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Federal Department of the Environment, Transport,
Energy and Communications DETEC
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech Division

Final report dated 2 April 2025

Annex 58 HTHP-CH – Integration of HTHPs in Swiss Industrial Processes

Appendix 6

Case Studies Report

Date: 2 April 2025

Location: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Bern
www.bfe.admin.ch

Subsidy recipients:
OST Ostschweizer Fachhochschule
Institute for Energy Systems (IES)
Werdenbergstrasse 4, CH-9471 Buchs SG 1, www.ost.ch/ies

EPFL Valais
IPESE – SCI-STI-FM
Rue de l'Industrie 17, CH-1951 Sion, www.epfl.ch

HEIG-VD
Institute of Energies (IE)
Avenue des Sports 20, CH-1401 Yverdon-les-Bains, www.heig-vd.ch

CSD INGÉNIEURS SA
Route Jo-Siffert 4, CH-1762 Givisiez, www.csd.ch

Authors:
Cordin Arpagaus, OST IES, cordin.arpagaus@ost.ch
Pierre Krummenacher, HEIG-VD IE, pierre.krummenacher@heig-vd.ch
Nicole Calame, CSD INGÉNIEURS SA, n.calame@csd.ch

Industrial partners:
Cremo SA, Laurent Giansetto
Gustav Spiess AG, Christian Jansen
ELSA, Stéphane Vesin

SFOE project coordinators:
Stephan Renz, info@renzconsulting.ch
Elena-Lavinia Niederhäuser, elena-lavinia.niederhaeuser@bfe.admin.ch

SFOE contract number: SI/502336-01

This is an appendix to the summary report on the project "Annex 58 HTHP-CH – Integration of HTHPs in Swiss Industrial Processes". The report and other appendices can be downloaded at https://www.aramis.admin.ch/Texte/?ProjectID=49514.

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Abbreviations

BB:	Black Box
CIP:	Cleaning-in-place
COP:	Coefficient of Performance
HP:	Heat Pump
HTHP:	High-Temperature Heat Pump
HVAC:	Heating, Ventilating, and Air Conditioning
MER:	Minimum Energy Requirements
MVR:	Mechanical Vapor Recompression
SFOE:	Swiss Federal Office of Energy
SGHP:	Steam Generating Heat Pump
UF:	Ultrafiltration
VSG:	Villars-sur-Glâne
WB:	White Box

Foreword

This document was elaborated in the High-Temperature Heat Pumps for Switzerland project framework (HTHP-CH) (SFOE contract number: SI/502336-01). The case studies described were used to develop a web-based tool to support HTHP integration in industries and produce guidelines on the same subject.

The case studies themselves generated experience on the practical integration of HTHP in Swiss industries, which was disseminated through various events. A dedicated webinar presented the results described in the present report.

- The Webinar PDF presentations are available online to download on the SWEET DeCarbCH Website: Webinar on Integration of High-Temperature Heat Pumps in Swiss Industrial Processes (HTHP-CH): SWEET DeCarbCH
- The video recordings are available on the SWEET DeCarbCH YouTube channel: https://www.youtube.com/@sweetdecarbch

Part of the source data used for this work is confidential. This report provides the results obtained within the limits allowed for publication. Plans or photographs could not be published for the same reason.

This document is an Appendix to the Final Report. Please refer to the latter, which provides an overview of the documents published in the framework of the HTHP-CH project, notably the Integration Guidelines Report, which describes topics such as HTHP technologies and principles of Pinch Analysis for appropriate placement of heat pumps.

Acknowledgments

The HTHP-CH project team thanks the Swiss Federal Office of Energy (SFOE) for their financial support. We are also grateful to the industrial partners who agreed to provide data and time to make these case studies possible:

- Cremo in Villars-sur-Glâne
- Gustav Spiess AG in Berneck
- ELSA Group in Estavayer-le-Lac

1 Case study Cremo

1.1 Introduction

As an industrial dairy, it was to be expected that Cremo would present different opportunities for HTHP integration. Cremo had several applications in mind.

Contrary to the analysis approach presented in the document "D4.1 Guidelines for the implementation of HTHPs in industrial processes" (Appendix 9 Integration Guidelines Report), a big picture and quantitative data on heating and cooling requirements were missing, and Cremo did not wish to have such an analysis carried out beforehand. Cremo wanted to focus on "local" integration solutions for this project. As the project evolved, different options were defined.

The presentation of this case study endeavors to trace the various stages when aiming at the integration of HPs, the difficulties encountered, the possible concepts, the practical constraints, the decisions made, and the results obtained for the concept chosen. The process leading from the various theoretically possible concepts to the actually relevant concept being evaluated is important and highlighted.

Particular attention is paid to the description of the site, its processes and its utilities to fully understand the very specific features of the site and issues of this case study, which explain the gap between the initial theoretical concept and a technically feasible, if not profitable, solution.

1.2 Company and site activities overview

1.2.1 Company and products

Cremo is Switzerland's second-largest milk processing company, employing around 800 people. It collects and processes milk from Western Switzerland. Cremo is 90% owned by milk producers.

Cremo operates several production sites, of which Villars-sur-Glâne (VSG) is the largest and the headquarters. The highest production building is 11 floors high (see Figure 1 and Figure 2).

This site produces cheese (Gruyère, Vacherin fribourgeois, Raclette), butter, and a range of milk powder products (e.g., from skim milk, whey, milk permeate, etc.). Table 1 summarizes the key energy and mass figures.

Figure 1: Sky view of Cremo Villars-sur-Glâne site (https://map.geo.admin.ch/)

Figure 2: Partial view of the Cremo VSG site (south side) (Photo by P. Krummenacher)

Table 1: Key energy and mass figures of the Cremo VSG dairy plant.

Figure	Value	Comment
Production (2021)		
Processed milk	237'836 t/a	100%
Milk for *Gruyère*	7'849 t/a	3.3% (about 785 t/a cheese with 10% yield)
Milk for *Vacherin Fribourgeois*	10'869 t/a	4.57% (about 1'087 t/a cheese with 10% yield)
Milk for *Raclette*	10'798 t/a	4.54% (about 1'080 t/a cheese with 10% yield)
Milk for *organic Raclette*	1'356 t/a	0.57%
Milk for milk Powder	190'578 t/a	80.13%
Milk for organic milk Powder	16'387 t/a	6.89%
Cream for Butter	25'000 t/a	
Cream (from Whey) for Butter	2'000 t/a	
Energy consumption (2021)		
Electricity	28.1GWh/a	118.2 kWh/t processed milk
Natural gas	44.2 GWh/a, of which: Steam boilers: 23.9 GWh/a Spray driers: 17.5 GWh/a Backup 105 °C: 2.8 GWh/a	185.9 kWh/t processed milk
District heating (DH) (105/78°C)	29.4 GWh/a	DH heat from the waste incineration plant
City water	777'254 m^3/a	About 1'000 to 1'500 m^3/d for CIP
Wastewater		Temperature 27 to 30°C
Capacity of utilities		
Cooling water (towers)	Not available	
Chilled water	Not available	
Steam boilers	2x 5.0 MW 1x 5.25 MW (backup) 17 t/h @ 10 barg	12 t/h baseline consumption
District heating 105/78 °C	3x 4 MW heat exchanger 2x 5.5 MW backup boilers Parabolic trough collectors	Supplying internal water loop at 105/70 °C
Indirect heaters (burners) for spray dryers	9.9 MW$_{th}$	TU1: 5.5 MW, TU3: 3.5 MW, TU4: 0.9 MW
Solar thermal energy	330 kW$_{th}$ (installed capacity)	581 m^2 installed collector area (parabolic trough collectors)

1.2.2 Production processes and supporting side processes

Figure 3 shows the simplified milk processing routes at Cremo VSG, while Figure 4 sketches the steps of powder production. Below, the focus is on the processes involving heating and/or cooling requirements.

Cremo VSG combines three main factories: a cheese factory (*Fromagerie*), a butter factory (*Beurrerie*), and a milk powder factory (*Séchage*). In addition, in the *Laiterie*, liquids are mixed to produce cream of various specifications.

The raw milk is pre-processed in *Traitement Lait,* where centrifugation is applied to separate cream from skim milk and then pasteurization. Skim milk is later processed by the powder factory, while cream is sent to the butter factory.

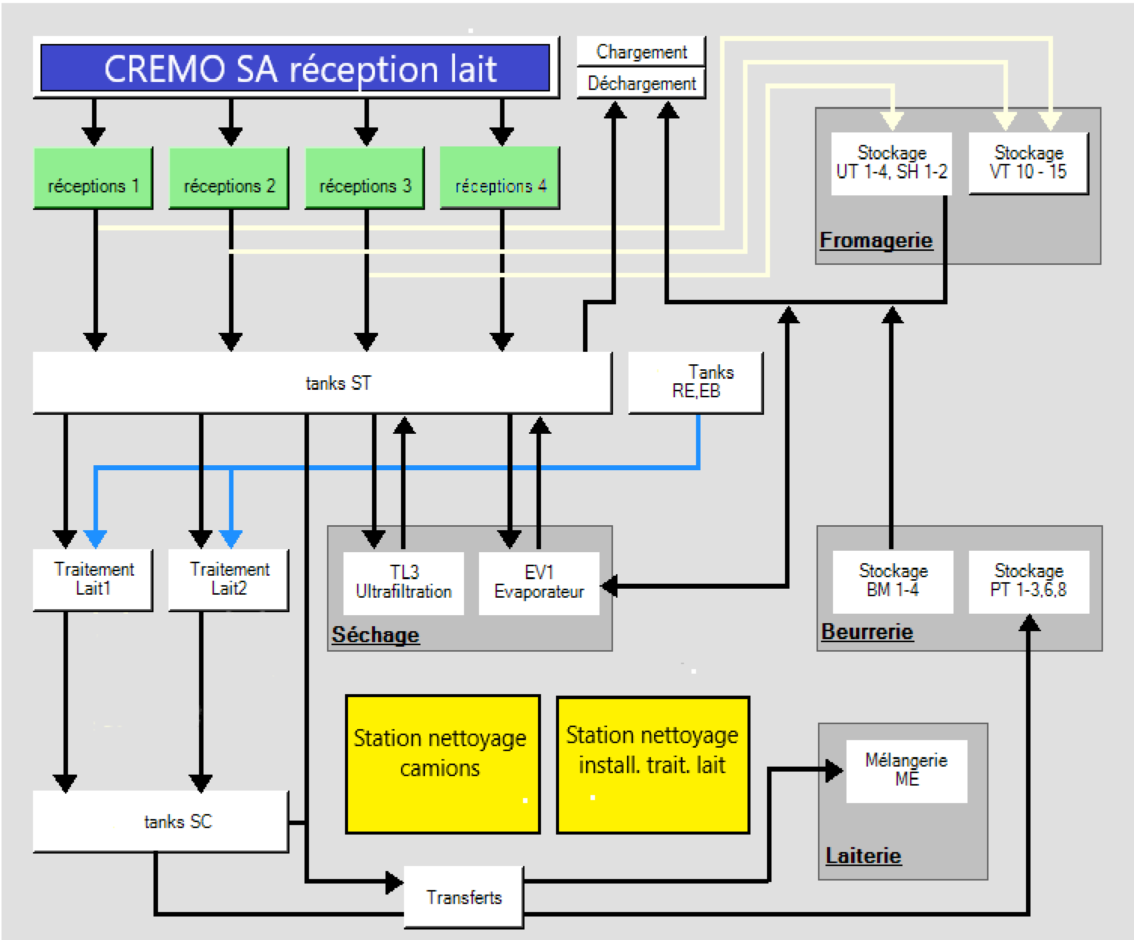

Figure 3: Milk processing routes at Cremo VSG (see explanations in the text).

