is extracted from the beets by cutting them into cossettes and bringing them into contact with warm water. The resulting sugar-rich solution is then concentrated through several falling film evaporation steps, in the end resulting in the production of sugar as the final product. The newly developed heat pump generates steam at temperatures around 140 °C for the first evaporator, utilizing a heat source consisting of around 75 °C vacuum steam from one of the last evaporators. The heat pump is based on a screw compressor with a double shaft seal using Pentane (R-601) as a refrigerant, and has a thermal heating capacity around 4 MW which provides up to 6 % of the total heat demand for steam in the sugar factory, which yields an estimated annual CO_2 saving of 3,500 t/a.

2. Methods

Several assessments and development activities have been made to design and operate the compressor and heat pump at a higher temperature. For proprietary reasons these cannot be disclosed in detail, but among other this includes the selection of a suitable oil type, material selections for the bearings and sealing materials, and thermal insulation of selected electrical equipment.

Figure 1 shows a 3D 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 in Figure 2).

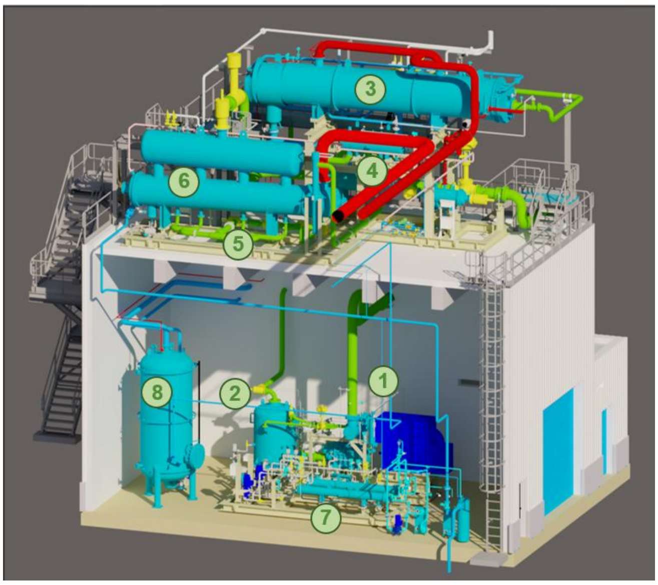

Figure 1. Layout of the heat pump.

