High-Temperature
Heat Pump Symposium

SPIRIT demo case I: Full-scale on-site demonstration of a cascade industrial heat pump producing steam at 145 °C

Gustavo Otero Rodriguez[1], *Wouter de Vries*[1], *Miguel Ramirez*[1], *Koen Verplancke*[2], *Jaran Rauø*[3],
Simon Spoelstra[1]

[1] TNO, Sustainable Technologies for Industrial Processes, Energy & Materials
Transition Unit, Petten, The Netherlands, Gustavo.OteroRodriguez@tno.nl /
Miguel.Ramirez@tno.nl
[2] Mayekawa Europe, MYCOM, Zaventem, Belgium
[3] Stella Polaris AS, Kårvikvegen 306, 9307 Finnsnes, Norway

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Extended Abstract

Introduction

Industrial processes are currently responsible for 20% of the total greenhouse emissions in Europe [1]; heat pump technology can achieve a significant reduction of emissions arising from industrial heating by reusing industrial waste heat. A critical factor hindering the deployment of high-temperature heat pumps is the end-user hesitation to disrupt existing processes. This hesitation is partially inherent in capital-intensive industrial sites but also concerns the need for more operational experience. Therefore, the SPIRIT-HEU project aims to demonstrate industrial heat pumps at three different process sites with sink temperatures above 135°C; this will result in a double effect: (1) establishing end-user confidence in the technology and (2) ensuring the technology reaches TRL 7 [2].

Process and industrial heat pump description

Demonstration 1 of the SPIRIT-HEU project is deployed at Stella Polaris, a leading cold-water shrimp processor in Norway [3]. Its production involves multiple stages: thawing, maturing, cooking, cooling, peeling, freezing, and packaging. Heat flows are critical for maintaining product quality. In this demonstration case, the heat pump replaces a propane-fired steam boiler, which consumes approximately 2,700 MWh of fuel annually; the steam is used to cook the shrimps. The refrigeration plant, where the shrimp are frozen for later packing, utilizes a single stage ammonia refrigeration system which rejects its heat in the ammonia condenser to seawater; this waste heat is used as heat source for the SPIRIT-HEU heat pump. With the integration of the heat pump system, the projected primary energy consumption is expected to drop to 1,043 MWh per year, resulting in an estimate CO2 savings of around 621 tons of CO2/year.

The heat pump, manufactured by Mayekawa Europe [4], consists of an industrial heat pump of approximately 700 kWth thermal capacity, which can cover the full demand of the process under normal operating conditions. As mentioned, the heat pump uses the heat rejected from the shrimp freezing plant at ~18 °C and produces steam at 145 °C (4 bar abs) to cook the shrimp. Due to the large temperature lift of over 130 K, a cascade cycle was chosen, see the schematic in Figure 1. This setup includes two connected cycles: an ammonia cycle at the bottom and a pentane cycle at the top. These are linked through a heat exchanger, where the ammonia condenses and transfers heat to evaporate the pentane. The source heat from the bottom cycle heat pump is supplied to the top cycle heat pump at approximately 82 °C. According to performance estimates, the heat pump is expected to achieve a Coefficient of Performance (COP) of 1.8 for heating, and 2.5 for combined heating and cooling performance.

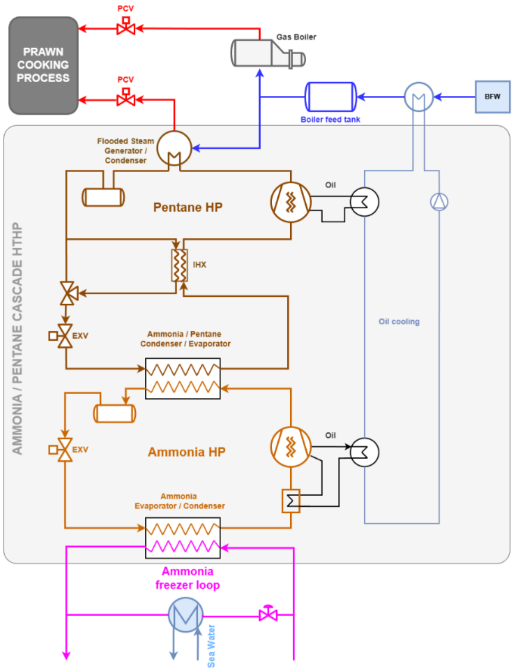

Figure 1. Integration of the cascade heat pump from Mayekawa into the shrimp process of Stella Polaris

