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Breaking the 100°C Barrier: Advanced Ammonia Heat Pump System for High-Temperature Industrial Applications

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Abstract

Industrial heat pumps (IHPs) are increasingly recognized as a critical technology for decarbonizing process heat in industries such as food and beverage, chemicals, and pharmaceuticals. However, commercially available IHP solutions are typically limited to maximum heating temperatures of around 90°C, restricting their applicability in processes requiring steam. This paper presents a breakthrough high-temperature industrial heat pump system capable of delivering leaving water temperatures in the range of 120-140°C, addressing a significant gap in the market. The system features a high-pressure, low-displacement single screw compressor operating with ammonia (R717), a natural refrigerant known for its excellent thermodynamic properties and zero global warming potential.

The high-temperature heat pump offers flexibility to adapt to a wide range of thermal lift requirements while optimizing energy efficiency. A standout feature is its ability to generate low pressure steam, eliminating the need for vacuum operation and ensuring seamless integration with standard industrial steam systems. For applications requiring even higher temperatures, the design supports optional integration with mechanical vapor recompression (MVR) technology. The heat pump is Conformité Européenne - Pressure Equipment Directive (CE-PED) compliant and features a compact design, enabling straightforward installation and integration into existing industrial setups.

This paper outlines the design principles, component selection, and thermodynamic performance of the system, along with preliminary performance data demonstrating high COPs within industrial operating conditions. The presented technology represents a major advancement in sustainable thermal energy systems, offering industrial users a cost-effective and climate-friendly alternative to fossil fuel-based steam generation for high-temperature heat applications.

Keywords: High-temperature heat pump; Industrial process heat; Steam generation; Ammonia (R717); Mono-screw Compressor technology;

1. Introduction

Industrial process heating accounts for nearly two-thirds of global industrial energy demand and represents one of the most challenging sectors to decarbonize due to its dependence on fossil-fuel-based steam and hot water generation [1]. In industries such as food and beverage, chemicals, and pharmaceuticals, significant potential exists to recover and upgrade low-grade waste heat into usable thermal energy. However, the deployment of industrial heat pumps (IHPs) has so far been constrained by technology limits—most existing commercially available systems operate below 90–95°C, restricting their use in steam-driven processes [2].

To address this gap, a high-temperature IHP system has been developed that can deliver pressurized hot water up to 145°C and generate positive low-pressure steam up to 117°C. This advancement enables the direct replacement of fossil-fuel boilers in many medium-temperature process applications, while maintaining the energy efficiency and operational stability associated with vapor compression systems. The design incorporates a high-lift, single-screw compressor optimized for ammonia (R717), a natural refrigerant with zero global warming potential and excellent thermodynamic performance characteristics.

The system is engineered to handle discharge pressures up to 120 bar, supporting wide temperature lifts and reliable operation under demanding industrial conditions. This makes it suitable for recovering waste heat from cooling water, condensate streams, or exhaust gases and repurposing it as valuable process heat. Beyond process industries, the technology is also applicable to district and campus heating networks that require elevated supply temperatures. With its compact, skid-based configuration and Conformité Européenne - Pressure Equipment Directive (CE-PED) compliant design, it facilitates straightforward installation in both retrofit and new-build environments.

Together, these attributes position the high-temperature IHP as a key enabler of industrial decarbonization—bridging the performance gap between traditional heat recovery solutions and fossil-fuel boilers, while offering a scalable, energy-efficient pathway toward carbon-neutral thermal systems.

