SPIRIT Demo Case 3 - Integration of a high temperature heat pump in a paper mill

Maximilian Kriese[1], *Fatma Cansu Yücel*[2], *Nancy Kabat*[3]

[1] German Aerospace Center e.V. (DLR), Department of High Temperature Heat Pumps, Zittau, Germany, Maximilian.Kriese@dlr.de
[2] German Aerospace Center e.V. (DLR), Department of High Temperature Heat Pumps, Cottbus, Germany, Fatma.Yuecel@dlr.de
[3] German Aerospace Center e.V. (DLR), Department of High Temperature Heat Pumps, Cottbus, Germany, Nancy.Kabat@dlr.de

Keywords:
High temperature heat pump integration, Mechanical vapor recompression, R718, Waste heat recovery

Abstract

Nowadays the technology of high temperature heat pumps (HTHP) has reached a high level of maturity. Therefore, this technology is not only suitable for decarbonizing the heat demand in domestic houses, but also for the process heat demand in the industry. However, yet the application is not widespread even there is a high interest from the industry. This is mainly because of a knowledge gap of the technology himself as well as its application within an industrial process, meaning design, construction, commissioning and operation. In this context another major issue is the is the lack of the suitable components. To this end, existing technologies need to be adapted, improved and optimized. The SPIRT project is going to address these problems by implementing three full-scale (> 0.7 MWth) demonstrators into operational production facilities of a sugar company, a prawn processing plant, and a paper mill. In addition to the technical developments/optimizations, the economic efficiency of the three demonstrators will be evaluated so that potential users can estimate the investment costs and amortization period. In addition, CO_2 savings will be recorded. Moreover, a comprehensive market analysis will be prepared so that the needs of the industry can be identified and taken into account in the developments. In this context, cutting quantities to other sectors such as district heating will be made.

The SPIRIT consortium consists of a total of 17 partners. Of these, a total of nine are working on the three demo cases. This means one RTO (TN, DTI, and DLR) works with one technology supplier (Mayekawa, GEA, and Spilling) and one end-user (Smurfit Kappa, Tiense Suiker and Stella Polaris) on one demo case. In addition, eight partners are involved. They take on tasks such as dissemination (EHPA and Euroheat & Power), cross-section to other sectors (DTU, TVP solar), modeling tool development (TLK Energy) and developing business models and performing a market analysis (SINLOC and EURAC research).

The poster presents the construction and integration as well as the challenges while implementing the HTHP in a paper mill (SPIRIT Demo Case 3). Alongside the DLR, Smurfit Kappa is the end-user selected for the industrial demonstration and Spilling was chosen as the technology provider. Latest mentioned have a portfolio of steam compression systems capable of raising the pressure of unusable low-pressure steam or waste/excess steam from production. As part of the SPIRIT project, Spilling's ambition is to develop standardized steam compressor units to lower the purchased equipment cost.

Smurfit Kappa produces 74.5 kton/year corrugated packaging material at their site in the Czech Republic. The steam required (around 12 to 13 t/h) for the paper drying process is being produced by using a natural gas boiler at a pressure of approx. 6 bar absolute. This steam is used to heat a total of 36 cylinders over which the paper webs run. After each cylinder has passed, the moisture content in the paper webs decreases, i.e. the heat requirement decreases with each cylinder. To meet these individual requirements, the cylinders are clustered into groups which are supplied with a different steam mass flow rate at different steam pressures. Replacing the steam mass flow of one of these cylinder groups was not considered sensible. Therefore, it was agreed to gather respectively generate steam, upgraded this steam by applying the mechanical vapor recompression system and refeed it into the steam line between the boiler house and the drying plant. As a result, the boundary conditions of 6.1 bar absolute and 180 °C at the compressor outlet were defined. Additionally, the thermal capacity of the heat pump system is limited to 0.8 MW_{th} due to the available technical basis.

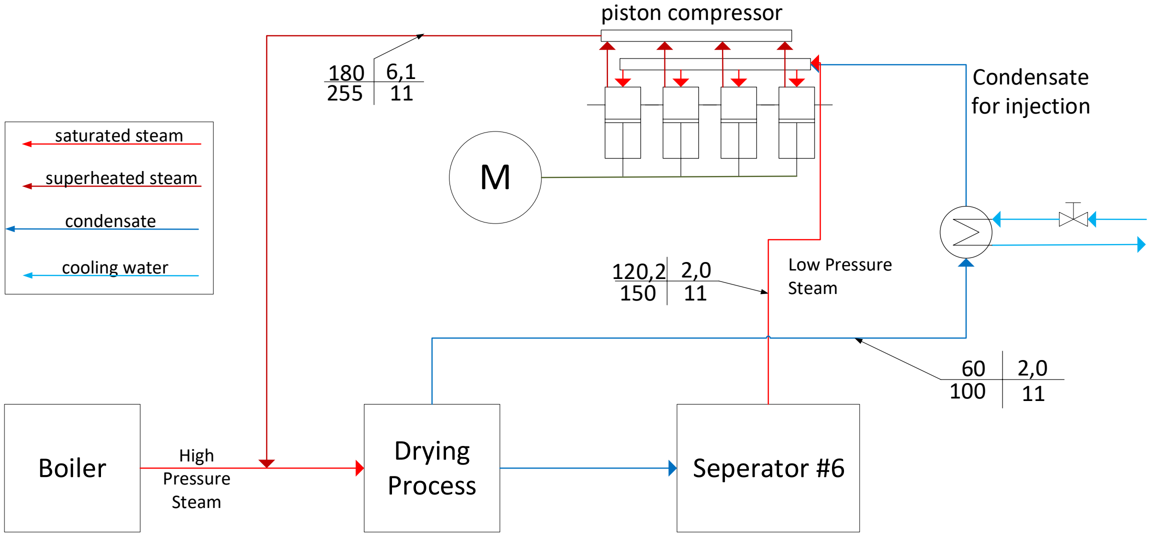

Figure 1 - Simplified flow chart of the integration of the mechanical vapor recompression heat pump system