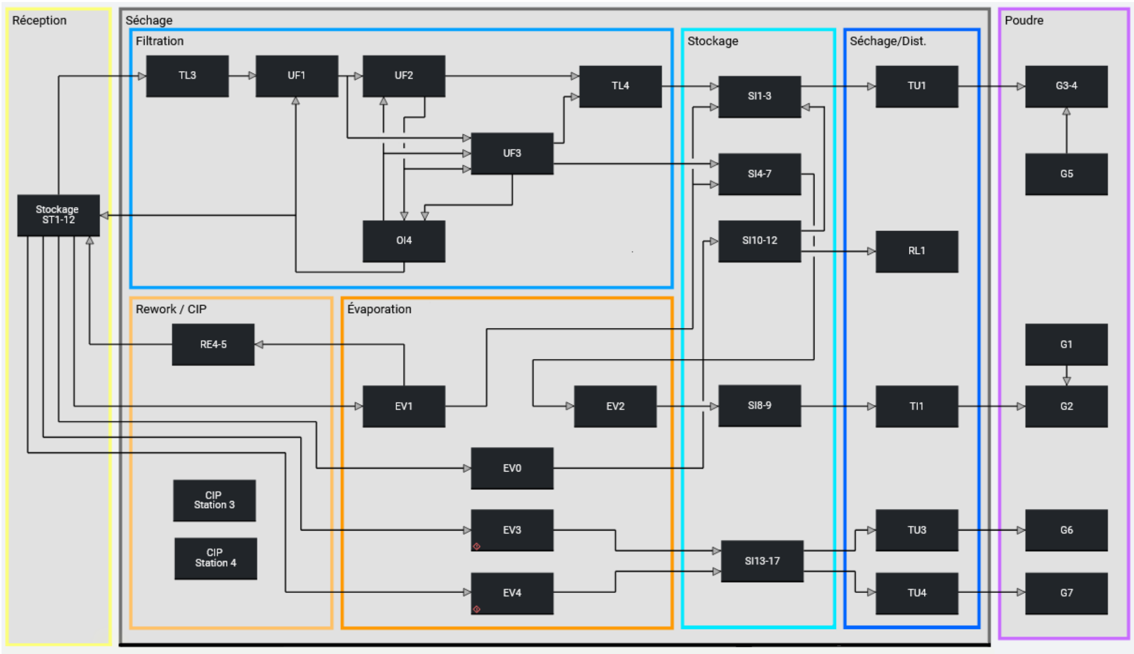

Figure 4: Block diagram of the concentration and drying processes for powder production at Cremo (see explanations in text).

The **cheese factory** operates the following main processes:

- Milk thermization, resp. Bacterofugation and pasteurization, depending on the type of cheese.
- Milk and culture mixture heating in an open, steam-heated jacketed vat. After coagulation, whey is separated and cooled down for temporary storage before being heated and centrifuged to recover cream for butter making. In contrast, “skim whey” is sent to the powder factory.

In the **butter factory**, the cream is pasteurized, then cooled back and stored in maturation tanks, where culture is added. Next, the cream is heated for churning, and liquid butter is cooled in a jacketed cooler to achieve the right consistency for packaging. Finally, buttermilk stemming from the churning step is cooled for storage, concentrated in evaporation units (see later in the text), and spray dried.

The **powder factory** involves filtration, concentration, and finally drying itself. Therefore, the powder factory operates the following main processes:

- Bacterofugation, followed by ultrafiltration to extract milk proteins (as retentate). There are several ultrafiltration (UF) units, each fitted with different types of membranes to allow various product specifications from various feeds (skim milk, sweet whey, whole milk, buttermilk, etc.). To achieve this, the ultrafiltration units may be used in a cascade.
- After ultrafiltration, the products may be pasteurized again before concentration.
- Concentration is achieved using falling film evaporators (EV). The evaporators feature various evaporation capacities and are designed to process different feeds. They apply mechanical vapor recompression (MVR) to sustain the evaporation process itself, complemented by steam ejectors for specific purposes. Note that evaporators also include pasteurization.
- Drying is mainly achieved in several spray dryers (TU). Still, it is also completed by a so-called Tixotherm (TI) process involving a paddle dryer to produce UF permeate (milk sugars) powder and by a roll/drum dryer (RL) for milk powder for the chocolate industry.

The following side processes support the production processes:

- Cleaning-in-place (CIP): Each sector has its own CIP station.
- Hot water preparation (separately for different processes/factories).
- Wastewater pre-treatment (centralized).
- Heating, ventilating, and air conditioning (HVAC) of the production/storage and administration areas.

Typical **operation schedules** of the production sectors/factories are:

- ***Réception Lait***: from 9 h (arrival of the first truck) until about 19 h (last truck), 7 days/week
- ***Traitement Lait***: about 2 x 8 h (depending on the delivered milk quantity), plus 2 x 3 h/day cleaning
- ***Séchage*** (EV, TU, TI): 3 x 8 h, 7 days/week
- ***Fromagerie***: 1 x 8 h, 5 days/week
- ***Beurrerie***: from midnight to noon, then cleaning, 6 to 7 days/week

1.2.3 Utilities and Existing Heat Recovery

Compressed air: Two separate compressed air networks supplied by two groups of air compressors:

- 3 air compressors for general purposes of the site.
- 2 air compressors for the powder factory, especially for cleaning bag filters.

Heat supply: Heat is produced and supplied in several forms:

- Three **gas-fired burners**, as part of the TU units, are used to indirectly post-heating the main primary air mass flow of spray dryers.
- Three **gas-fired steam boilers** supply the following consumers:
  - Paddle dryer (TI) process
  - Cheese factory (pasteurization, vat, CIP so far)
  - Butter factory (final heating of cream for pasteurization, as well as final heating to achieve sterilization)
  - Roller/drum dryer (RL) for special milk powder
  - Some needs for evaporator units (e.g., heating steam during start-up, sealing steam for MVR-fan, motive steam for thermal vapor recompression, pasteurization before evaporation, etc.)
  - Others (backup heat source for various heat sinks, etc.)
- The heat from **district heating** provides heat to an internal 98/70 °C water loop, which, in turn, provides heat to the following units:
  - Spray dryers (TU)
  - Tixotherm (TI) drying process

- Evaporators (EV)
- Milk pre-processing (TL)
- CIP stations
- An internal heat distribution network (*Réseau Chauffage PAC*) was originally designed to be supplied by heat pumps but could never be commissioned due to a fire in the plant. This network is heated through a heat exchanger on the return of 98/70 °C loop, ensuring the district heating is cooled to the specified return temperature. The *Réseau Chauffage PAC* network, in turn, supplies many "low temperature" heat sinks and also allows for local heat recovery from flash steam of condensate tanks:
  - Building HVAC
  - Hot tap and process water
  - Diverse

- Two **gas-fired water boilers** ensure backup supply in a scenario of district heating shortage.
- **Parabolic trough solar collectors** supply heat to the internal 98/70 °C water loop.

Cold supply: Cold is produced and supplied to the processes at various temperatures and by different means.

- Glycol water (-6 °C): 2 compression chillers
- Chilled water (2 °C): 4 compression chillers
- Cooling water (about 20 °C): 3 groups of 2 wet cooling towers each

Heat recovery: At present, heat recovery is applied in the following processes:

- Pasteurisation processes (TL1, TL2, TL3, TL4)
- Concentration by evaporation: preheating of feed, MVR in evaporators
- Spray dryers: preheating of drying air using waste heat from hot exhaust air (only for 2 out of 3 spray dryers) and exhaust gases from the burner (indirect heat transfer loop)
- Tixotherm dryer: preheating of drying air using waste heat from exhaust hot air (indirect heat transfer loop)
- Flash steam from condensate tanks

Heat recovery is not implemented in the following facilities:

- Air compressors
- Chillers and cooling water
- Wastewater (notably CIP exhaust)

Comments: Several heat distribution networks at different temperature levels enable heat consumers to be connected to the network with the nearest temperatures and heating requirements, featuring large temperature glides that can be heated stepwise/stagewise by several networks (notably for air heating in spray dryers and Tixotherm). However, this principle is not always applied consistently for various reasons, and there is room for improvement in allocating heat consumers to heat distribution networks.

1.3 Preliminary HTHP integration concepts

During the HTHP-CH project, Cremo successively suggested several opportunities for integrating an HTHP. The corresponding possible concepts are briefly described below, along with the motivation/benefit and the reasons for abandoning or going for it.

Note that the production area is very densely packed with process equipment and piping (Note: this holds for the utility area too). This is a particularly severe constraint in the powder building, which hosts massive and heavy pieces of equipment (e.g., evaporators, spray dryers, etc.) extending over several floors and featuring complex routing of interconnection piping.

1.3.1 Concept 1: Boost district heating network distribution temperature

Besides gas boilers and solar collectors, the Cremo factory's heat needs are currently supplied by the local district heating provided by a waste incineration plant. A possible future reduction of its supply temperature level motivated Concept 1.

Given the heat exchangers' capacity and internal hot water loop specifications, an HTHP producing heat at 105 °C in the range of 10 MW would be needed. This would allow the production equipment in the factory to continue operating under the same conditions.

As this modification in the district heating distribution temperature is an uncertain hypothesis, Concept 2 was not retained in favor of a more concrete concept that could be implemented (see Concept 3). It should, however, be feasible if need be.

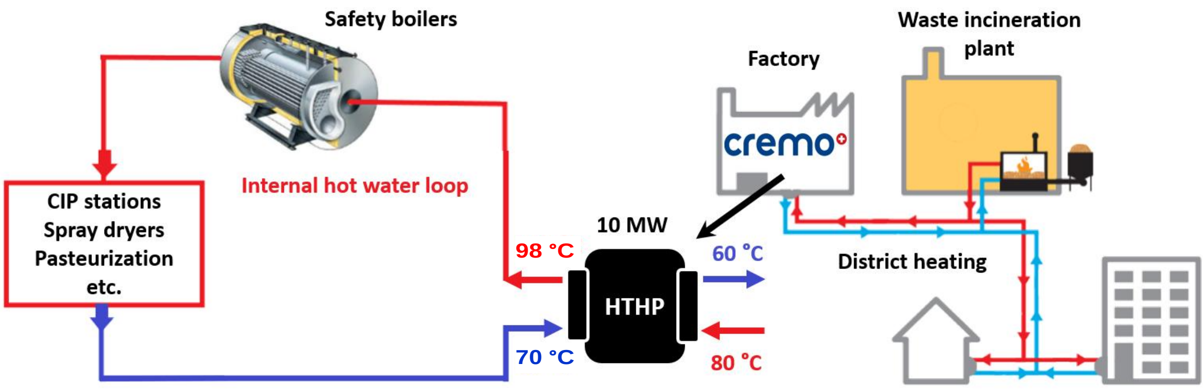

Figure 5: Schematic of the Cremo case study integration Concept 1.

1.3.2 Concept 2: Upgrade heat recovered in the factory to a hot water loop

While Concept 3 was being analyzed, Cremo mentioned an opportunity to integrate an HP for the *Réseau Chauffage PAC*, a concept that Cremo has historically envisioned. An inventory of waste heat sources throughout the factory must be made beforehand. This requires much preparation before an HP integration can be designed and sized. Furthermore, an HTHP would not be needed, as a condensation temperature below 100 °C would be suitable.

Note that Concept 2 could, in the medium term, complement Concept 3 in that it could supply the evaporator of the HTHP of Concept 3.

