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High-temperature heat pump based on Mechanical Vapor Recompression technology for 150°C steam supply in an industrial drying process

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Abstract

This paper presents the development and application of an innovative high-temperature heat pump system, which was specifically engineered to address the needs of a leading provider of industrial insulation solutions. The system was installed at a major production facility in Roslev, Denmark and integrated in a drying process, replacing steam from a traditional gas-fired boiler. The implemented heat pump uses mechanical vapor recompression (MVR) technology, enabling the recovery and upgrading of low-grade thermal energy. The cycle features six centrifugal blowers, that compress up to 4 tons of process vapors from 1 bar(a) to 4.8 bar(a) and deliver up to 4.5 tons of steam per hour close to saturated temperature. The thermal output of the system reaches 2.65 MW_{th}, requiring a power input of only 0.48 MW_{el}, resulting in a coefficient of performance (COP) of 5.5. A notable feature of this open system is that a dew-point-optimized process allowed the direct use of the exhaust water vapors as working fluid, which eliminates potential environmental hazards and enhances overall system efficiency and sustainability. The excellent thermodynamic properties of water, combined with the multi-stage design, contribute to high efficiency in heat recovery, significantly reducing electricity consumption. In addition to the core heat pump functionality, the system integrates advanced modules to support process optimization. These modules include a de-superheating control unit to regulate steam temperature between stages and an operating point monitoring (OPM) system that ensures efficient performance under variable process conditions. In drying applications where high temperature and high efficiency are essential, High-temperature heat pumps based on Mechanical Vapor Recompression technology present a promising alternative. As a result of this implementation, the Branden plant in Roslev estimates to reduce its CO_2 footprint by 42%, saving 6,800 tons of CO_2 annually.

Keywords: R718; MVR; Blowers & Compressors; Drying process

1. Introduction

Drying is among the most energy-intensive and inefficient processes in industry. It is estimated that drying operations account for approximately 15–25% of total industrial energy consumption in developed countries, with typical process efficiencies ranging between 35% and 45%, and in some cases as low as 10% [1].

Despite this inefficiency, drying remains a fundamental step in countless industrial production chains, essential for stabilizing the structure of solid materials or extending the shelf life of products. The process itself cannot be eliminated, but the way energy is supplied and recovered within it offers significant potential for improvement. In a conventional thermal drying process, three main stages can be identified [2]:

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1. Heat transfer from the drying medium to the moist material
2. Evaporation of the moisture contained in the material
3. Release and discharge of the resulting vapor to the drying medium

The latent heat associated with this evaporated moisture represents a major opportunity for recovery. Although various approaches, such as heat integration or optimization of heat exchangers, have been explored, the overall improvements achieved to date remain limited. One of the primary challenges lies in the temperature range at which most industrial drying processes operate, typically above 120 °C and often exceeding 150 °C, normally supplied with steam produced by fossil-fuel-fired boilers. Generally, this has constrained the application of conventional heat pump technology, whose temperature-lift capabilities were insufficient for such conditions. However, recent advancements in High-Temperature Heat Pump (HTHP) technology have begun to overcome these barriers, opening new possibilities for efficient heat recovery and energy reuse in drying systems. A growing number of demonstration projects have validated this potential. Notable examples include: DryFiciency, which showcased substantial efficiency improvements through the integration of industrial heat pumps in drying processes [3]; SteamDry project that focuses on developing and piloting Superheated Steam Drying technology [4]; or the ongoing IEA HPT Annex 59: Heat Pumps for Drying Processes, which aims to describe the possibilities and advantages of heat pump integration in dryers [5]. In short, the emergence of high-temperature heat pumps marks a turning point in efficiency enhancement of drying processes.

This paper presents the implementation of an innovative heat pump system at Skamol A/S in Roslev, Denmark. The Heat Pump is based on Mechanical Vapor Recompression (MVR) technology developed by Piller Blowers & Compressors GmbH, utilizing the VapoFan® low-mass-flow compressor integrated in a modular VapoStation® arrangement. The system represents a compact and flexible approach to process-integrated heat recovery in industrial drying applications.