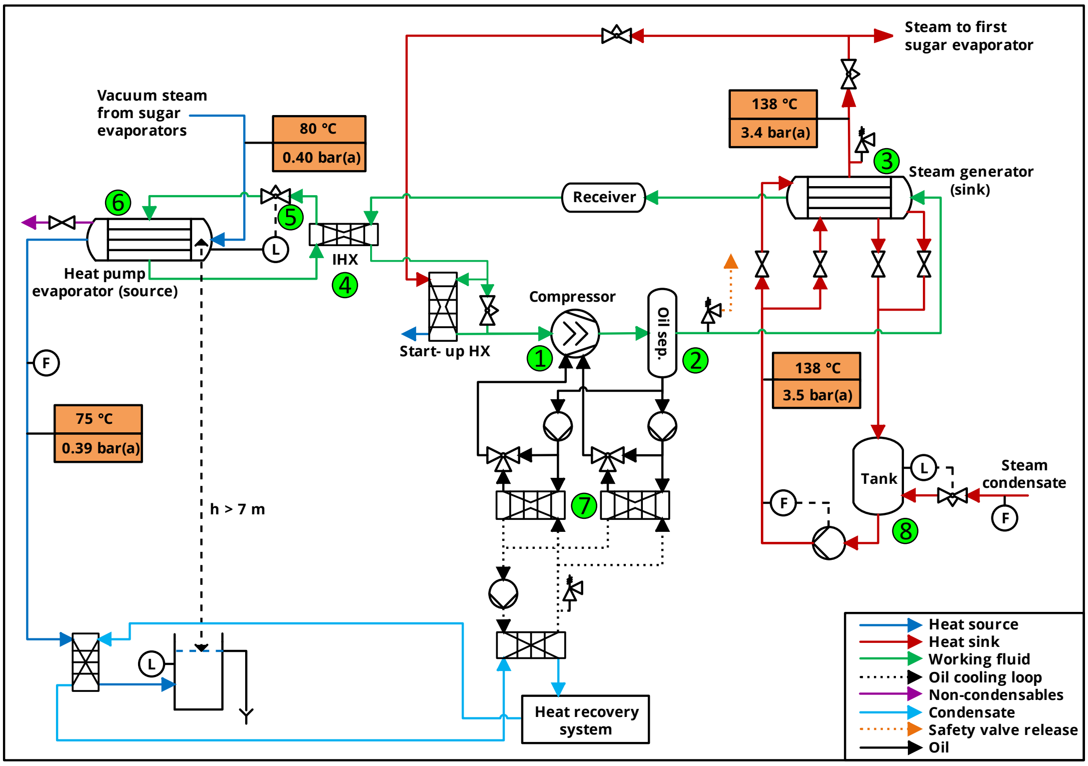

Figure 2. Flowdiagram of the heat pump.

The compressor (Figure 2, point 1) is driven by a 1.4 MW electrical motor with a frequency drive, and the both the condenser (point 3) and evaporator (point 6) is shell-and-tube heat exchangers, with a width of 9 m and 7 m, respectively. Both are made in stainless steel, which creates the possibility for the operator to be able to clean the steam side of the exchangers, if necessary, which was a requirement in this case.

For the integration of the heat pump a new machine room building were constructed. This consists of compressor room in the bottom where also the oil coolers, oil separator (point 2 in Figure 2) and a condensate tank (point 8 in Figure 2) are located. On the top floor the large heat exchangers are located in ambient conditions. The elevated height of the Pentane evaporator is an advantage in order to avoid issues with NSPH for the condensed vacuum steam.

Throughout the project there has been a high focus on safe design, and hence safe operation of the heat pump. Relevant regulations, directives, and standards have been used during the design such as for example IEC 60079-10 about electrical apparatus for explosive gas atmospheres. Hence several Atex aspects have been handled which for instance includes the installation of several gas detection sensors, advanced ventilation system, and an anti-static floor in the machine room. See Figure 3 for pictures of the compressor machine room (left) and heat pump building (right).

Figure 3. Pictures of the GEA heat pump installed on-site in Tienen.

3. Results and discussion

The sugar is produced during two main production campaigns. The regular beet campaign is typically starting in September and running to January, and subsequently a thick juice campaign from around March to May. As a part of the commissioning of the heat pump, the first operation in part load with the heat pump was carried out at the end of the thick juice campaign in 2025.

After the first experience with testing of the the heat pump, the time towards the beet campaign in the fall 2025 were utilized for making several improvements and investigations, such as making oil analyses, re-installing a repaired bypass valve in the Pentane discharge line, installing a motorized valve in the oil rectifier line, and adding more trace heating to selected places. On the condensate/steam side of the system the number of plates in the heat exchanger for the oil cooling loop was increased, and preventative measures was taken to avoid air or condensed water being trapped in the vacuum steam line for the heat source of the heat pump.

After these improvements further demonstration and testing of the heat pump continued in the beet campaign in the fall of 2025 and thick juice campaign 2026. In the following figures a start-up sequence for heat pump is shown followed be a 1.5 hours test period on 12th of November where the heat pump reaches steady-state conditions. Figure 4 shows the compressor speed and the power used by the compressor. After around 20 minutes the compressor is running at full capacity with 3600 RPM and a power consumption just above 1 MW.

