

SPiRiT Demonstration Case 2 - Integration of Heat Pump Technology in a Sugar Production Plant

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Keywords:

High-temperature heat pump, R-601, industrial process heating, steam generating heat pump

Introduction

The core of the SPiRiT project consists of three full-scale demonstrations of high-temperature heat pump technologies in industrial processes. The second demonstration case presented in the poster aims to use a heat pump to partly electrify the sugar production process by generating the part of the steam produced by fossil fuel-driven boilers. The overall goal of the project is to demonstrate that it is possible to decarbonize the whole process and replace fossil fuels. The poster will present an outline of the heat pump system and the integration in the process as well as the planned testing activities.

Methods

The end-user of this demonstration is a sugar production plant located in Belgium and owned by the sugar producer Tiense Suikerraffinaderij, while the technology supplier is GEA Refrigeration Germany and the research institute involved is Danish Technological Institute (DTI).

The production of sugar is an energy-intensive process, as it requires steam to crystallize sugar from a solution. In the process at Tiense Suikerraffinaderij the sugar solution is sent through a multiple-effect evaporation line, with nine evaporator units that operate at decreasing pressures. The purpose of each evaporator unit is to increase the concentration of the sugar solution by evaporating part of the water. The heat source used for the evaporation is steam, that condenses in the evaporator unit. The water evaporated from the sugar solution in each evaporator unit is used as a heat source for the next evaporator unit. Currently, the steam is generated by a fossil fuel-driven boiler and the goal of this demonstration is to divert 4 MW of heat from the boiler to a high-temperature heat pump. The heat pump will run in parallel with the existing boiler to produce steam by re-heating condensate from one of the evaporators.

The plant operates two production campaigns every year: the main campaign runs from September to January and requires steam at around 138 °C, and the secondary campaign runs from March to May with a steam temperature of 114 °C.

The first step for demonstrating the technology is the design phase, where the technology supplier and the end-user generate the basic and detailed engineering of the heat pump skid and plant site, respectively, and the research institute develops models and provides scientific guidance. The design is

followed by a construction and commissioning phase, where the ordered components will be installed and integrated into the plant site. Finally, a testing program will be performed to monitor and validate the performance of the system.

Results and discussion

The basic design and engineering of the demonstration case have been completed and detailed engineering is currently being carried out to determine details and to make final decisions before the construction of the heat pump. Detailed piping & instrumentation diagrams for both the heat pump and the integration with the steam system have been developed. The main components have been designed and ordered.

Figure 1 shows the process flow diagram during the main production campaign. The heat pump uses n-Pentane (R-601) as a refrigerant and a GEA screw compressor. The heat source of the heat pump is vacuum steam around 80 °C from the last sugar evaporators, which has no direct use in the production. On the sink side, the heat pump produces steam by reheating the condensate from the first sugar evaporator, from which condensate is available at the highest temperature (around 138 °C). The condensate is evaporated and delivered back to the sugar evaporator at the saturation temperature of 138 °C.

The sink and source heat exchangers that have been selected are both shell-and-tube types. The refrigerant is on the tube side of the sink and on the shell side of the source. The source heat exchanger features an outlet for the extraction of non-condensables, as these might collect on the tube side. Different substances (non-condensable gases, ambient air, sugar droplets, calcium salts) can be expected in the heat exchangers and it will be necessary to clean the system with alkaline and acid solutions once a year. Therefore, the heat exchangers and piping material that is in contact with the steam system of the sugar plant should be stainless steel. An oil separator is placed after the compressor and the water used for cooling the oil comes from another process within the sugar plant. Since there are no intermediate loops between the heat pump and the steam from the sugar factory, detection sensors will be added in the sink, source, and oil cooling loop to detect any potential leaks in to the steam system of the sugar plant.

To avoid condensation of the refrigerant during compression, the refrigerant after the evaporator is superheated in an internal heat exchanger. During startup, when the hot side and the cold side of the internal heat exchanger are approximately at the same temperature, alternative actions to avoid condensation during compression are decreasing the compressor suction pressure or superheating the refrigerant using a different heat source. Therefore, it is proposed to place a regulating valve on the suction side of the compressor to regulate the pressure during startup, and to install an additional start-up heat exchanger using steam taken from the first sugar evaporator as a heat source.

The total heat demand of the sugar production plant is many times larger than the output of the heat pump and therefore the heat pump will normally be operated at maximum capacity during the whole sugar production campaign, except during the part load testing. Even with fluctuating inlet conditions at the sink side, the steam level in the sink heat exchanger is kept constant by an overflow control that regulates the pumps feeding the sink side. On the source side, the flow of vacuum steam is self-regulated because the flow is generated by the condensation of steam which adds to a liquid column, which forces water through the pipe.