The paper outlines the main design features and operating characteristics of the installation, listing the configuration of subsystems implemented to improve performance and reliability. Special emphasis is placed on measures to enhance overall efficiency and the use of water as a safe refrigerant, demonstrating how MVR-based heat pumps can contribute to the decarbonization of thermal drying processes while maintaining stable and continuous operation under industrial conditions.

2. Drying lines – Original installation

At the Branden production site, the drying process of the insulation panels is organized into three parallel drying lines, each comprising an autoclave, a pre-dryer, and a post-dryer, as illustrated in Figure 1. The thermal energy required by these units is supplied by one gas-fired steam boiler, which delivers 6.7 t/hr of steam at 7 bar(a). The combined boiler capacity amounts to approximately 18 MW, corresponding to an annual natural-gas consumption of around 34,000 MWh/year for drying.

Because each section of the drying line serves a distinct purpose and operates under different temperature and humidity conditions, the potential for waste-heat recovery varies significantly between units. A detailed assessment and process analysis were therefore carried out to evaluate alternative integration points for a heat pump system. Based on these results, Skamol decided to implement the MVR heat pump exclusively at the pre-dryers, which showed the highest recoverable heat potential and the most favorable boundary conditions in terms of vapor composition, temperature level, and operational stability. This configuration provided the best balance between technical feasibility, investment cost, and expected energy-efficiency improvement.

The parameters considered for selecting the heat pump technology were the ability to operate under variable process conditions, the availability of proven industrial references, low maintenance requirements, and the use of natural refrigerants. Based on these criteria, a multi-stage Mechanical Vapor Recompression (MVR) system operating with water (R718) was identified as the most suitable option.

This configuration offers the required temperature lift within the operating range of the drying process while maintaining high efficiency and avoiding the environmental impact associated with other type of refrigerant. In addition, the use of R718 (water/steam) allows the system to operate safely at the pressures and temperature levels typical of industrial drying, ensuring seamless integration and compatibility with the existing steam and condensate infrastructure at the Branden site.

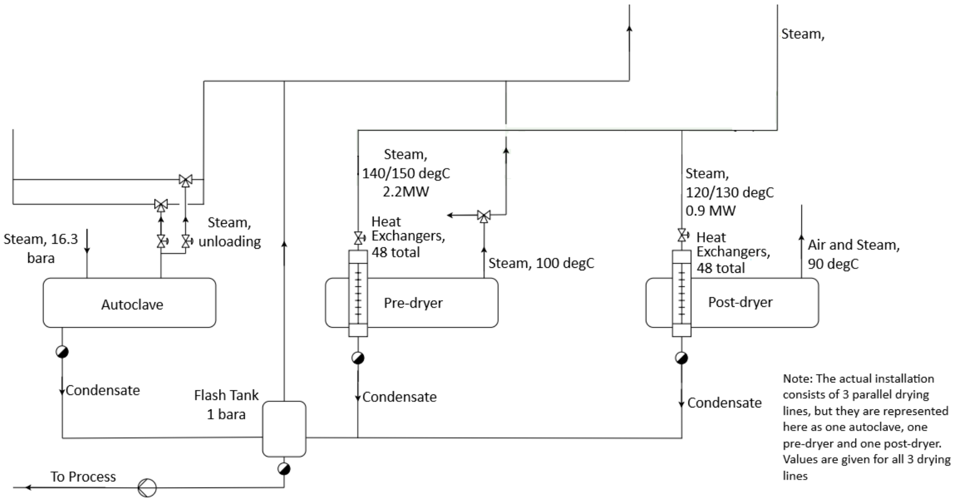

Figure 1. Drying Lines before the implementation of the heat pump system.