2. Single-stage Ammonia Based Industrial Heat Pump – Design

The VQ series high temperature IHP is single-stage heat pump with a Vilter single-screw, high pressure low displacement (HPLD) series of compressors. The IHP is designed to support two primary applications: Pressurized Hot Water Production and Low-Pressure Steam Generation (LPSG)

2.1. Pressurized Hot Water Production

The maximum achievable outlet temperature in pressurized hot water applications is governed by the temperature differential (ΔT) across the sink side or sink split. Representative cases include:

- With Sink Split = 85K ie. sink side water entering at 60 °C, the system can deliver an outlet temperature of up to 145 °C.
- With Sink Split = 5K: the heat pump can still achieve an outlet temperature of 119 °C

The temperature split on the sink side has a direct impact on system performance, particularly in terms of sub-cooling potential and overall efficiency:

- High ΔT scenarios enable greater sub-cooling, which enhances heating capacity and improves the Coefficient of Performance (COP). In such cases, the integration of a sub-cooler is technically and economically justified.
- Low ΔT scenarios (<5 K) offer limited sub-cooling benefits, which do not offset the additional cost and hydronic pressure drop associated with an extra heat exchanger.

A typical T-h diagram for pressurized hot water is presented in Figure 1. The sub-cooler is optional depending on the end-use case.

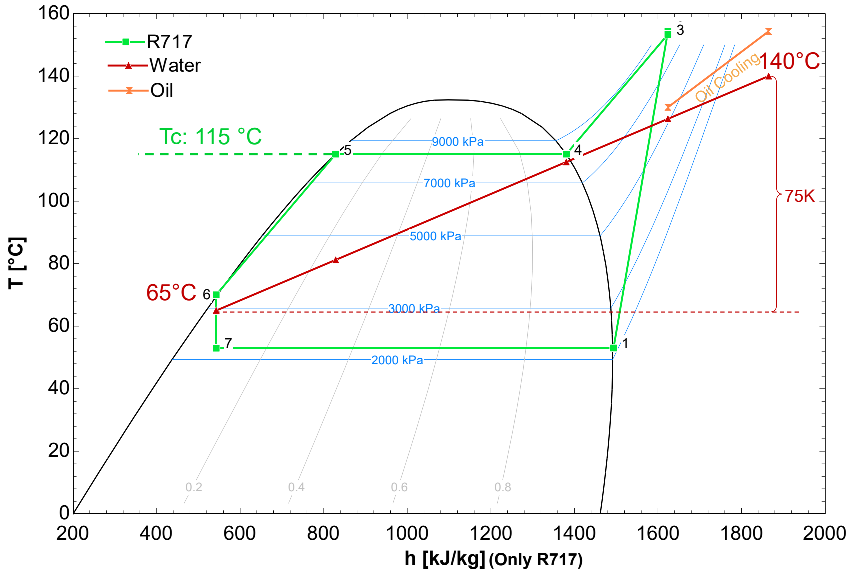

Figure 1: T-h diagram of VQ HTHP with high ΔT sink split (75K) for pressurized hot water application

2.2. Low-Pressure Steam Generation (LPSG)

For efficient low-pressure steam generation (LPSG), minimizing the sink temperature split is essential. A smaller split enables steam production at higher saturation temperatures, which in turn supports the Mechanical Vapor Recompression (MVR) system in achieving higher pressure lift. Using a source temperature of 70 °C with the HPLD-243, the largest compressor in the product line, the system can produce approximately 1.36 tons per hour of saturated steam at 117 °C.

Paramount to maximizing leaving fluid temperatures is the ability to locate the oil cooling exchanger at the highest temperature point in the heating circuit, with careful balance between ensuring safe operation of the compressor while optimizing heat exchanger selections for enhanced system efficiency. The unit is designed with hydronic connections on the skid to enable ease of integration, however, it is important to coordinate required hydronic side pressurization with the system integrator to avoid any chance of flashing at hot spots in the discharge desuperheater and oil cooling exchangers at elevated discharge temperatures.

3. Capability and Performance: Operation Envelope, Heating Capacity and COP

In our application strategy, we recommend encouraging project stakeholders to consider higher sink splits where feasible, as this can enable supplying higher temperatures, significantly enhance capacity and improving system performance.