1.3.3 Concept 3: Steam for milk permeate powder drying plant

This concept consists of supplying steam to the paddle dryer of the Tixothem milk permeate powder drying process. It has been selected for further study in the framework of the Cremo case study.

Preliminary reasons justifying this choice are:

- Low-pressure steam needed in the equipment at 1.4 bar(a)
- Estimated 10% to 15% of the factory steam consumption (currently from a gas boiler)
- Assumed long annual operating time
- Simultaneity and proximity between heat source and sink (heat recovery on humid exhaust air on the semi-continuous drying process)
- Availability of P&IDs, supervision screenshots, and operating manual

1.4 The Tixotherm process

1.4.1 Function and description of the process

The Tixotherm process is specifically used at Cremo VSG to produce milk permeate powder. Figure 6 shows a simplified diagram of the process:

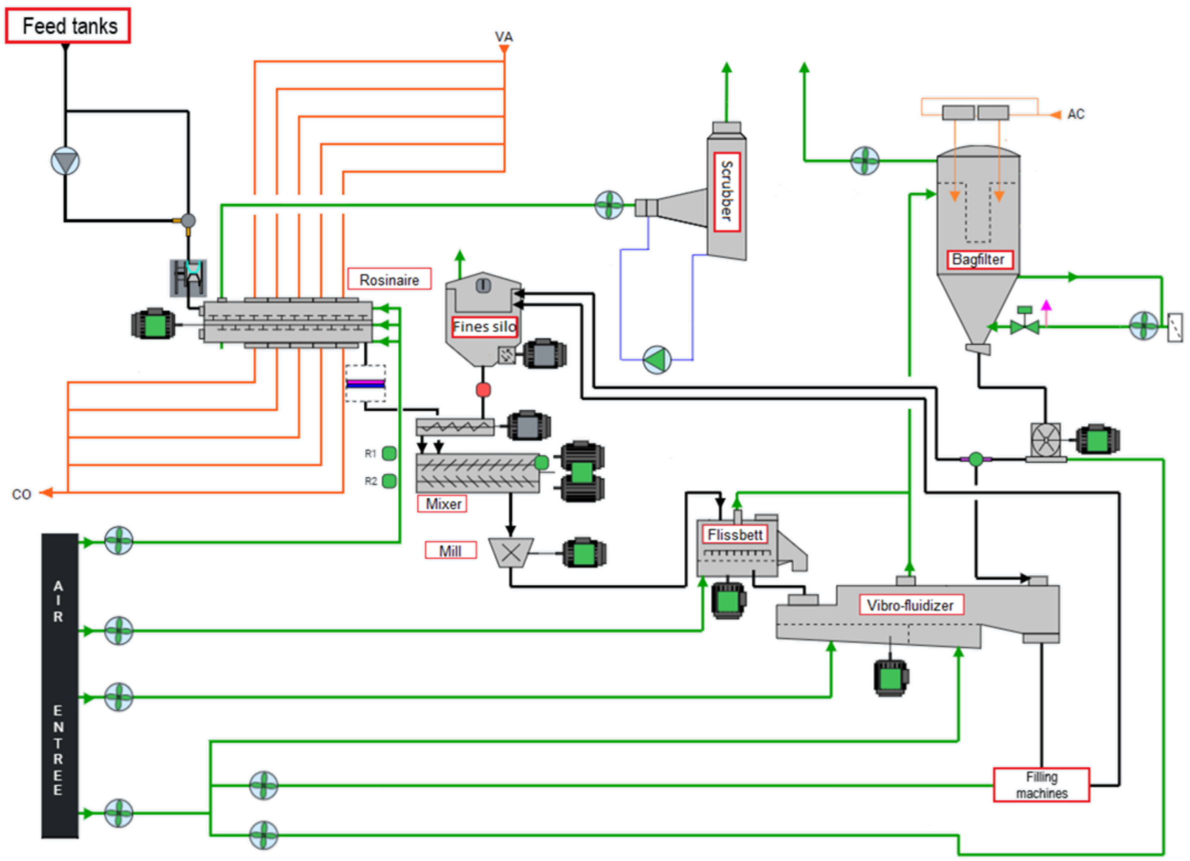

Figure 6: Simplified diagram of the Tixotherm process at Cremo.

The pre-concentrated feed undergoes a first drying stage in a paddle dryer (Rosinaire), in which heating zones are supplied with low-pressure steam (1.2 to 1.4 bar(a)). The evaporated water is moved away by the flow of sweep air. This sweep air, loaded with product particles, is washed by the scrubber.

Before being dried to the desired value in the "static" fluidized bed, followed by the vibro-fluidized bed, the pre-dried coarse material is crushed into powder. The exhaust air that flows from the fluidized beds contains powder particles that are retained in the bag filter. A strong pulse of compressed air periodically shakes the bags to loosen and recover the powder.

From an energy point of view, the heat requirements of the process are supplied by various sources:

- The total outside airflow is preheated to a setpoint of about 30 °C. Preheating is achieved in a large heating coil supplied by a heat recovery loop; this loop recovers heat from the exhaust air of the bag filter and that from the scrubber but also stabilizes the supply temperature by the 98 °C/70 °C network.
- Further heating of air flows is achieved stagewise by the 98 °C/70 °C network, followed by heating with steam at about 4 bar(a) steam for air flows with setpoints beyond about 75 to 80 °C (namely sweep air of the paddle dryer and air supplied to the (static) fluidized bed).
- As stated above, the paddle dryer heating zones are heated with 1.2 to 1.4 bar(a) steam. Heat and mass balance calculations show that the steam consumed by the paddle dryer amounts to over 60 % of the total steam consumed by the Tixotherm process.

Comments:

- It took Cremo over one year to find the appropriate operating conditions, which finally deviate significantly from nominal conditions (in particular as regards the Rosinaire paddle dryer. The actual sweep air flow is considerably larger, leading to a lower water content of the exhaust air and a lower dewpoint).
- As is usually the case in production processes, process instrumentation controls the important parameters to ensure the product's quality and safe operation. However, the quantities that would enable heat recovery to be calculated on the one hand and the heat supplied by the various hot utility networks on the other are not monitored.

1.4.2 Ideal Concept 3: Optimal local heat recovery and HTHP integration

The very first approach to the local integration of an HTHP for the Tixotherm process is based on a white box (WB) model of the process (refer to Integration Guidelines Report), i.e., ignoring any existing heat recovery and assuming that all heat exchanges could be modified and designed according to the pinch design method. This corresponds to the ideal situation featuring the largest heat recovery potential.

Applying this WB approach, the cold streams are defined as:

- Heating of air flows from the outside air temperature to their target temperatures of the process as presently operated (due to the difficulties in finding appropriate operating conditions mentioned above, assuming changes like a reduction of sweep air flow are unacceptable).
- Heating and evaporating condensate water to supply the Rosinaire with low-pressure steam (as calculated from an energy and mass balance around the Rosinaire). This is a replacement steam since the Rosinaire paddle dryer, and its heating zones cannot be changed without modifying the process technology.
- Consistent with the WB approach, heating of the feed up to its target temperature for evaporation in the Rosinaire should be considered. However, the feed to be concentrated arrives already "hot" from the filtration, and further heating would mean modeling the Rosinaire

process and recalculating its operating conditions (while ensuring the product's quality would not be negatively impacted by further heating). As this modeling would go beyond the project's scope, feed heating is not included in the list of cold streams.

As regards the hot streams of the process, it consists, in fact, of two waste heat streams (soft streams):

- Cooling of exhaust air from the scrubber
- Cooling of exhaust air from the bag filter

The resulting Composites Curves (CCs) and the Grand Composite Curve (GCC) represented in shifted temperature T* [1] are depicted in Figure 7. The CCs indicate that a heat recovery potential through direct heat transfer of about 720 kW between airflows could be achieved (as compared to about 70 kW at present). Furthermore, to substitute steam generation from the steam boilers, the GCC shows that an HTHP should have a 1’050 kW heating capacity at a condensation temperature of about 115 °C to 120 °C.

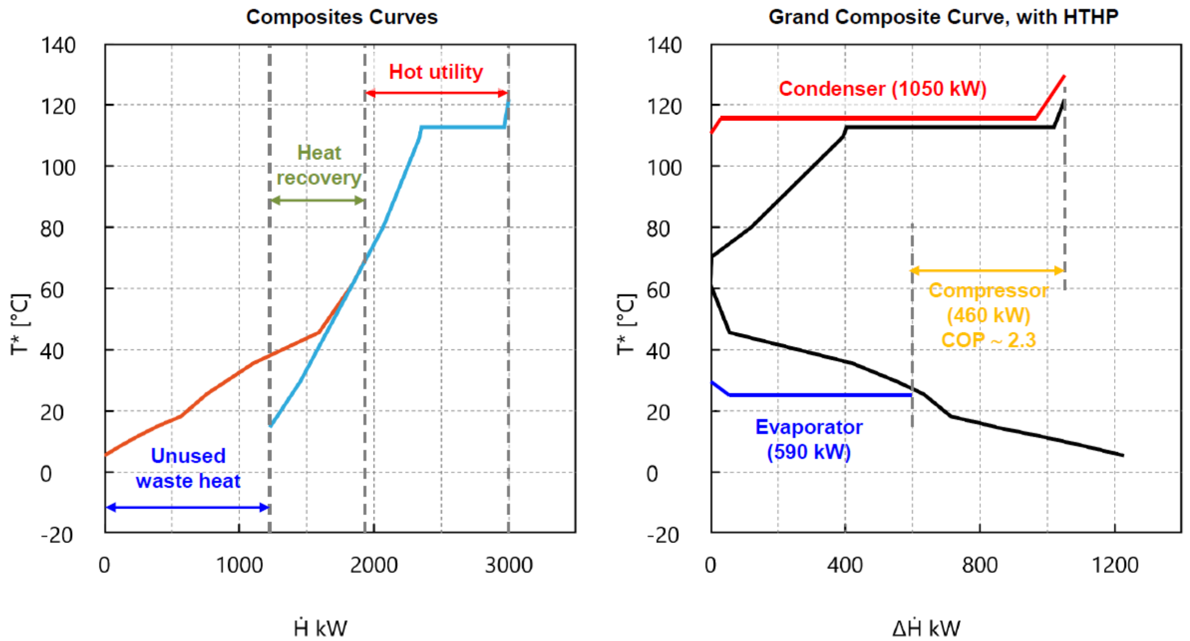

Figure 7: Composite Curves (CCs, left) and Grand Composite Curve (GCC, right) of the Tixotherm process, modeled according to Ideal Concept 3. The possible integration of an HTHP at the process level is sketched on the GCC.

The challenge is the low evaporation temperature (and hence the large temperature lift) if waste heat has to be recovered exclusively from the process. Therefore, extra sources of significant waste heat (about 600 kW or more) at a temperature of about 35 °C to 40°C should be identified to get a reasonable COP and a chance to reach profitability (or as another option, the HTHP capacity should be limited to 300 to 400 kW).

But this analysis and its conclusions are unfortunately not relevant in practice due to the following severe limitations:

- Staged heating of air flows by several utilities, whose heating coils are integrated into a single chassis

[1] Here using a stream specific DT_{min} contribution of 2 K for 2’000 W/m^2K of film heat transfer coefficient.