Design, modifications, and implementation

Integration:

The integration of the ammonia refrigeration plant with the heat pump was performed with a control valve to divert superheated ammonia vapor to either the existing seawater condenser or to the bottom heat-pump evaporator. The steam utility system is an extension of the existing utility system in place. In an attempt to make the production process fossil free, Stella Polaris has installed an electric steam boiler in parallel to the existing propane boiler in 2023. When in operation, the three utility generators can be operated simultaneously, with the priority order being as follows: (1) Heat pump, (2) Electric boiler, and (3) Propane boiler.

Safety considerations were paramount due to the use of hydrocarbons in the high-temperature (pentane) loop. A dedicated ATEX-compliant housing was constructed to mitigate explosion risks, incorporating anti-static flooring to prevent electrostatic discharge, robust ventilation systems to maintain safe concentrations of vapours, and explosion-proof electrical installations to eliminate ignition sources; a picture of the pentane heat pump being installed into this housing is shown in Figure 2. In addition to these structural measures, safety protocols were implemented, including continuous hydrocarbon gas detection positioned near the steam generator, compressor and condensate lines to enable early leak identification. Furthermore, an emergency blow-down system was integrated to provide controlled venting in case of leakage or emergency conditions, thereby safeguarding both personnel and equipment during operation.

Heat pump

The **ammonia-based heat pump**, see Figure 3, extracts heat from the source through a plate-and-shell evaporator and transfers it to the pentane cycle via a cascade heat exchanger, where ammonia condenses while pentane evaporates. Compression in this stage is provided by a reciprocating compressor designed for stable operation under varying load conditions. Additional components control valves to regulate refrigerant and a control the heat pump.

The **pentane high-temperature heat pump**, see Figure 2, further elevates the temperature to produce saturated steam at approximately 145 °C from the boiling feed water. This cycle employs a custom-designed screw compressor driven by a 355 kW ATEX-certified motor; the compressor was previously tested at TNO's Carnot laboratory [5] to mitigate any potential technical risk. The pentane condenser—a flooded plate-and-shell heat exchanger—condenses pentane while generating steam. Supporting heat exchangers, such as sub-coolers and suction gas superheater are included to prevent condensation during pentane compression, while expansion valves maintain liquid level control and system stability.

An energy efficiency feature of the system is its integrated oil heat recovery strategy, see right side of schematic Figure 1. Both cycles utilize oil coolers that reclaim heat from the compressor lubrication circuits. This recovered heat is used to preheat the boiler feed water before it enters the pentane condenser, where it is converted into steam. By leveraging this secondary heat source, the system improves overall energy efficiency and reduces reliance on external heating/cooling.

Figure 2. Mayekawa's Pentane heat pump being installed at Stella Polaris' site

Figure 3. Mayekawa's Ammonia heat pump installed at Stella Polaris' site

Control software

A software was developed for the ammonia freezing plant (source), ammonia heat pump (bottom cycle of the cascade), pentane heat pump (top cycle of the cascade), and steam utility system to maintain stable operation and steam production. The refrigeration plant uses a pressure control valve and float valve to regulate heat supply and ammonia flow. The ammonia heat pump adjusts it compressor speed to control discharge pressure (and condensation temperature), manages ammonia level via an expansion valve downstream of the liquid receiver (acting as a buffer), and maintains suction superheat through cooling water flow. The pentane heat pump similarly controls steam pressure by modulating compressor speed, regulates pentane level, and adjusts liquid flow for superheat. The steam system uses valves to maintain steam temperature and pressure to cook the shrimps, with backup boilers compensating for demand changes. Start-up and shutdown sequences gradually stabilize conditions, ensuring smooth transitions and equipment protection. A preservation mode can be activated for long term standstill, while maintaining standby healthy conditions with minimal energy consumption.