Due to constraints on the high-side pressure of the system, the maximum allowable condensing temperature is limited to 120 °C. Even though the sink supply temperature is typically the primary parameter of interest for end-users, the condensing temperature is inherently linked to the sink entering water temperature—i.e., the return temperature—into the heat pump. For systems operating with low temperature splits, such as a 5K difference between return and supply, the relatively high return temperature restricts the maximum achievable supply temperature to 119 °C as shown in the operating envelop in Figure 2. Conversely, with larger temperature splits, for example an 85 K split as shown in operating envelope, the lower return temperature allows the supply temperature to reach values as high as 145 °C.

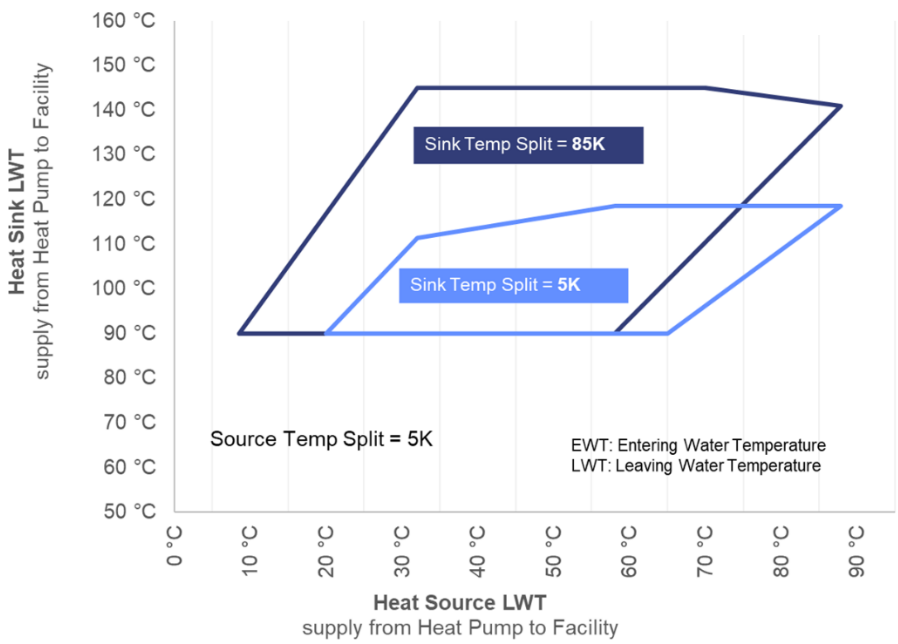

Figure 2: Operating Envelope with 5K and 85K sink splits showing maximum possible pressurized leaving hot water temperature.

Additionally, a comparison of two heating capacity plots in Figure 3 reveals that the heating capacity of the heat pump also increases with a higher temperature split on the sink side. For instance, at a 15K sink-side temperature split and at a source water inlet temperature of 60 °C, the heat pump delivers approximately 1.11 MW of heating energy while supplying water at 120 °C (dark blue). In contrast, with a 75 K split at the same source temperature, the heat pump can deliver 140°C water with 19% higher heating capacity of 1.32 MW.