- Gas flows involve large ducts in tight space
- Lack of space, complex layout, dimensions, and distances between process components
- Prohibitive costs involved

1.4.3 Measurements and results

As highlighted above, a WB model is inappropriate in this retrofit case. Hence, to propose a suitable HTHP integration concept, a closer analysis of heat transfer devices and various measurements need to be undertaken:

1. Check of heat transfer devices: type of construction (bloc or modular), free space availability for retrofit/expansion, actually required supplied temperature, etc.
2. Measurements of the existing heat recovery loop (temperatures, mass flow, heat contributions)
3. Monitoring of operation of the Rosinaire (steam supply, temperature of feed) and annual production
4. Additionally, identify and verify on-site that the conditions required for transport, installation, operation, safety, etc., are met for the integration option(s) envisaged

This leads to the following results (numbering the same as above):

1. Lowering the pressure of steam supplied to heating coils for air heating to target temperature, from 4 bar(a) to about 1.8 bar(a) (see result 3 below), is hardly possible due to the required size increase, space, and repiping. Hence, an HTHP concept to supply the Rosinaire and two air-heating steam coils must produce 4 bar(a) steam, not only 1.8 bar(a).
2. The heat recovery loop has a low efficiency. On average, the heat recovered on the scrubber exhaust air is negative[2], and the 98/70 °C loop supplies most of the heat needed to reach its setpoint temperature. This loop aims at preheating outside air to 30 °C. Hence, it very likely leads to heat transfer across the pinch temperature, which is not optimal. In addition, loop temperatures are not stable, showing periodic oscillations. This may be caused by the periodic injection of “cold” compressed air into the bag filter. Hence, ideally, the loop concept should be radically modified, but in practice, a retrofit seems hardly possible, at least in the frame of this project.
3. Based on the annual production and the Tixotherm capacity, the annual operating time is only 35% to 40% of that initially estimated, adversely affecting the amortization and profitability of any HP integration. Regarding the required steam pressure for the Rosinaire, a pressure drop of approx. 0.4 bar seems necessary to ensure correct operation of the control valves, meaning that the pressure of steam needed to supply the Rosinaire is approx. 1.8 bar(a), compared with the current pressure of 4 bar(a) upstream of the control valves for the various Rosinaire heating zones. Hence, separate control valves must be used to operate the Rosinaire with a steam supply pressure of 1.8 bar(a).
4. On-site checks of constraints and technical feasibility have identified a suitable location for the HTHP integration.

[2] i.e., the fluid of the heat recovery loop is cooled by transferring heat to the humid exhaust air from the scrubber, instead of cooling the humid exhaust air (the heat exchanger operates in the reverse direction).

1.5 Practical Concept 3 HTHP integration

1.5.1 Integration constraints and hypothesis

As the HTHP integration is done at the process level, the HTHP will be installed close to the production lines. For this reason, Cremo demanded that the machine not contain refrigerant fluid. This led to the choice of mechanical vapor recompression (MVR) technology.

The MVR technology has been used for years in industries and is mature and reliable. Moreover, it benefits from very good efficiencies. Various MVR concepts exist, as shown in Figure 8. The second concept (MVR + flash tank) was selected for suitability with the project constraints. In this case, the condensates are evaporated before a recompression stage lifts the steam to the required pressure level. Given the hot water loop (98°C), evaporation must occur at sub-atmospheric conditions, i.e., < 1 bar(a).

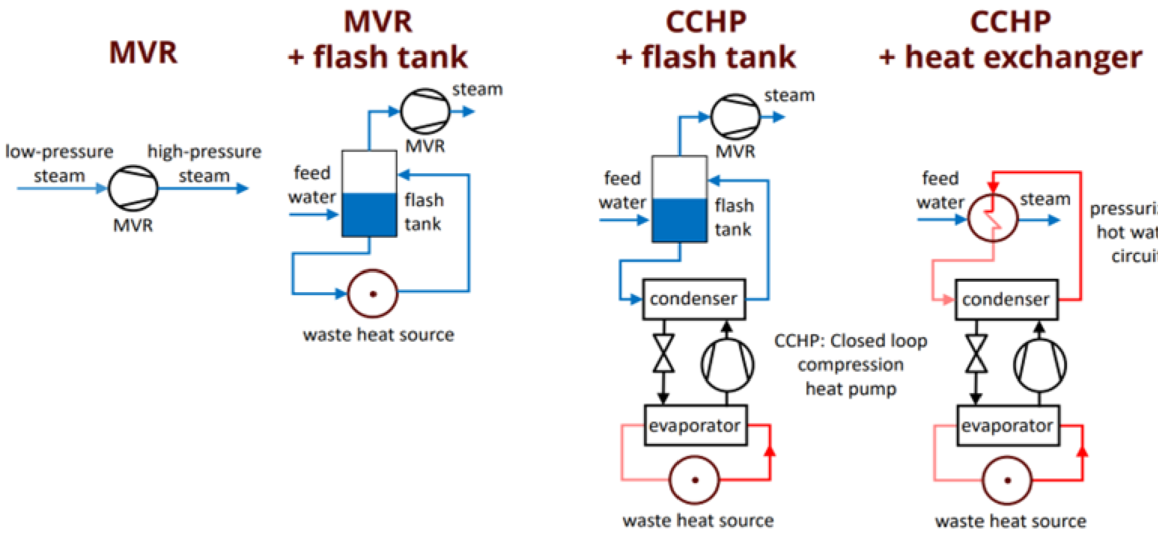

Figure 8: Different MVR HTHP concepts (IEA HPT, 2023),

Space is available close to the paddle dryer. It was further confirmed that the size of the HTHP allows its integration in the same room. Moreover, the structural resistance of the slab at this location is sufficient to support the machine, according to Cremo. Redundancy for the HTHP production is provided by keeping the actual steam supply as a backup. Compliance with hygienic specifications is mandatory for all equipment installed on the production lines. Therefore, a small, dedicated room would be designed to isolate the HTHP and auxiliary equipment.

1.5.2 Practical Integration Concepts

Given the fact that the exhaust air streams from the Tixotherm process are already valorized and integrated for heat recovery, the internal hot water loop (98 °C) is selected instead as the only alternative heat source available. The local district heating network supplies this hot water loop with a small share of gas boosting. As a result, the global gas consumption and CO_2 emissions linked to the paddle dryer steam supply will be drastically reduced thanks to the HTHP integration running with electricity. Cremo supported this concept, although the heat source would not be free of charge.

Complementary research for an alternative matching energy source from heat recovery among the factory streams was out of this project's scope. Two variants to the ideal HTHP integration concept in the milk permeate powder drying plant emerged, as described below.

Figure 9 illustrates the base case concept further used in the case study. Given the measurements and heat balance calculations, the streams and conditions are the following:

- Heat sink: 810 kg/h steam at 1.8 bar(a) to supply the paddle dryer from condensate return
- Heat source: 98 °C hot water from the existing internal network

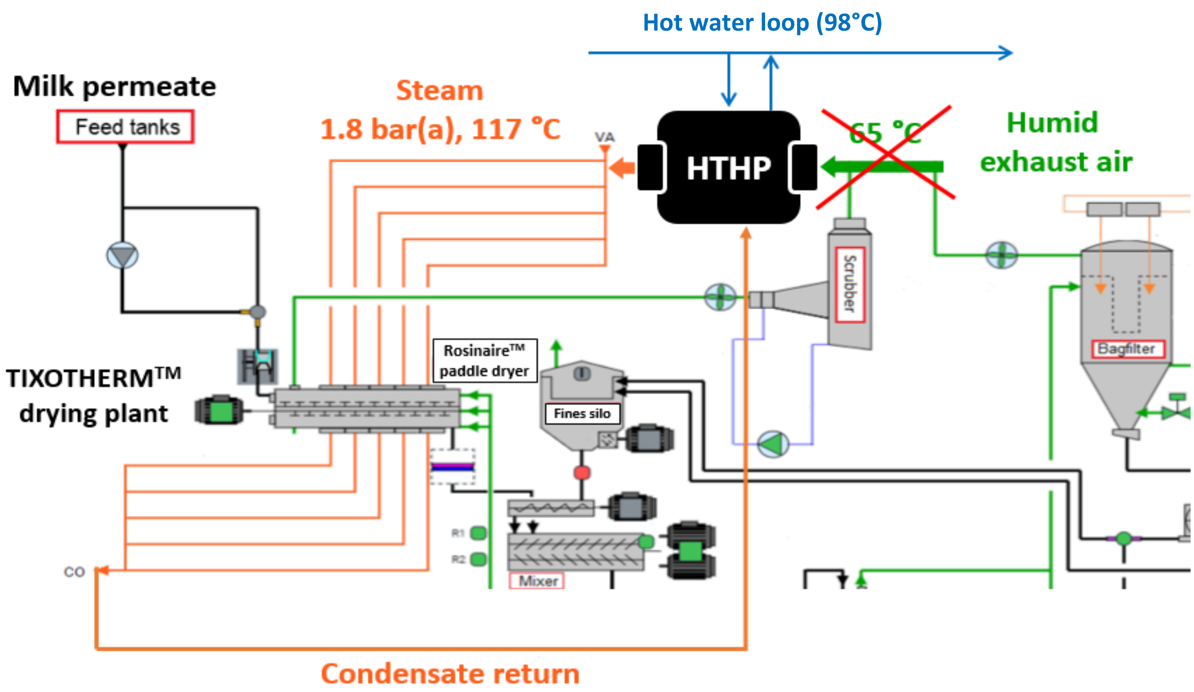

Figure 9: Scheme of the selected HTHP integration concept for the Cremo case study.

1.5.3 Abandoned Alternative Concept

Alternative pressure and temperature conditions enabling steam supply to the air heaters and the paddle dryer have been enquired. The specifications used to find adapted HTHP products are:

- Heat sink: 1'300 kg/h at 4 bar(a)
- Heat source: 98 °C water loop

In this case, the steam produced by the HTHP is subsequently expanded to the operating conditions of the paddle dryer as they are less demanding. This sub-optimal concept of operation leads to energy losses. It was investigated to increase the flow rate of the steam produced to find a suitable HTHP, as this parameter was a limiting factor in the search for an HTHP product.

This alternative case proved to be a technical no-go with MVR-HTHP on the market for the required combination of pressure level and flow rate. For example, the contacted manufacturer, Piller, advised that a minimum steam flow rate of 5'000 kg/h would be required with their smallest TurboFan machine. Five compression stages are needed to achieve the 4 bar(a) outlet pressure conditions. Such a setup would cost about 700 kEUR.

Besides, the previously mentioned spatial constraints apply to the air heating room, with limited space for modifying existing equipment.

1.5.4 Preliminary economic evaluation

A preliminary evaluation was conducted using the initial data and hypothesis to assess the economic feasibility of the retained concept. The calculation model used is based on specific investment costs for HTHPs, assesses a cost factor for the complexity of the planning and integration of the machine and considers maintenance costs. The conditions retained for the economic evaluation were as follows:

- Production of 810 kg/h (500 kW) of saturated steam at 1.8 bar(a) (117 °C) from condensate
- The heat source is a hot water loop at 95 °C
- Annual operating time 2'700 h/year
- Specific HTHP costs 450 CHF/kW (thermal)
- Available heat recovery opportunity on exhaust humid air
- Subsidies obtainable from myclimate & SFOE

Following the values in Figure 10 for the corresponding operating conditions (temperature lift of about 25 °C), a COP value of 9 was considered for the MVR heat pump.