3. Heat Pump implementation

Figure 2 illustrates the integration of the heat pump system into the existing process layout. A modification was done in the drying/autoclave chambers to make them more airtight in order to optimise the dew point by reducing the air intrusion from atmosphere which enables the MVR/Heat Pump for using the vapors (waste heat) generated from process directly without intermediate heat transfer loop. The selected configuration allowed for adaptation to the current installation with minimal structural, process and safety related modifications. This approach reduced implementation complexity and costs. Moreover, to ensure stable operation, a detailed operational procedure was established to maintain a constant vapor flow to the compressor train. During the reloading phase of the dryers, when the material is exchanged and vapor generation temporarily decreases, the exhaust vapor flow directed to the compression unit (see Point A in Figure 2) is reduced. To compensate for these fluctuations and ensure stable compressor operation, a buffer tank was integrated (see B in figure 2). This vessel serves three purposes: it collects additional steam from the autoclave, wash and saturate part of the steam and acts as a safety buffer, enabling steam venting or recirculation during periods of low flow.

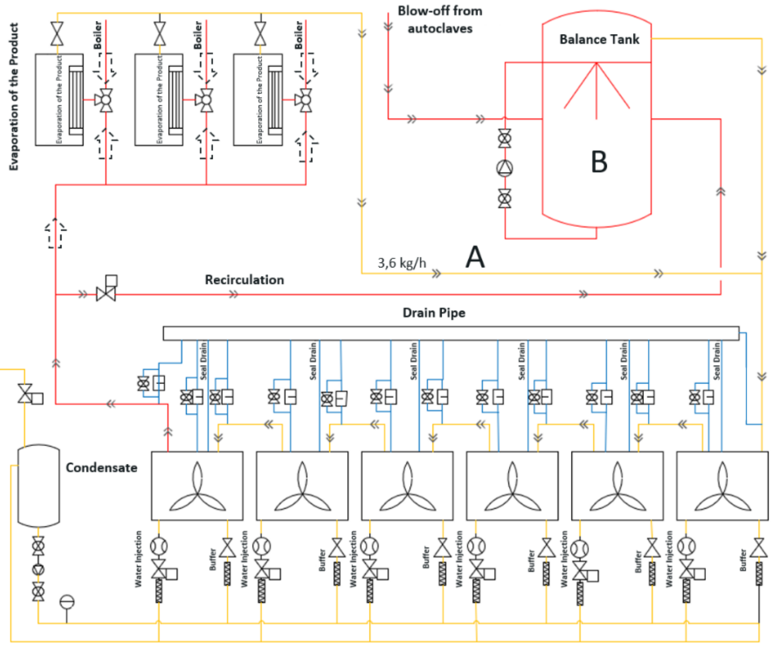

Figure 2. Heat Pump integration schematic.

The control and automation framework is a key enabler for stable and efficient heat pump operation under varying process conditions. During normal operation, fluctuations in compressor inlet flow and steam demand, driven by changes in site production load, are continuously managed by a dedicated control system. The required pressure rise across the MVR compressor train is achieved through coordinated speed control of all six compressors, ensuring precise matching of compression capacity to process demand. In addition, an override discharge pressure control is implemented to maintain the discharge pressure within defined operational limits and to protect system integrity. The integration of closed-loop feedback control with automated sequencing allows the system to accommodate the inherent variability of the drying process while meeting the operational requirements of the heat pump, thereby enabling continuous, reliable, and energy-efficient performance.

4. Multi-Stage MVR Heat Pump design

From the pre-dryers and considering an additional fraction of vapor periodically originating from the autoclave, approximately 4 t/h of steam are available for compression. It should be noted that the stream from the pre-dryers still contains a small amount of entrained air, which must also be handled by the compression system. The mixture enters the compressor train at 98 °C and 1 bar(a), corresponding to saturated conditions.

The steam demand for the drying process is approximately 4.5 t/h at saturated temperature. To achieve this required temperature lift of around 52 K, a six-stage compression train was selected, as shown in Figure 3. The main characteristics of the multi-stage MVR system are summarized in Table 1.

While centrifugal blowers offer a cost-effective means of vapor compression, their temperature increase per stage is typically limited to 10–11 K, restricting their use in applications requiring large temperature lifts. However, advances in control systems and stage interconnection have enabled the development of multi-stage MVR configurations capable of operating with up to 11 stages in series, achieving overall temperature lifts exceeding 100 K while maintaining stable and efficient operation [6].

Figure 3. Six-stage compressors train.

Table 1. Technical data of the Heat Pump - MVR system.