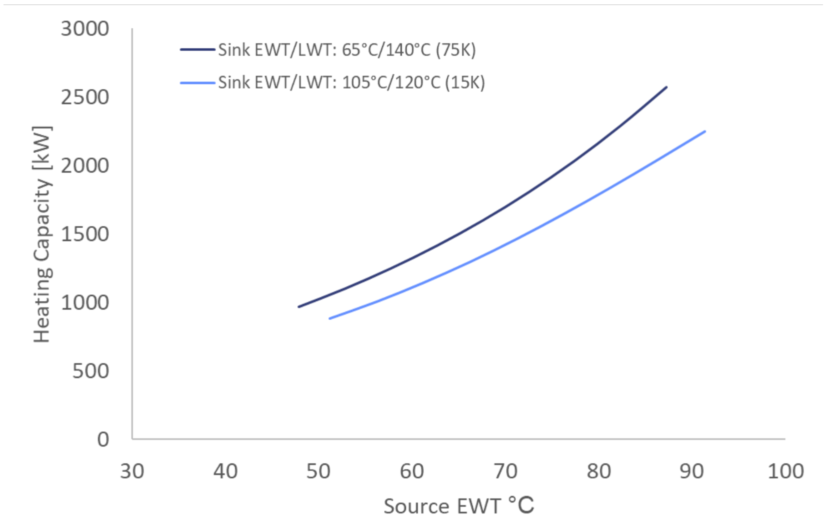

Figure 3: Heating capacity at sink temperature split of 15K and 75K at different source entering water temperature.

Similarly, the Coefficient of Performance (COP) is influenced by the sink temperature split. Comparing the COP plots in Figure 4, at a source temperature of 60 °C, the COP is 2.5 for a 15K split and sink leaving temperature of 120 °C, whereas it exceeds to 3.0 for a 75 K split, again with a supply temperature of 140 °C.

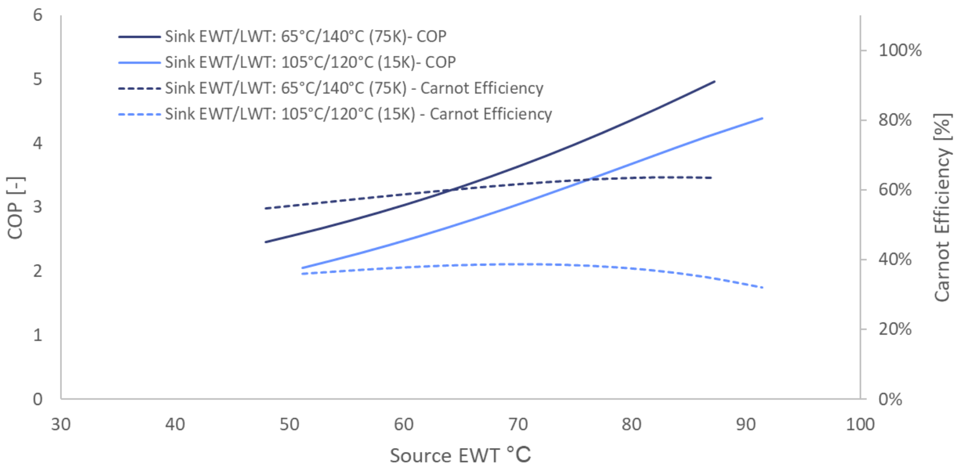

Figure 4 Coefficient of Performance (COP) at sink temperature split of 15K and 75K at different source entering water temperature

The industry often benchmarks heat pump performance against the Carnot COP, as shown in Figure 4, for sink temperature splits of 15 K and 75 K. At 75 K split and source temperature of 60°C, the Carnot efficiency reaches 60%. As an application example with geothermal source supplying hot water at 60-80°C, achieving 140 °C with COP of more than 4 with Carnot efficiency of more than 50% can really be game changing for steam process industries. Just for reference, Carnot COP was calculated as shown in Equation (1)

$$COP_{Carnot} = \frac{T_{sink,w,out}}{T_{sink,w,out} - T_{source,w,out}} \quad (1)$$

4. Multiple Unit Applications

In most projects the heating demand exceeds the capacity of a single heat pump unit. To meet these requirements, multiple heat pumps are typically deployed, configured either in parallel or in series on the hydronic side. For the same specific temperature levels, each configuration offers distinct advantages and trade-offs: parallel setups provide redundancy, full temperature lift, and reduced hydronic pressure drop, while series configurations can enhance overall system performance. As shown in Figure 5, connecting three VQ units in series on both the source and sink sides can yield a 13% increase in heating capacity and a 14% improvement in COP, for the identical source and sink temperature conditions. While parallel configurations offer operational flexibility and lower pressure losses, the optimal setup is determined on a case-by-case basis.