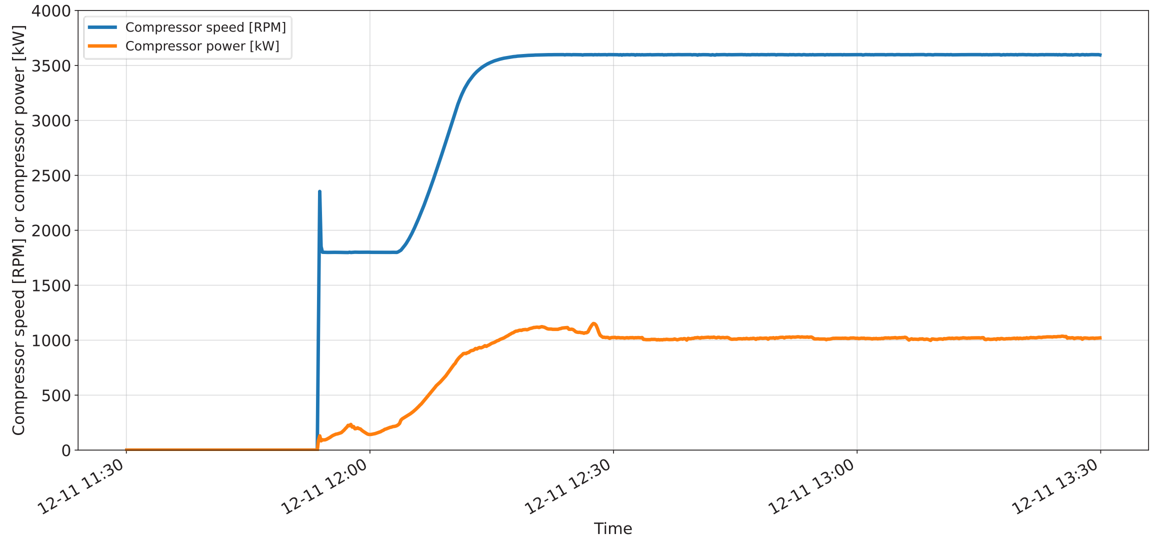

Figure 4. Compressor speed (blue) and power (orange).

Figure 5 show the discharge pressure and suction pressure for R-601, with values of around 14 bar(a) and 2.6 bar(a), respectively after the start-up period.

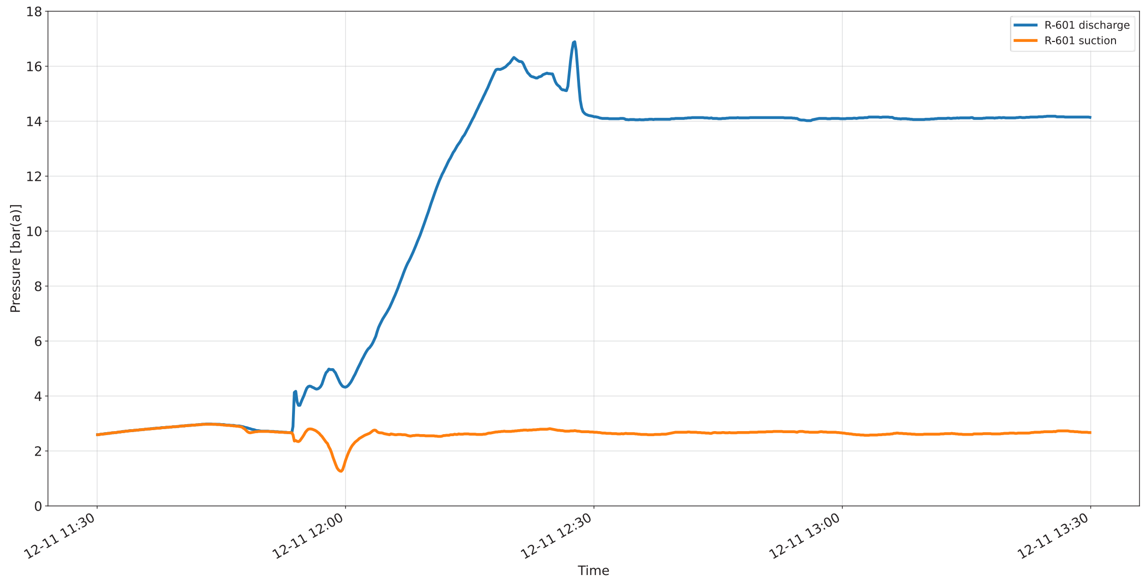

Figure 5. Discharge and suction pressure during testing of heat pump.

Figure 6 on the next page shows several temperatures in the system during start-up. During start-up 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.