System Type	VapoStation®
Number of stages	6
Nominal inlet vapor flow	4000 kg/h
Nominal outlet steam flow	4500 kg/h
Temperature inlet	98 °C
Temperature Outlet (saturated)	150 °C
Casings material	EN 1.4462/AISI 2205 Duplex
Impellers material	EN 1.4501/Alloy F55 Super Duplex
Motor installed power	160 kW x 6
Driver	VSD
Calculated shaft power	480 kW
Internal efficiency grade	~78 %

4.1. Operating Point monitoring system

The new MVR heat pump required the installation of an operating point monitoring (OPM) system to ensure a stable operation of the compressor train. In cases when the steam flow is not sufficient to meet the minimum requirement of the compressor train, a recirculation antisurge control valve enables the steam recirculation from the last stage to the buffer tank and the first stage, avoiding that the VapoStation® is operated with excessive turndown that could cause mechanical damage and system instabilities (Surge protection). Additionally, the utilization of multiple measurement instruments ensures that the machines are subject to continuous monitoring. This, in turn, facilitates safe operation and the implementation of an active control protocol. In figure 4 the P&ID is illustrated, showing the interconnection between stages, the measuring instrument, and how condensate drain connections are placed between stages.

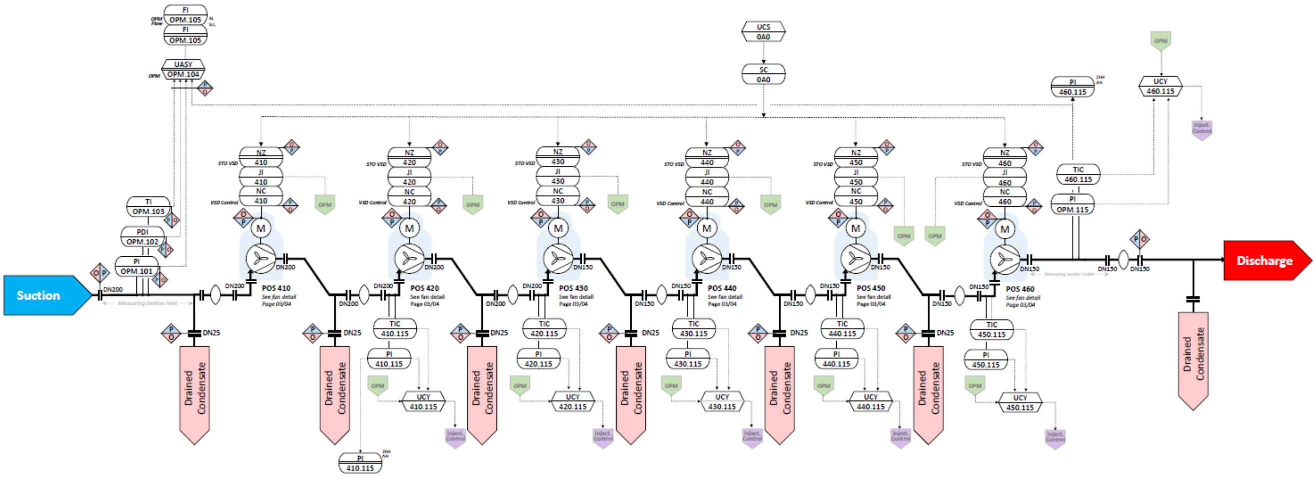

Figure 4. P&ID Compressors train.

4.2. Water Injection system – de-superheating

The design of the de-superheating system features a common rail that manages the quantity of liquid (steam condensate) that is injected between stages. PILLER´s design with direct condensate injection in the blower impeller offers multiple benefits. First, it helps maintain clean the impeller by preventing solid material build-up, which can cause imbalances and lead to vibrations or damage. Second, the injected water helps to keep the steam saturated, which maximizes the thermal efficiency of the system. Third, enables the generation of additional steam (3% - 4% per stage) by absorption of the enthalpy of superheat by condensate injected. Lastly, it helps to control the level of superheating between stages and the steam discharge to the process (In the range of 2-5K). These benefits contribute to the overall reliability and efficiency of the MVR Heat Pump system.