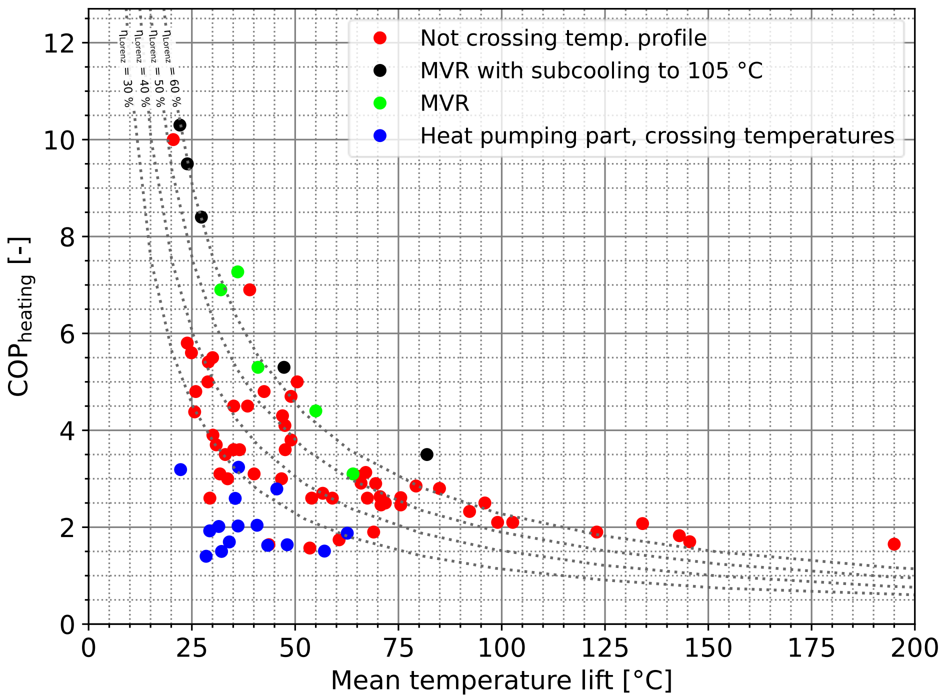

Figure 10: COP values vs. mean temperature lift for HTHP products based on manufacturer data (IEA HPT (2023).

The first result estimates based on the available information are the following:

- Annual energy saving: 15%
- Annual CO_2 emissions reduction: 94%
- Payback of 4 years

These encouraging values justified pursuing the case study.

1.5.5 Market available HTHP search and challenges

Given the measurement campaign and analysis led, the market available MVR-HTHP should have 500 kW heating capacity (810 kg/h steam) and be able to produce low-pressure steam at 1.8 bar(a) from a heat source at 98 °C. These conditions imply a sub-atmospheric evaporation.

Because of the reduced flow rate, the small capacity required from the MVR HTHP was out of the specification range for various suppliers by a factor of about 3.5 on the flow rate.

An important performance gap appeared with the first estimates. Indeed, the expected COP value of 9 for an MVR-HTHP was not achieved with the market-ready machine proposed by EPCON for the case study conditions (see Appendix 1: EPCON Datasheet, IHP-MVRi-2S-8).

The effective COP value of 5.4, including losses (e.g., heat, motor, VSD), is due to the compression technology switch due to the low steam flow rate in the present case. The centrifugal fan cannot handle the small flow rate, and root blowers are applied as a replacement. This latter technology's expected isentropic efficiency of 70% to 90% drops to 40% to 60%. It is known that better efficiencies are achieved for large-scale compressors in general for mechanical reasons. Still, this change in the compressor type has a much larger negative impact on the COP and, hence, on the OPEX, for it is directly linked to electricity consumption.

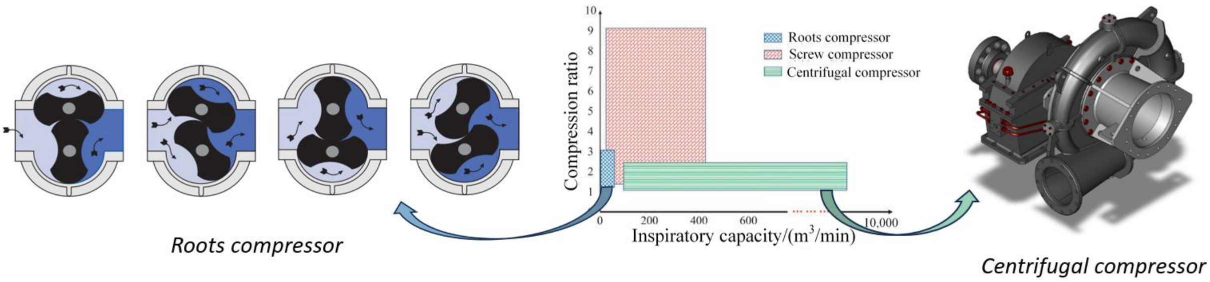

Figure 11: Illustration of different steam compression technologies and their domains of operation.

Being set in a 9-floor tower, the Cremo production site provided spatial constraints to introduce the HTHP to its final location. Bringing the machine to the 5th floor using the freight lift was made feasible by the supplier with a proposed HP setup on 2 skids. They are to be assembled on-site and set on anti-vibration mounts.

1.5.6 Practical integration

The hot water loop guarantees the simultaneity between the heat sink and the source, which is always available, whereas the need for steam is limited to the production phases. Therefore, there is no need to integrate heat storage solutions. The available flow rate reserve in the pipe leading to the paddle dryer location and pumping capacity was considered sufficient by Cremo to supply the cold side of the HTHP with their network.

Sufficient space is available next to the paddle dryer for installing an HTHP. This contributes to limiting the piping length to a bare minimum. The structural resistance of the slab is sufficient to make it possible to install the machine at this location. To comply with the hygiene requirements of the production zone, the creation of a small, enclosed area to house the HTHP and accessory equipment was proposed. This also limits the access to the technical equipment.

No electrical power reinforcement is needed at the factory site, given the modest consumption (<100 kW). Modifying the distribution and the connection to the nearest electrical cabinet suffice.

The introduction of the HTHP to its location on the 5th floor is possible through existing access and the use of the freight lift, which has direct access from outside. For this, the manufacturer proposed building the HTHP equipment on two skids that fit the required dimensions and could be assembled on location. This prevents opening a wall and hiring a crane to bring the machine in at a high rise.

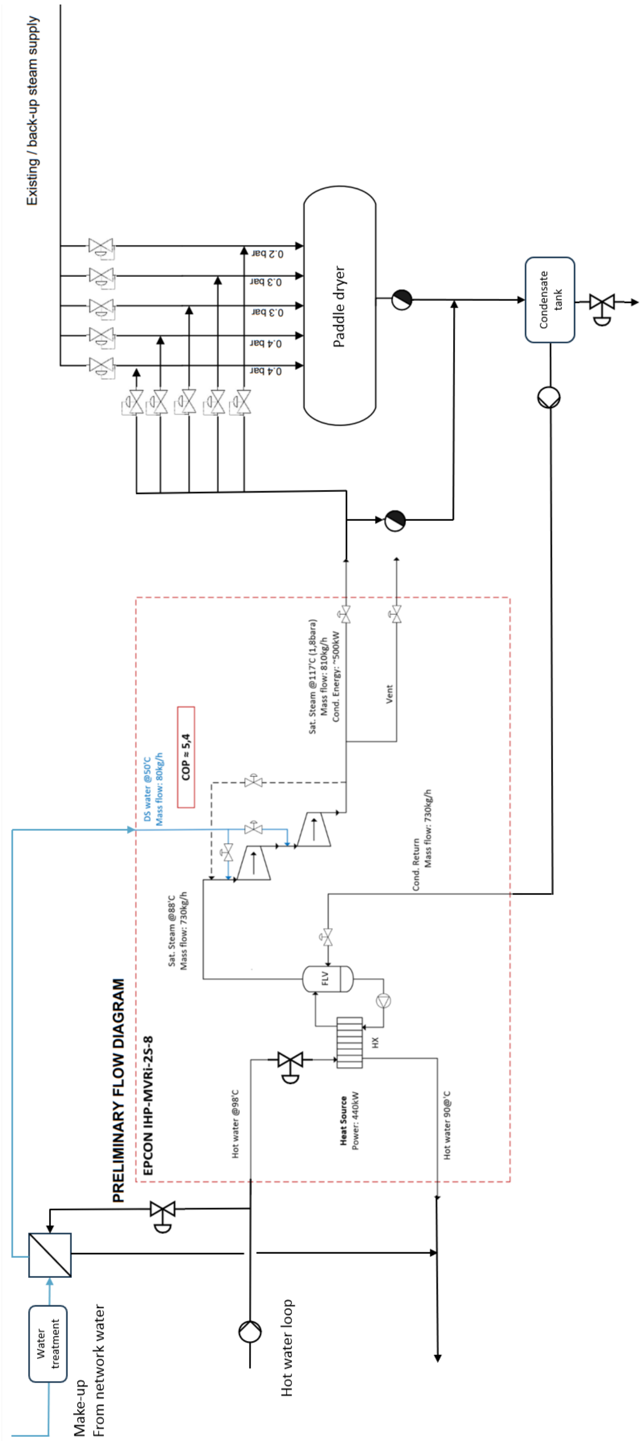

Figure 12: MVR-HTHP integration scheme of the Cremo case study (Based on Appendix 1: EPCON Datasheet).

Practical integration of an MVR-HTHP in the present case study has shown to be technically feasible. Figure 12 illustrates the hydraulic integration of the EPCON solution (Appendix 1). Specific points are:

- Connection to the existing hot water network as a heat source for the steam production HP as well as for the water make-up pre-heating (98 °C, 47 m3/h)
- A water make-up treatment plant is needed to add network water to the factory steam network. The HTHP requires this make-up for de-superheating between the compression stages (50 °C, 80 kg/h).
- Connecting the saturated steam produced to the existing heat supply of the Rosinaire dryer below the existing control valve (1.8 bar(a), 117 °C, 810 kg/h)
- Return of condensate back to the HTHP and boiler room from underneath the dryer.

1.5.7 Equipment sizing and costing

CAPEX calculation for the project was realized with +/- 20% precision. Sizing and selection of the necessary equipment to realize the concept presented in Figure 12 in Cremo's production site was carried out and costed (304 stainless steel requirement).

The price supplied by EPCON for the MVR-HTHP, including delivery and installation, is 1'100 kEUR (+/- 20%, excluding tax). The MVR-HTHP investment cost alone was not disclosed, but it has been estimated to be 700 kCHF for the calculation (specific investment cost of about 1,400 CHF/kW of heating capacity).

Table 2: Project cost breakdown of the 500 kW MVR-HTHP system for Cremo with primary and secondary side installation.

				Material and Installation (CHF)
Primary side	**4%**	Equipment	Heat exchanger for water make-up	481
			Treatment plant for water make-up	7'930
			Circulation pump (existing)	0
		Fittings and instruments	Armatures and fittings (i.e., valves, purges, drains) and instrumentation	10'000
		Electricity	Electrical wiring, cable trays and ducts	5'000
		Piping	Supply & return pipes from the hot water network to the MVR-HTHP source side and water treatment plant	30'370
			Piping and connection to cold water network	1'600
			SUBTOTAL 1:	55'381
MVR HTHP	**86%**	Equipment	1 MVR-HTHP, 1.8 bara saturated steam, 500 kW	1'090'700
		Electricity	Modification of electrical cabinet, creation of new 200A feeder	3'000
			Electrical supply to MVR-HTHP cabinet and connection	12'000
		Civil engineering	Openings for electrical cable routing	1'000
			Creation of a concrete base for the HP and anti-vibration material	3'000
			SUBTOTAL 2:	1'109'700
Secondary side	**6%**	Equipment	Condensate return accumulator and pump	6'500
		Fittings and instruments	Valves and fittings (purge and valves)	10'000
			Process steam control valves	29'415
		Piping	Steam pipes (incl. tapping, elbows, assembly, welding, insulation)	28'700
			Condensate return modification and connection	4'350
			SUBTOTAL 3:	78'965
Other	**4%**	Civil engineering	Machine room for the HTHP and water treatment plant	9'400
		Regulation	Programming and modification of existing MCR panel, peripheral devices	40'020
			SUBTOTAL 4:	49'420
			TOTAL	**1'293'466**
			Fees 12%	**155'216**
			Miscellaneous and unforeseen 15%	**194'020**
			FINAL TOTAL	**1'642'702**

1.6 Energy, environmental, and economical results

1.6.1 Calculation inputs

As input, the energy costs of electricity, gas and district heating were set according to Cremo's contractual values from its suppliers. The current annual operating time of the Tixotherm process is 2'700 h/a. Efficiencies were considered at 85% for the existing boiler and a COP of 5.4 for the MVR-HTHP, according to the manufacturer. Start-up energy for the heat pump wasn't considered for it is unknown (not provided by the manufacturer). A maintenance cost factor of 4% was considered.