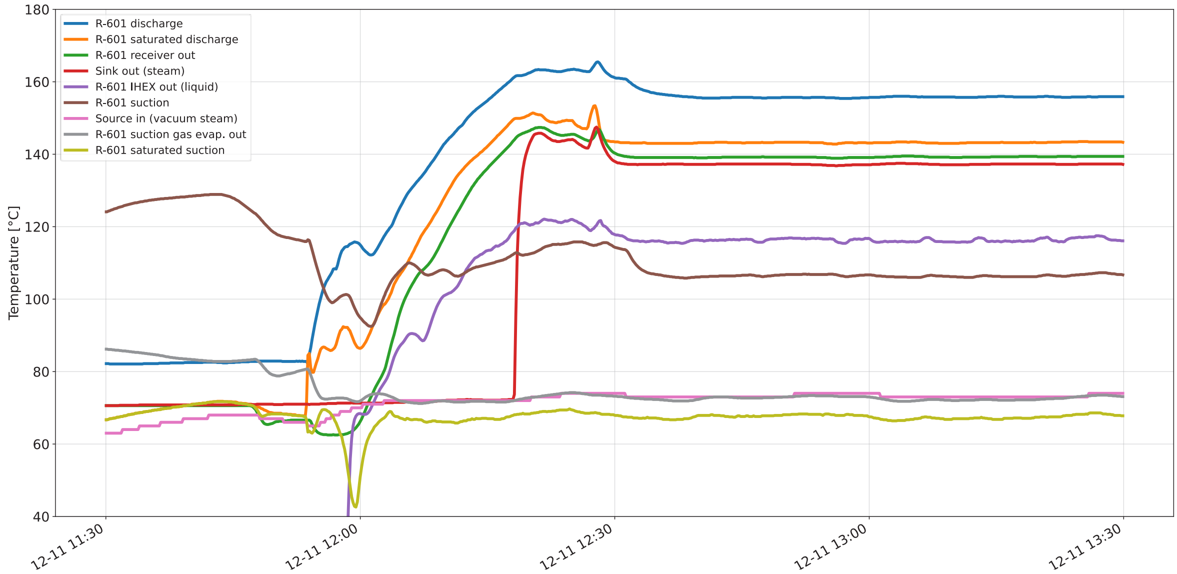

Figure 6. Temperatures during testing of heat pump.

Figure 7 shows the flow rates of both flow to the condensate tank (point 8 in Figure 2) in orange, and also in blue the flow on condensate made by the pump located after the condensate tank and the steam generator (heat sink side). It can be seen that after the start-up period a steady state value around 5 m^3/h is sent to the system which is this case corresponds to a steam flow produced around 3 MW and a COP of 2.9 in this case. The steam generator is here controlled in "spray mode", meaning an overflow of condensate flow is pumped to the steam generator and sprayed into the steam generator through an array of nozzles, in this case with a flowrate of around 42 m^3/h, where around 5 m^3/h of the condensate evaporates as steam and the remaining returning to the condensate tank. An alternative method to operate the steam generator is in "flooded mode", where a lower flow of condensate flow is pumped to the heat exchanger where the condensate flow not evaporating can return to the condensate tank through different overflow pipe connections.