Given the complexity of needing to control three thermodynamic cycles on top of each other, the software required validation for robustness and fine-tuning under simulated operating conditions, as it is directly connected to the process. This setup left little room for error during the initial startup phase. To mitigate risks, TNO developed a model written in Dymola (Modelica [6]) utilizing components available in TIL suite [7] for the cascade heat pump focused on the dynamic operations (i.e., during start-up, how to ramp up the compressor, how to operate in partial load, how to control the auxiliary system?). Built using reliable data provided by the manufacturer—including component specifications, control narratives, and system architecture—the dynamic model served as a virtual replica of the physical system, enabling early testing and troubleshooting. After analyzing the dynamic simulation, we selected a different expansion valve insert to better cover all operating scenarios.

Status and way forward as of December 2025

Due to an incident during pre-commissioning in February 2025, the commissioning of the heat pump at SPIRIT Demonstration 1 was postponed. The incident involved a failure of the electrical oil heater of the pentane compressor; the oil overheated therefore building pressure until the vessel fail causing an oil spill which triggered damage to associated components and required a reconstruction of the affected equipment. Fortunately, there were no injuries, and ATEX compliance of machine and machine room prevented a further escalation. Following the incident, it was decided to disconnect the pentane heat pump compressor skid and shipped it back to Mayekawa Europe in Belgium, where replacement parts were ordered—including a new oil heater—and the skid was repaired and reassembled. Meanwhile, the building at Stella Polaris was cleaned and made ATEX compliant ones more. The refurbished compressor skid was shipped back to Norway by the end of October 2025. The re-integration of the pentane compressor heat and the rest of the cascade heat pump was completed by early December 2025.

Giving the limited experience among system integrators regarding safety standards/compliance requirements for high_temperature heat pumps, a strict safety checklist was developed by Mayekawa to mitigate any additional incidents during commissioning and startup. This checklist introduces an enhanced precommissioning step to ensure full compliance before the actual commissioning phase begins; which included rechecks on the wiring, junction box connections and its ATEX certified, calibration of refrigerant detection sensors, among other. Following this detailed checklist, the precommissioning will take place in January 2026, followed by refrigerant filling and startup in February 2026.

The expectation is that SPIRIT demonstration 1 will run its test plan during 2026 which combines a short-term dynamic campaign (cold/hot start-up and shut-down, part-load ramps, among other) and a long-term stability run targeting more than 2,000 of running hours. Data acquisition integrates the heat pump's PLC with the site SCADA for synchronized logging and remote support.

Conclusions

The SPIRIT-HEU project marks a significant stride in advancing the integration and utilization of industrial heat pumps within high-temperature processes, targeting a reduction in greenhouse gas emissions associated with industrial heating. The comprehensive demonstration of an industrial heat pump at Stella Polaris shrimp plant not only showcases the potential of heat pump technology but also addresses the crucial aspect of end-user confidence and TRL enhancement.

The SPIRIT-HEU demonstration at Stella Polaris has highlighted both the technical potential and practical challenges of integrating high-temperature industrial heat pumps. Early experiences showed that robust safety protocols and thorough pre-commissioning are essential, especially when working with hydrocarbons at high temperatures. The use of dynamic modelling proved valuable for troubleshooting and optimizing the control software before commissioning. Importantly, the project has underscored the need for clear communication and collaboration among manufacturers, system integrators, and end-users to build confidence and ensure successful implementation. These lessons will guide future deployments and help accelerate the adoption of high-temperature heat pumps in industry.

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