As for subsidies, the potential amount offered by the SwissEnergy program was included in the calculation, although Cremo's eligibility has not been strictly confirmed following our request. An estimated amount of CHF 180'000 was admitted for an equivalent 500 kW gas installation in the context of this factory. The difference between the project and the fossil alternative is CHF 1'463'700, of which 40% could be obtained as subsidies.

Moreover, an OPEX overcost of 200 CHF/tCO_2 saved has been admitted. Companies can practice this approach to manage the higher cost implied by switching to sustainable heat production systems. Common payback calculations on this case study would typically not make sense with OPEX increasing compared to the current situation.

1.6.2 Energy consumption reduction

The efficiency increase brought by the MVR-HTHP technology allows for an annual energy saving of 15% on the steam production used to supply the paddle dryer. This value could reach 84.3% if the heat source wasn't taken from the internal hot water loop but valorized from waste heat.

1.6.3 Environmental impact

From an environmental perspective, the project brings pure benefits. Drastically reducing the gas consumption in favor of low-carbon district heating and electricity adds up to an annual CO_2 emissions reduction reaching 87.3% based on the contractual CO_2 content from the electricity and district heating consumed by Cremo.

Another positive point is linked to the choice of MVR technology. The absence of refrigerant fluid in the heat pump guarantees that no additional CO_2-eq emissions can be generated from a possible leakage or serious accidental damage. In the present situation, water itself plays the role of refrigerant.

1.6.4 Economical evaluation

Calculations were conducted to assess the project's cost-effectiveness. Detailed financial data are not disclosed in the present report. Global values and indicators present the financial results. Identified pathways to improve the cost-effectiveness of this project are given below.

Economical results:

- Following the concept sizing and costing, the project's total cost (CAPEX) amounted to CHF 1'642'700, corresponding to a specific cost of CHF 3'285/kW of installed heating capacity. In terms of avoided CO_2 emissions, integrating an MVR-HTHP to supply steam to the paddle dryer leads to an OPEX increase of 82.7 CHF/ton CO_2 reduction. Even with the conceded additional 200 CHF/tCO_2 of avoided emissions and unconfirmed financial support from subsidies, the project leads to a payback of almost 28 years. The calculation is very sensitive to the energy prices. Should gas and electricity prices double with every other parameter kept identical, the payback period would drop to 9 years. The effect would be the same if the HTHP heat source was available at no cost from waste heat instead of supplied by a district heating network.

- Given the economic calculations, a cost factor 2.3 was found by dividing the total investment costs (CAPEX) by the MVR-HTHP investment cost (estimated value). This indicator presents a low value due to the limited integration costs for the machine, along with the high MVR-HTHP investment costs.

Cost efficiency improvement:

- The various parameters impacting the results are discussed hereafter.
- Defining a project where the heat needs are higher, leading to a larger capacity heat pump, would help to reduce the specific costs of the machine and drastically increase its efficiency. This is here specifically due to the change of compressor technology allowing for smaller flow rates, as discussed above.
- The hot water loop has a cost, whereas the exhaust air wouldn't. On the other hand, these streams have lower temperatures, which induces a reduced COP of about 2.3. Besides, the spatial restrictions in the air treatment room prevent modifications to use these streams as a source for the HTHP. Heavy modifications would indeed be required to the existing heat recovery system.
- As an advantage, the availability of the hot water loop as a source is guaranteed. However, the search for alternative heat sources outside the scope of this project could prove to be an interesting economic and efficient solution. If the waste heat that could be identified could reduce its cooling need by serving as a heat source for the HTHP.
- Increasing the paddle dryer's operating time would positively impact the cost-efficiency as it would have an increased cost for gas vs electricity cost.

Subsidy programs:

- Two subsidy programs are aimed at supporting the integration of heat pumps in the Swiss industries. They are shortly described hereafter:
- HP for process heat offered by SwissEnergy/SFOE
    - Subsidy of max. 40% of the over-costs generated for an industrial heat pump project compared to a conventional installation
- Industrial heat pump subsidy offered by Myclimate
    - Global amount of 18 cents/kWh (average over last 3 years consumption)
    - Yearly payment of CHF 160/tCO_2 up to the subsidy amount is reached
    - Subsidy agreement until the end of 2030
- The eligibility conditions of the projects are to be carefully checked, regarding CO_2 tax refunds and existing target agreements, as well as the payback time of projects.

1.7 Conclusions

A technically feasible solution has been found, described and costed.

The following benefits can be highlighted:

- Environmental: 87.3% annual CO_2 emissions reduction for the paddle dryer steam supply is achieved.
- Technology: The considered MVR-HP is mature and contains no refrigerant fluid.
- Integration level: The installation close to the production process unit decreases integration costs.
- Efficiency: Make the production as close as possible to the process's fundamental heating needs.
- Heat source: The hot water loop offers a constant heat source for the HTHP.

The following challenges have occurred or were identified:

- No pre-existing Pinch Analysis was available, leading to a lack of data to define sufficient waste heat sources at an interesting temperature level
- No profitability was reached by replacing fossil steam production with the feasible HTHP concept.
- Very low steam flow rate for MVR usual technology, not much choice on market-ready products:
  - Performance gap with larger machines
  - Increased specific price (CHF/kWh) for small-size HTHP
- Semi-continuous production with moderate operating time
- Access: HP introduction to the defined location in the factory building on the 5th floor
- Subsidy programs
  - Not eligible for myclimate subsidies
  - Unconfirmed eligibility to SFOE subsidies program for heat pumps in industries

1.8 Lessons learned

This case study has established or confirmed the relevance of the following recommendations:

1. Pinch Analysis first: despite the complexity of the processes and the effort needed for data collection / extraction, convince the client to perform a Pinch Analysis. There are broader issues and opportunities to be addressed (however, the scope and time frame of the project did not allow it).
2. Preliminary screening: devise possible integration concepts and perform preliminary rough calculations to check whether conditions for profitability are likely met, possibly met, or clearly not met. This can prevent spending time and money on concepts that are not viable (in this case study, the small heat duty / steam mass flow required could have switched on the red light earlier (few market-ready products, high specific costs, poor MVR performance). Further, the effect of a non-free heat source on the profitability threshold could have been anticipated.

3. Don't take information and data supplied by the customer as gospel: make crosschecks (using mass energy balances, cross calculations, spot measurements, ...) to verify the consistency of the data and the orders of magnitude. Although P&ID as well as detailed process specifications are available, don't automatically trust the values quoted - actual values (steam consumption, air flow, etc.) may deviate significantly from “nominal” values.
4. Double check estimates of the annual operation time given by the company, as overestimated values (in this case by a factor 3 or more) can be a killing factor for the profitability of the HP.
5. Propose measurements as needed. If the client does not wish to pay for measurements, inform them in writing of the risks involved in taking shortcuts. Measures key data and check factors that may kill the feasibility and/or the profitability. In particular, small capacity HTHPs feature large specific costs and a lower efficiency compared to large HTHPs. The steam consumption of the paddle dryer could not be measured but has been calculated by energy and mass balances in which several values are still inaccurate (heat losses, specific heat of feed, humidity of exhaust air, ...). Remember that inaccurate heat pump specifications can have detrimental effects on its operating efficiency and profitability.
6. Find out about any flexibility requirements in process operation (e.g. CIP phase, rapid heating and “sterilization” at start-up, etc.), as temperature requirements may be higher and not allow efficient heat pump operation, or even make it impossible and require heat from existing utilities.
7. Anticipate increased workload when the site includes several utilities at different temperature levels, and corresponding networks. This situation is generally more restrictive for retrofitting heat pumps at utility level than in the absence of intermediate distribution levels.

2 Case study Gustav Spiess

This case study investigates the technical and economic feasibility of integrating a steam-generating heat pump (SGHP) at Gustav Spiess AG into the pasteurization and cooking/smoking processes.

2.1 Company and Site Activities Overview

2.1.1 Company and products

Gustav Spiess AG is a family-owned company in Berneck (SG, in the Eastern part of Switzerland) that produces meat products such as sausage, ham, and bacon (Figure 13, left). The company has two production sites, one in the center of a 40-year-old building and another in the industrial zone. In 2022, when the HTHP-CH project began, the new production facility was under construction. Meat production started in Spring 2023. Of the 160 employees, 3 work in infrastructure maintenance (Jansen, 2023).

As part of the SBTi (Science-based Targets Initiative[3]), the company committed to reducing its Scope 1 (direct, electricity) and Scope 2 (indirect) greenhouse gas emissions by 50% by 2030 (2018 base) and to measuring and reducing its Scope 3 emissions (Jansen 2023). One measure was installing a 400 kWp PV system on the roof of the new building to generate renewable electricity (Figure 13, right).

Gustav Spiess AG is willing to invest in a green future, but the new technologies must be economical. The requested payback times of energy projects should be below 6 years. The aim is to reduce CO_2 emissions to zero.

Figure 13: New meat production building at Gustav Spiess AG in Berneck (Left: Jansen (2023), Photo right: M. Furrer, 8/2024).

2.1.2 Production processes and supporting side processes

The meat comes from a slaughterhouse located in St. Gallen to Berneck. Meat products like sausages require cutting, cooking/smoking/cooling, packaging, cooling/storage processes, and other logistics. Figure 14 shows some impressions during a site visit on 1 September 2022.

[3] https://sciencebasedtargets.org/target-dashboard

Figure 14: Impressions during the site visit at Gustav Spiess in Berneck (SG) on 1 September 2022 (Photos: C. Arpagaus).

For pasteurization and cooking/smoking, low-pressure steam is introduced into the cabinets and condenses on the cold sausage surfaces (20 °C). The cabinets supplied by Sorgo Anlagenbau GmbH (www.sorgo.at) have smart programming software that controls the steam generation via electricity in the heating coils and the steam generation from gas boilers. From the operator's point of view, a gas boiler is considered a safe/reliable system.

100 g large Cervelat sausages require around 2 hours of cooking time. Cervelats must be cooked once at 72 °C. To cool down, the Cervelats come into direct contact with drinking water (15 °C) and are then stored at 2 °C in a refrigerator. In this way, the Cervelats have a shelf life of 18 days.

For large sausages, the cooking time is even 2.5 hours. Wood smoke is added to the cabinets for meat products to impart flavour and colour. The processing steps vary slightly depending on the sausage product (smoking, steaming). For example, Bratwurst sausages are processed without smoke and are cooked twice, first at 60 °C (only the meat, direct steam/smoke contact), next cooled down to avoid softening, then packed in plastic and pasteurized at 72 °C providing a hygienic product and high shelf-life (30 days). The cooling water can only be used once before being drained at about 20 °C to the community sewage. Drain water recycling is not possible because it is not clean enough. It contains different amounts of proteins, fat, etc.).