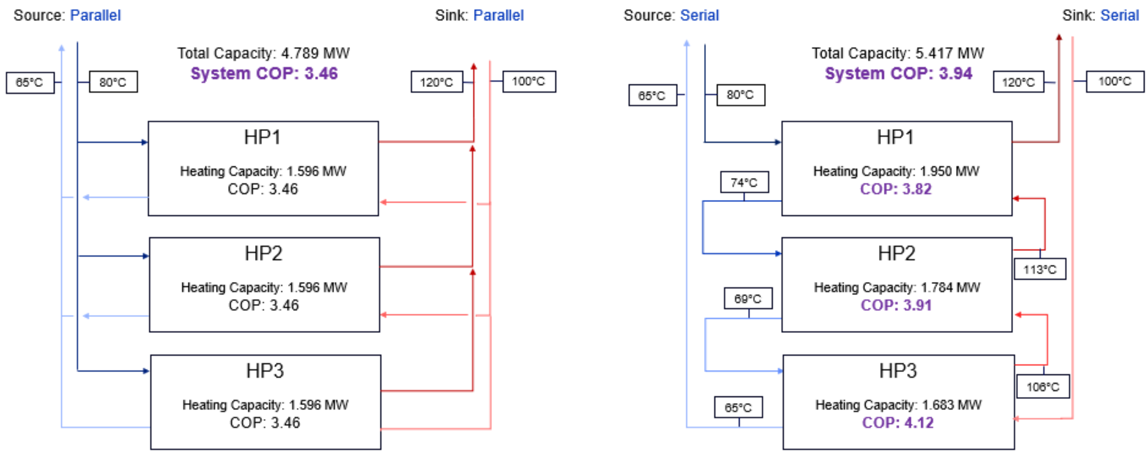

Figure 5: Impact of circuiting multiple heat pump units in serial or parallel configuration on heating capacity and COP

For applications involving lower source temperatures—where higher-pressure ratios are required it may be more effective to adopt a cascade system approach. In such configurations, each heat pump operates within the optimal pressure ratio range, thereby avoiding the efficiency losses associated with single-stage operation at high pressure ratios. The lower stage of heat pumps would reject heat to an intermediate fluid loop that then serves as the source for the high stage heat pumps. This system architecture allows greater flexibility of sizing and operation by decoupling the low and high stages which enables different numbers of units to be installed and operated.

5. Conclusion

The development of a high-temperature ammonia-based industrial heat pump capable of delivering pressurized hot water up to 145 °C and generating low-pressure steam marks a significant milestone in industrial decarbonization. By overcoming the traditional 100°C barrier, this technology enables direct substitution of fossil-fuel boilers, while maintaining energy efficiency and operational reliability. The integration of a high-pressure, low-displacement (HPLD) single-screw compressor with a natural refrigerant helps in aligning with sustainability goals. Furthermore, the system's compliance, compact skid design, and adaptability to various temperature lifts make it suitable for both retrofit and new installations across diverse industrial sectors. Preliminary performance evaluation demonstrates that higher sink splits can substantially enhance capacity and COP, offering a compelling case for widespread adoption. As industries seek cost-effective and climate-friendly solutions for process heat, this advanced heat pump technology provides a scalable pathway toward carbon-neutral thermal systems.

Nomenclature
CE-PED: Conformité Européenne - Pressure Equipment Directive
COP: Coefficient of performance
HPLD: High pressure low displacement
IHP: Industrial heat pump
LPSG: Low pressure steam generation
EWT: Entering water to HP temperature
LWT: Leaving water from HP temperature
SC: Sub-cooling

References

1. IEA (2022) – The Future of Heat Pumps: Analysis and Forecasts to 2030. International Energy Agency, Paris.
2. European Commission (2020) – Energy Efficiency in Industry: Decarbonising Process Heat.