The steam condenses during the drying process so that it cannot be used directly for the recompression. After each cylinder group the two-phase flow is collected in a separator, in which the steam is separated from the liquid water. The steam is used for example in thermo-compressors or in cylinder groups that have a lower pressure level, but none of this could be used for the recompression. Therefore, the condensate is collected from 4 of the 5 existing separators in a new one. As next, the condensate is throttle from around 5.5 bar absolute to 2 bar absolute. By doing that, flash steam of around 800 kg/h is generated, which will be sucked by the piston compressor. During compression (aiming for a pressure ratio of 3), the temperature of the steam rises to around 270 °C. This causes two issues. On the one hand, as described above, at the feeding point the temperature of the steam should not exceed 180 °C. On the other hand, this is critical for the applied piston rings. Therefore, a condensate injecting upstream of the compressor is implemented in addition to the steam supply line. This condensate injection line contains a filter unit and a heat exchanger. The latter component is necessary because the condensate temperature should not exceed 60°C. The condensate will be taken from the first separator which already has a pump integrated. Furthermore, a condensate expansion vessel is integrated by Spilling, which will be used to collect the condensate that occurs during the start-up procedure. This condensate, as well as the condensate being drained while normal operation of the compressor, will be collected in an atmospheric open condensate collection tank. This is installed on basement level below the compressor on the plant site and will be returned from there to the factory. As already described, the steam for recompression is generated by expanding the condensate mass flow. The amount of steam correlates directly with the pressure difference during the expansion process. By expanding the condensate to a lower pressure level of 1.8 bar absolute, around 870 kg/h of flash steam will be generated. The minimum tank pressure to be investigated is 1.8 bar absolute, since the pressure ratio of the Spilling compressor will not be able to significantly exceed factor 3 during operation (as ratio p_{out}/p_{in}) and the outlet pressure of 6.1 bar absolute must be achieved in any case. The compressor has an operating range of 250 - 1000 kg/h, which is to be tested in the project. For this reason, a by-pass line will be integrated between the compressor outlet and the compressor inlet in order to achieve mass flows rate of more than 870 kg/h, especially with inlet pressures of more than 2 bar absolute. Thus, a partial mass flow is run in a closed-loop cycle.

After installation and commissioning on site, another important project milestone is testing and optimizing the heat pump. A minimum of 2000 operating hours will be monitored for long-term operation. Assuming a 24h operation seven days per week, this would correspond to a minimum of 83,5 days of testing. A three-week maintenance interruption must be considered. It was decided that the steam compressor shall start-up only by active command (operator has to press the “start button”). It will operate and shut down automatically. The regular operation mode of the steam compressor will be “inlet pressure controlled”, taking all 2 bar absolute pressure steam (low pressure level – LP) from separator 6 and compress this to 6 bar absolute level (high pressure level – HP). By this, the steam compressor will keep the LP level constant at 2 bar absolute, by adjusting its speed (and so its mass flow rate) within its control range of ~0,35 to 1,0 t/h. The 6 bar absolute HP steam level will then have to be controlled by the parallel operating fossil fired steam boiler(s), supplying the difference of steam demand from the consumers and steam supply by the compressor, and keep by this the 6 bar absolute steam pressure level constant. Additionally as describe above, a test mode operation is foreseen, where defined fixed steam mass flow rates shall be operated by the steam compressor (250/400/600/1000 kg/h). In this mode, the control value for the compressor is the steam mass flow rate from the mass flow meter, and it will adjust its speed to keep this flow rate figure constant. A distinction must be made between operation at higher and lower mass flow rates compared to the design point. Mass flows rates larger than 870 kg/h are achieved by running a partial mass flow in a "circuit". This means that it is extracted at the compressor outlet and fed in at the compressor inlet. For this purpose, a bypass including a pressure control valve was implemented. For operating the smaller mass flow rates of 250 kg/h, 400 kg/h and 600 kg/h, the condensate flow to separator 6 is partly reduced. Therefore, 3-way valves after separator 2 and 4 are implemented and one of them will be closed for this purpose. Eventually, that could mean that separator 6 produces less steam than required for a certain mass flow rate (e.g. 600 kg/h). In this case, the desired mass flow rate can be achieved by providing the additional required mass flow rate via the bypass line.

Depending on the above mentioned operating status, between 2.5 and 7.5 percent of the total required steam mass flow rate for the drying process is covered by the heat pump. This means, the project is considerably part of a greater strategy in decarbonizing the industrial processes of Smurfit Kappa. Generally, more than one technical solution is required for a 100% decarbonization. The strategy applied in this project allows for a 4,36% decrease in carbon emission when not accounting for CO_2 emitted by electricity, which means using 100% renewables. When accounting for an emission factor of 0,55 t CO_2/MWh (electricity mix in the Czech republic) the CO_2 saved is 1,4%. Within the scope of this project the main goal is to demonstrate the applicability of the heat pump technology in energy-intensive industrial sectors. Therefore, the current demonstrator case serves as a basis, such that the concept can be upscaled and implemented in different locations.