2.1.3 Utilities and Existing Heat Recovery

In a preliminary study in 2019 (before the HTHP-CH project started), Gustav Spiess AG evaluated various energy systems and options for steam generation. Table 3 summarizes the advantages and disadvantages of the investigated energy systems. A comparison of the total annual costs showed that the solution with the gas-fired steam boiler was the most economical.

Table 3: Advantages and disadvantages of different energy systems for steam generation.

Heating system	Advantages	Disadvantages
Electric steam boiler	+ High operational reliability + Proven technology	- High electricity consumption - High energy costs
Gas-fired steam boiler	+ High operational reliability + Proven technology + Lowest yearly costs	- CO_2 emissions - Fossil fuel
Wood-fired steam boiler	+ High proportion of renewable energy + Innovative solution	- Space requirement - High maintenance and servicing
Electric steam generator and gas heater	+ Low investment + Low maintenance and servicing	- High electricity consumption - High energy costs
Electric steam generator and pellet boiler	+ High proportion of renewable energy + Innovative solution	- Space requirement - High maintenance and servicing

As a result, a gas-fired steam boiler with a capacity of 4'000 kW (Astebo GmbH, Type THS-I 4000S, Gas burner from Weishaupt, Type WM-G30/1-A, max. 3'500 kW) was installed in 2022 in the new building at Gustav Spiess AG, providing high-pressure steam of 6 to 8 bar(a) to heat the pasteurization and cooking/smoking cabinets (Figure 14). The steam pressure is reduced to 1.5 bar(a) (115 °C) to achieve cabinet temperatures of 85 to 90 °C and a sausage core temperature of about 72 °C to deactivate bacteria (pasteurization) (Jansen 2023) (Figure 15).

Figure 15: Energy needs at Gustav Spiess for cooking meat products (Jansen 2023).

NH_3 chillers operating at -18 °C/-20 °C are used for cold storage of the sausages at 0 °C to 2 °C. The waste heat of the ammonia chillers between 40 °C and 50 °C is partly used to warm water, and the rest is rejected to the environment. A heat pump produces hot water at 65 °C, which is used for cleaning, building heating, and substituting a gas boiler, which uses the waste heat from the chillers.

2.1.4 Energy demand

Figure 16 shows a general map of the new site with the various areas and their functions/processes. The main feedstock are carcasses, meat and meat products, and the main products are meat and meat products such as sausage, ham and bacon. The utility distribution networks include steam, hot water, cooling water and ice water. A hot water boiler, heat storage tanks and cold storage rooms are integrated for this purpose. Waste is CO_2 emissions from fossil fuels, sewage water, bones, plastics, etc., and heat. Heat recovery potential lies in the waste heat from ammonia chillers and compressed air.

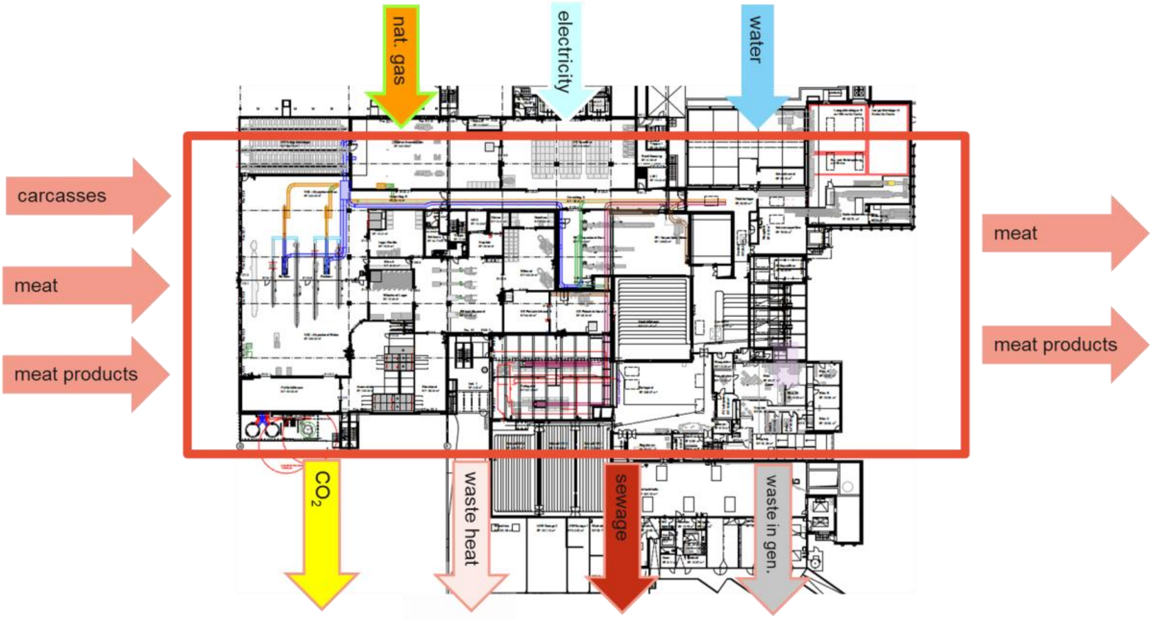

Figure 16: Energy needs at Gustav Spiess for cooking meat products (Jansen 2023).

Table 4 shows the overall picture of energy types at the site until 2022, with an outlook until 2024/25 and a possible integration of an electrically driven SGHP for steam generation. Monthly energy consumption and production data (electricity and gas consumption profiles) should be made available to obtain a better overview of seasonal fluctuations and the need for storage or adjustment of production planning.

Table 4: Overall picture of the types of energies at the site (Source: Gustav Spiess AG, Status 2022).

	until 2022	2023	from 2024/25
Natural gas total GWh	0.5 (gas for cleaning water, heating)	~1 (gas for cooking)	~0.5 (cooking HTHP & gas)
Electricity cooking GWh	~0.7 (coils)	0	~0.25 (HTHP)
Electricity warm water/heating heat pump GWh	0	~0.15 (heatpump)	~0.15 (heatpump)
Electricity total GWh	3.8	~3-3.5	~3.5
PV Prod. GWh	0	0.4	0.6
Water for cleaning 40°C m3	40000	~60000	~60000

The goal of Gustav Spiess AG is to have an SGHP using the waste heat of the ammonia chillers, keeping the gas or the electrical heating coils for a backup and start-up operation when using different heat sources (the priority should be on the SGHP). The carbon tax compensation as an incentive will depend on the SGHP's COP.

2.1.5 Energy costs

Figure 17 shows that the gas and electricity prices fluctuate greatly over a year. Figure 18 shows the average gas and electricity prices from 2020 to 2025. Gas prices are constantly changing as a market price. Gustav Spiess AG buys electricity on the free market[4]. Electricity prices are set annually based on Berneck's medium-voltage tariffs, including all levies. The purchased electricity mix of Gustav Spiess AG has a low CO_2 emission factor of approx. 0.012 kg CO_2/kWh.

In 2023, the average electricity price was 0.25 CHF/kWh, and the gas price was 0.13 CHF/kWh, resulting in an electricity-to-gas price ratio of around 1.9, which appears favorable for an electricity-driven SGHP.

In 2022, the average electricity price was 0.15 CHF/kWh (40% of which is energy costs, the rest is fixed taxes), and the gas price was 0.17 CHF/kWh, which corresponds to a price ratio of 0.9. The energy prices in 2025 are 0.21 CHF/kWh (energy 0.1 CHF/kWh and 0.11 CHF/kWh for grid and taxes), and gas is around 0.09 CHF/kWh, corresponding to a 2.4 ratio.

By comparison, biogas, excluding the CO_2 levy, costs CHF 0.183/kWh (100% Swiss production, as of October 2024), or 0.1 CHF/kWh more than natural gas.

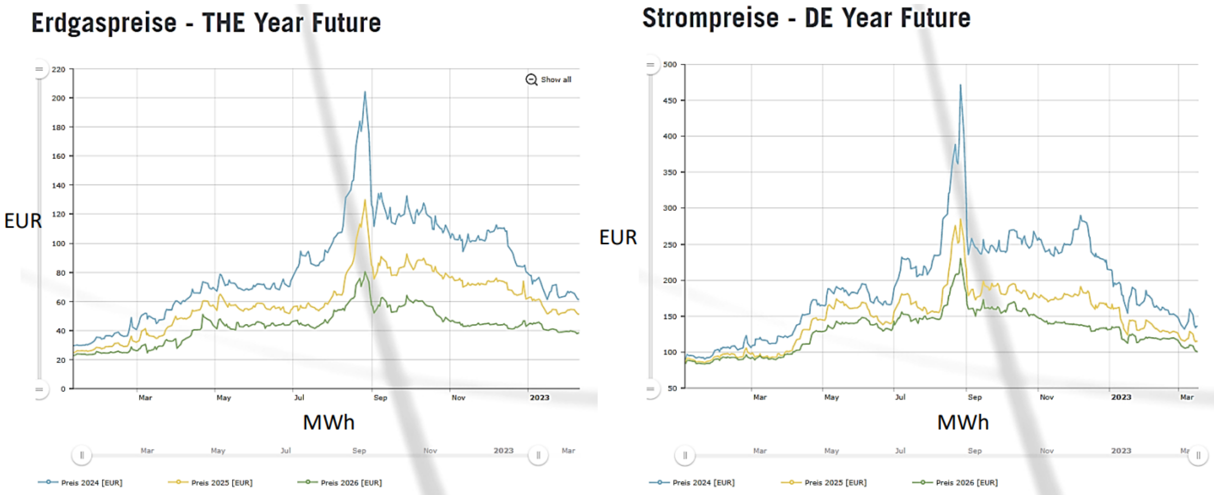

Figure 17: Energy prices on the spot market (Source: https://www.enerprice.ch/charts/erdgaspreise, https://www.enerprice.ch/charts/strompreis).

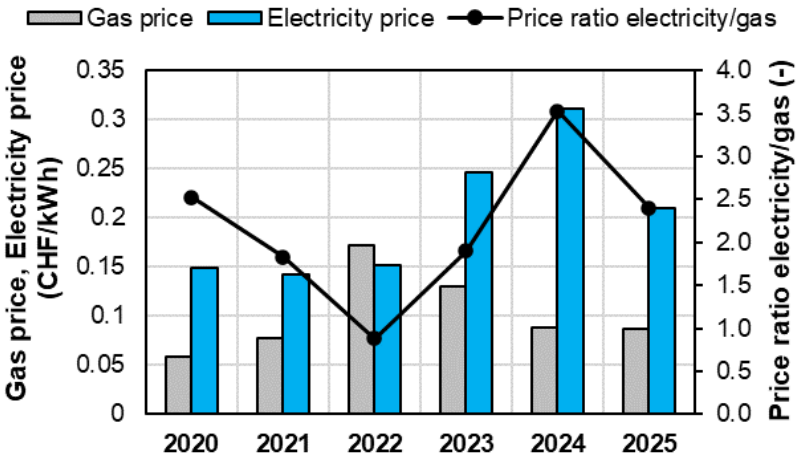

Figure 18: Average energy prices of Gustav Spiess AG from 2020 to 2025.

[4] https://www.strompreis.elcom.admin.ch

2.2 SGHP Integration concept

2.2.1 Integration concept

Figure 19 shows a simplified drawing of the considered integration concept of a 550 kW SGHP in the sausage cooking/smoking process (based on 840 kg/h steam demand for 5 cooking/smoking units in the 1st construction phase) using the waste heat from the NH_3 chillers as a heat source at 40 to 50 °C as a heat source and providing 1.5 bar(a) steam (110/120 °C) for the sausage cooking cabinets (Arpagaus et al. 2023, 2024b; Jansen 2023; Arpagaus 2024a).