4.3. Water as refrigerant R718

Water (R-718) shows a valuable thermodynamic performance. In addition, it has other favorable refrigerant characteristics, such as being environmentally friendly, non-flammable, non-toxic and available at low cost [7]. The combination of water as working fluid and the design of the desuperheating system enhances the performance of the MVR heat pump. Through the six-stages, the steam compression follows a polytropic path. Water injection at the compressor inlet promotes internal heat and mass transfer, providing evaporative cooling along the compression path while maintaining nearly adiabatic conditions with respect to the surroundings. As a result, the compression work per unit mass is reduced, the compressor power consumption is lowered, and the working fluid remains close to saturated conditions. Therefore, the heat is not lost to the environment like in a traditional cooler but remains available at the outlet of the compression train in the form of additional steam mass flow. The compression path can be approximated in thermodynamic diagrams with a stepwise polytropic paths interrupted by isobaric cooling.

5. Results

During operation, the system performed in line with design expectations. Both the steam output and the electrical power consumption remained within the predicted ranges throughout the monitored period. The compressor train operated continuously and stable, demonstrating the effectiveness of the control strategy implemented to manage flow fluctuations and load variations. The collected data confirms that the system maintained steady-state performance even under varying process conditions. These results validate the robustness of the multi-stage MVR design and its ability to meet the steam demand of the drying process.

5.1. Performance

On average, the system achieved a Coefficient of Performance (COP(H)) of 5.1, measured under typical operating conditions. The electrical power consumption of the total compression train remained below 500 kW, showing stable behavior during continuous operation.

When compared to the baseline case of steam generation using gas-fired boiler, the heat pump system demonstrated an overall energy saving of approximately 60%, which aligns well with the performance targets established during the project design phase. This reduction in primary energy demand directly translates into a significant decrease in CO_2 emissions, calculated in 6,800 tonnes per year, confirming the expected environmental and operational benefits. In addition, the observed performance stability over extended periods indicates that the multi-stage MVR configuration is well suited for industrial drying applications with variable loads.

6. Conclusions

The installation of a multi-stage Mechanical Vapor Recompression (MVR) heat pump at Skamol A/S in Branden demonstrates the practical applicability of high-temperature heat pumps for industrial drying processes. By recovering vapor from the pre-dryers and reusing it as process steam, the system significantly reduces the demand on gas-fired boilers, achieving the expected energy and CO_2 savings while maintaining stable operation under variable load conditions. The measured COP(H) and power consumption confirmed the design predictions, and the integration proved technically robust with minimal process disturbance. Overall, the project provides empirical validation of MVR technology using water (R718) at temperatures close to 150 °C and establishes a reliable reference for future implementations of high-temperature heat pumps in similar industrial applications.

7. References

[1] Michael Bantle. Energy efficient drying systems: Evaluation of future trends and possibilities. FME HighEFF Deliverable D3.2_2017_03 2017; p. 5.
[2] Fraunhofer IGB. Superheated Steam Processing at Atmospheric Pressure. Steam Processing 2024; p. 3.
[3] Schneeberger A., Helminger F., Bantle M. Waste Heat Recovery in Industrial Drying Processes. H2020-EE-2016-2017-PPP 2020.
[4] Paper Technology International. Revolutionizing sustainability: SteamDry unveils superheated steam drying for web-like materials. https://papertechnologyinternational.com/revolutionizing-sustainability-steamdry-unveils-superheated-steam-drying-for-web-like-materials/. Retrieved on 29.10.2025
[5] Heat Pumping Technologies. Project 59. https://heatpumpingtechnologies.org/project59/about-the-project/. Retrieved on 29.10.2025.
[6] Piller Blowers & Compressors. BASF gets an 11-stage compressor system. https://www.piller.de/news-events/news/article/basf-gets-an-11-stage-compressor-system/. Retrieved on 08.01.2026.
[7] Zühlsdorf, B., Schlemminger, C., Bantle, M., Evenmo, K., & Elmegaard, B. Design Recommendations for R-718 Heat Pumps in High Temperature Applications 2018. In Proceedings of the13th IIR-Gustav Lorentzen Conference on Natural Refrigerants. International Institute of Refrigeration. Vol. 2, p. 1007-1017.