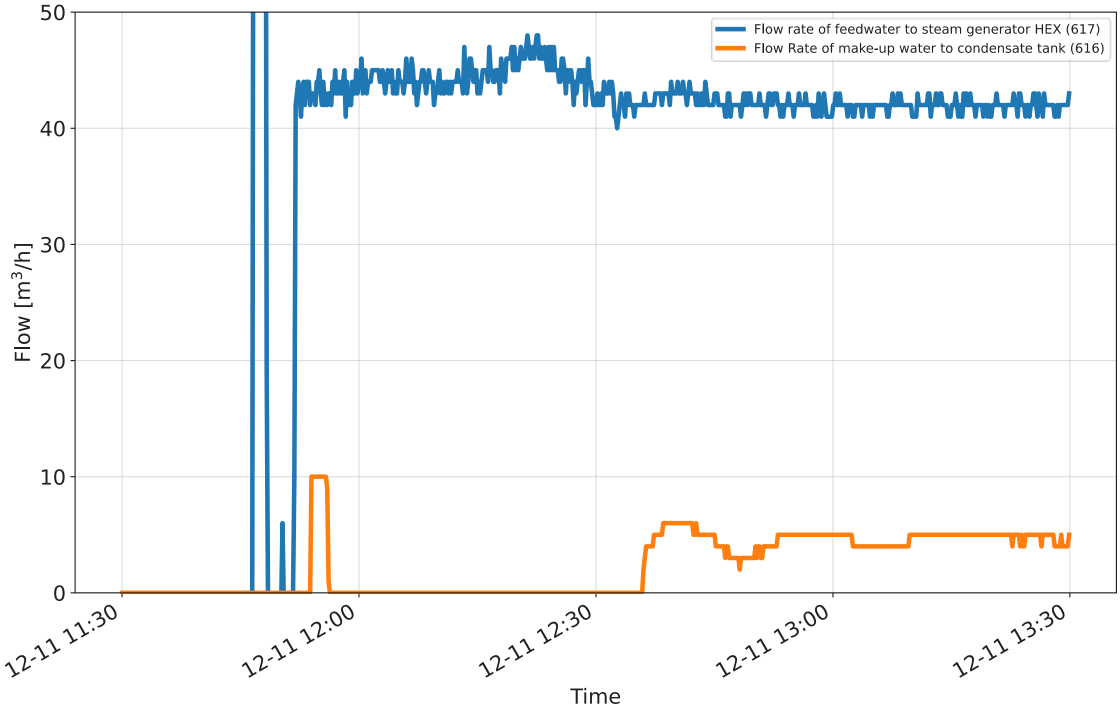

Figure 7. Flow rates of condensate for both condensate tank and steam generator HEX.

In figure 8, on the left hand side, results from a test with a higher steam pressure can be seen. 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. 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.

In figure 8, right hand side, the temperatures during operation in the thick juice campaign is shown. The heat pump is here making saturated steam a 115 °C with a thermal capacity around 3.4 MW and a COP of 3.7 at full load conditions.

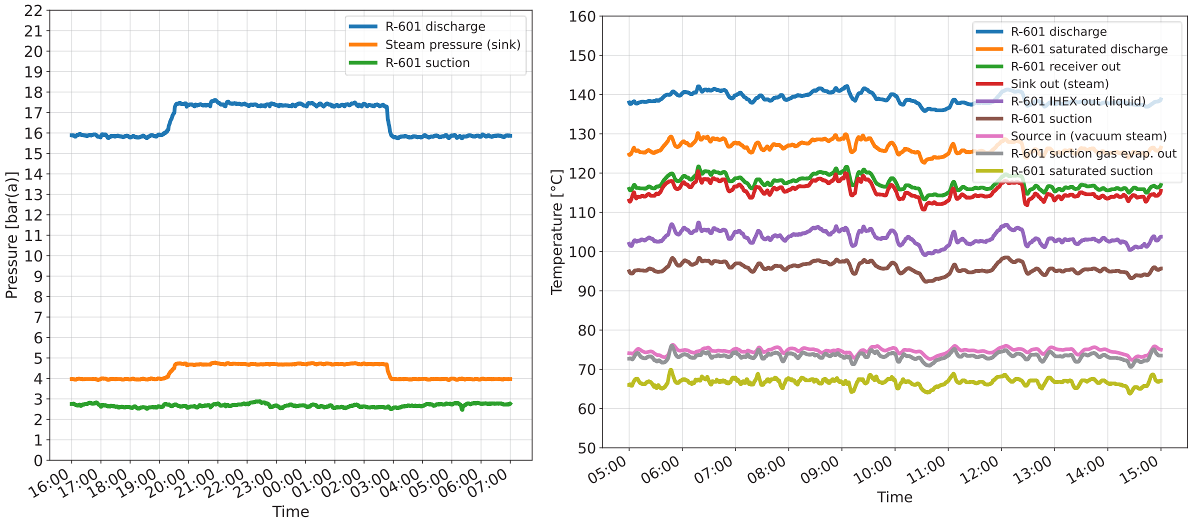

Figure 8. Left side: Change to higher steam pressure. Right side: Temperatures during operation in “thick juice” production campaign.

4. Conclusions and perspectives

This paper presents the development and design of GEA steam-producing high-temperature heat pump installed at a sugar factory at Tiense Suiker in Belgium. This demonstrator has been made as part of the SPIRIT project.

After the initial commissioning the heat pump has been operated successful and stable in different conditions. Steam temperatures up to 150 °C has been demonstrated in the beet campaign, and a of COP of 3.7 and a thermal capacity of 3.4 MW has been achieved during the “thick juice” campaign. Further long-term testing is planned to continue in upcoming sugar production campaigns, and there is a continuous focus on system optimization such as operation in flooded/spray mode for the steam generator and fine-tuning the control during variations of the source boundary conditions.

The heat pump shows the potential for further expanding the use of heat pumps at the factory, where the main part of steam production is currently produced at same temperature level as demonstrated here. 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.

Acknowledgements

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[2] “SPIRIT - Fostering the decarbonisation of industry through high-temperature heat pumps,” 2025. https://spirit-heat.eu/