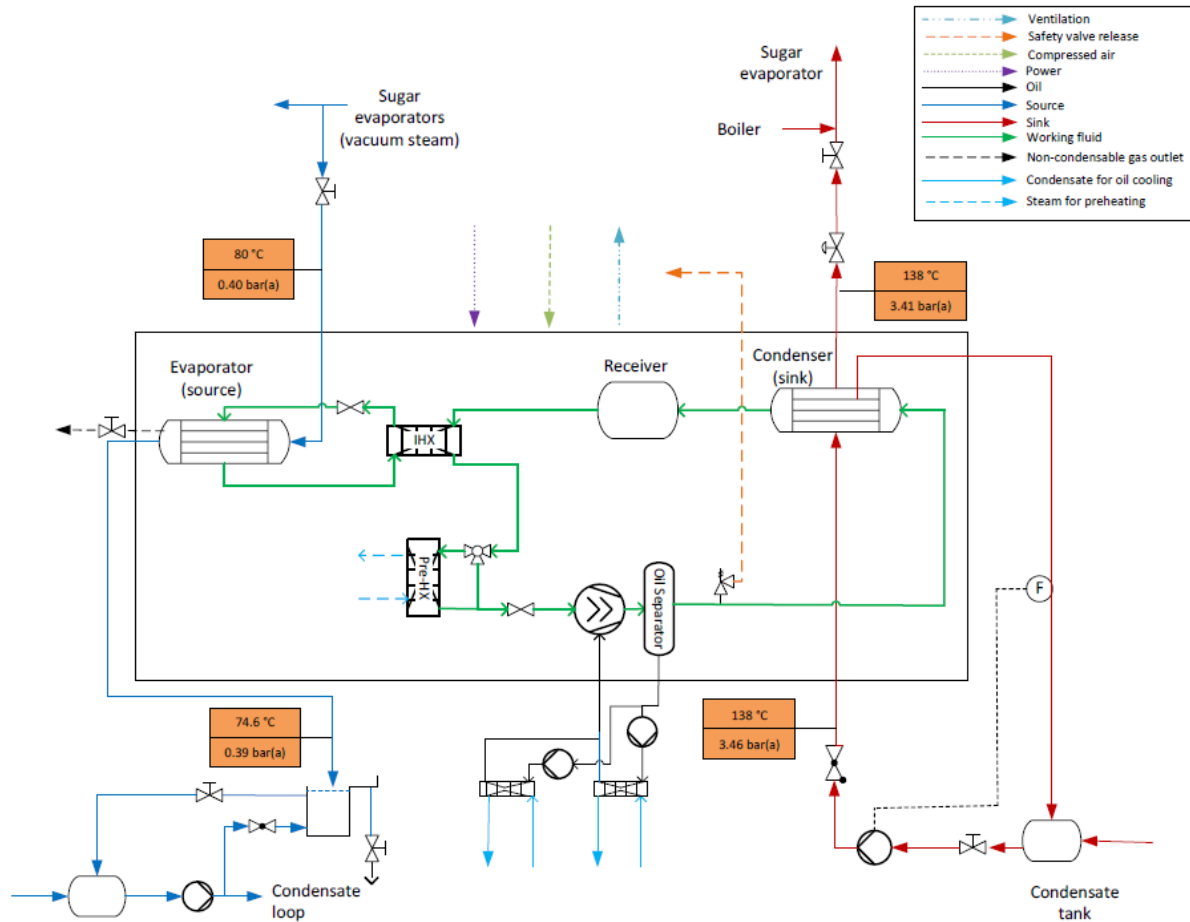


Figure 1: Process flow diagram

According to preliminary process balances calculations, the expected savings in CO₂ emissions are 2438 and 1560 tons of CO₂ in the main and secondary production campaigns, respectively (assuming emissions-free future electricity production and 208 gCO_{2eq}/kW_{th} in the present heat production). A steady-state model of the heat pump was developed using Engineering Equation Solver (EES), a general equation-solving program used to solve systems of simultaneous non-linear equations. The model was used for different purposes during the design phase, e.g. to choose which refrigerant to use, calculate overall mass and heat balance as well as COP, evaluate the effect of pressure drops, and calculate the effect of having a decrease in suction pressure during startup.

Finally, some aspects of the heat pump design and demonstration layout are currently being investigated before a final decision can be made. Different options are being considered for the location of the heat pump, in the same building as the sugar evaporator units or outside in a new building. The selection of the screw oil for the compressor is between three candidates: one non-food grade and two food-grade oils.

A testing program covering a wide range of operating conditions has been designed to validate the technology. The tests will run for at least 2000 hours to demonstrate the robustness and reliability of the system. The heating and cooling load and the COP of the heat pump will be determined at full load and part load and under off-design conditions. Moreover, the testing will be used to test the startup and shutdown process, monitor the oil quality, noise, and vibration level of the heat pump, determine optimal values of process conditions to increase efficiency and generate data for modelling a digital twin.

Conclusions

The project is ongoing and is currently at the end of the design phase. The components and control philosophy have been designed, while other aspects such as the heat pump location and the choice of compressor oil are not yet determined. According to the expected timeline, the components will be delivered in June 2024 and the heat pump will be installed between June and August 2024 and commissioned between September and October 2024 and the testing is foreseen to commence in November 2024 during the main production campaign.