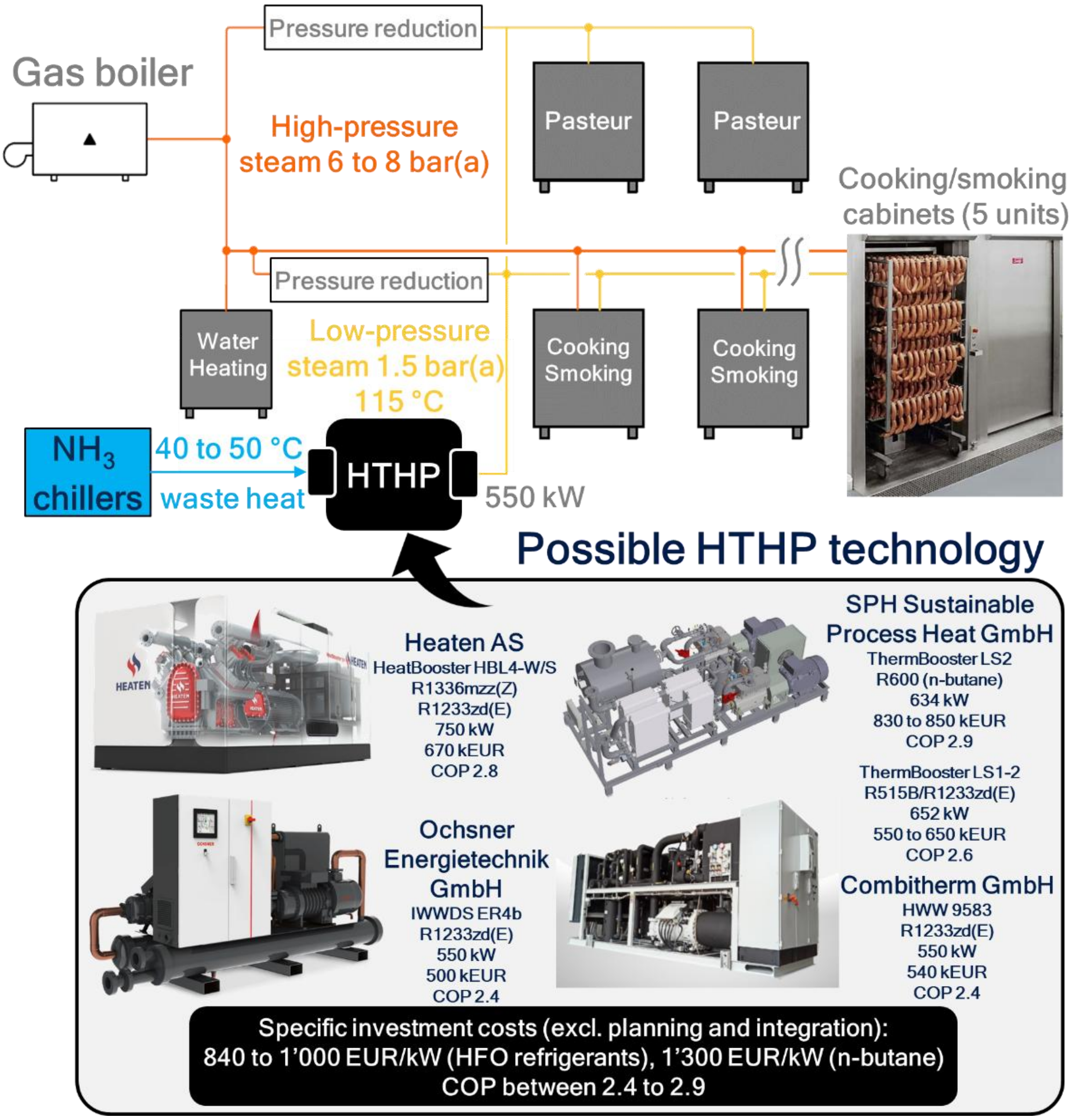

Figure 19: Integration concept of a steam-generating HTHP at Gustav Spiess AG for sausage cooking/smoking processes and possible HTHP technology providers (Arpagaus et al. 2023, 2024b; Jansen 2023; Arpagaus 2024a) (Status: 01/2024).

Figure 20 shows that the available space for the HTHP integration besides the existing gas/oil boiler is restricted (Arpagaus et al. 2024b). Flammable refrigerants would lead to additional safety costs.

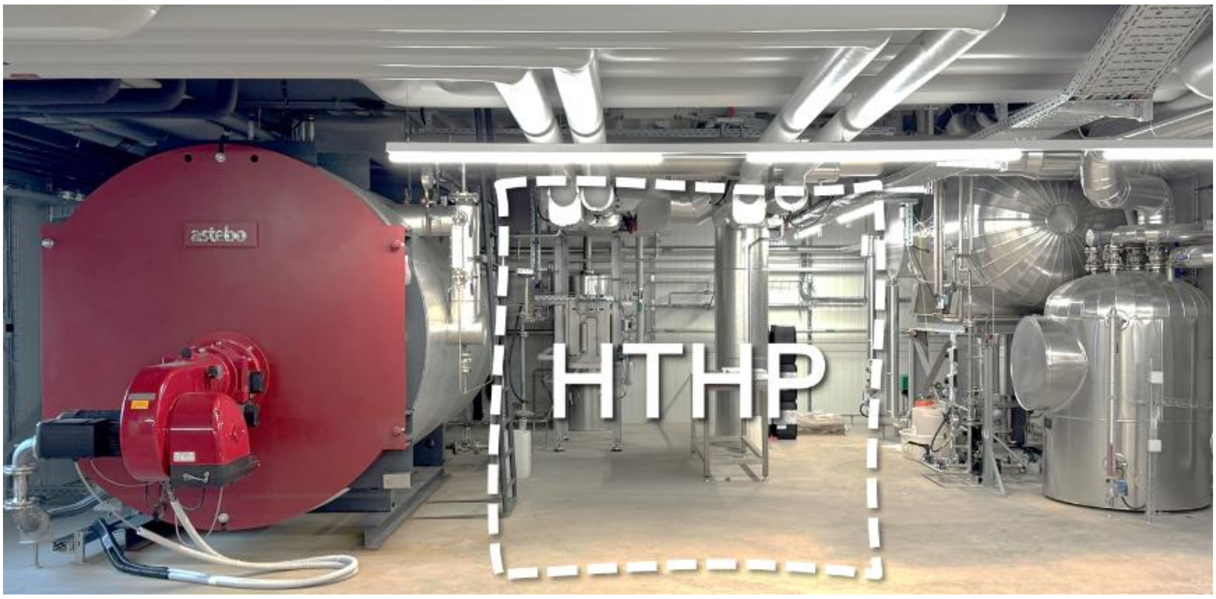

Figure 20: Space for HTHP integration besides the existing gas/oil boiler is restricted (Photo: C. Arpagaus, 14/01/2024).

2.2.2 Market available SGHP

An indicative offer from Ochsner Energietechnik GmbH (Austria) suggested investment costs of around 365 kCHF for a closed-cycle HTHP (Model IWWDS 540 ER4b) with synthetic refrigerant R1233zd(E) in 2023, including commissioning, resulting in specific investment costs of about 730 CHF/kW (Figure 21, left). The delivery time would be around 30 months.

Operating point	50/45 → 110/120	°C
Heating capacity	470	kW
Cooling capacity	274	kW
Electrical power	196	kW
COP	2,4	-
Investment cost (indicative)	339'100	CHF
Refrigerant surcharge	16'950	CHF
Comissioning	8'775	CHF

→ Specific investment costs: 730 CHF/kW

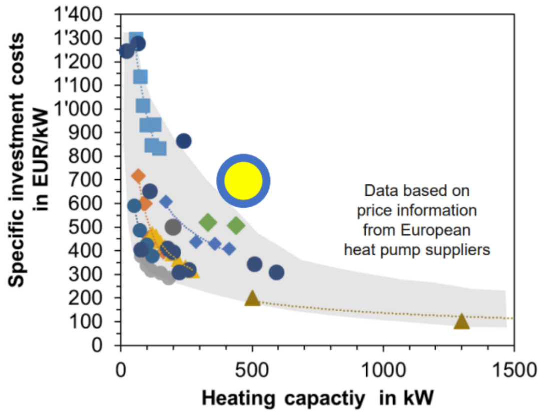

Figure 21: Left: Investment costs of a 470 kW HTHP for Gustav Spiess AG based on an indicative offer from Ochsner Energietechnik GmbH (10/01/2023) (Jansen 2023), Right: Comparison of the specific investment costs with other European heat pump suppliers (Arpagaus et al. 2021).

Today, there are various suppliers of HTHPs on the market that can generate steam directly or provide hot water that can be used to generate steam. (Arpagaus et al. 2024a) provided an up-to-date market overview. For this case study, Heaten AS (Norway), SPH Sustainable Process Heat GmbH (Germany), Ochsner Energietechnik GmbH (Austria) and Combitherm GmbH (Germany) were contacted for an indicative price offer. Figure 19 summarizes the results (Arpagaus et al. 2023, 2024b; Arpagaus 2024a).

The specific investment costs (excl. planning and integration) are estimated at 840 to 1'000 EUR/kW for HFO refrigerants (R1233zd(E), R515B/R1233zd(E) cascade) and 1'300 EUR/kW for n-butane (R600). The COPs are between 2.4 and 2.9 for the reference case conditions. The cost multiplication factor accounting for planning and integration is assumed to be 1.5 or 2.0.

Another efficient solution for this case study could be the Rotation Heat Pump (RHP) from ECOP (Austria). The indicative COP at 120/140 °C heat sink and 65/40 °C heat source is 3.29, and the list price for a 700 kW Gen3 RHP is around 750 kEUR (as of 09/2024). The working fluid is a noble gas.

2.2.3 Economic Evaluation and Sensitivity Analysis

A preliminary economic evaluation of the case study was made based on the calculation tool developed in MS Excel (Arpagaus et al. 2022a, b). It assumes that the gas boiler's investment is depreciated and remains for production safety, redundancy, start-up operation, and peak load coverage.

Input parameters to the evaluation tool are electricity price, gas price, operating hours, heating capacity, temperature lift between the heat source and sink, specific investment costs, maintenance cost factor, discount rate, CO_2 emissions factors of electricity and fuel, and CO_2 tax refund (subsidies).

The output results are the COP, CO_2 emissions reduction, annual cost savings, and the payback period. The calculation tool helps quickly evaluate an HTHP integration's economic feasibility as a "go/no-go" decision.

Table 5 shows the input and output parameters for a Reference Case (Ref) at 50 °C/115 °C heat source inlet/heat sink outlet, 550 kW heating capacity, and 1.47 electricity-to-gas price ratio.

Table 5: Input and output parameters of the economic evaluation for a Reference Case (Ref) (Arpagaus et al. 2023, 2024b; Arpagaus 2024a).

Input parameters		
Heat sink inlet/outlet temperature	**°C**	**20/115 (1.5 bara steam)**
Heat source inlet/outlet temperature	**°C**	**50/45**
Temperature lift	**K**	**65**
Heating capacity	**kW**	**550**
Fuel (gas, oil) price	EUR/kWh	0.17
Electricity price	EUR/kWh	0.25
Electricity-to-fuel price ratio	-	1.47
CO_2 tax (or subsidies)	EUR/tCO_2	92.5
Electricity CO_2 emissions factor	kgCO_2/kWh	0.012
Fuel CO_2 emissions factor	kgCO_2/kWh	0.201
Annual operating time (12 h/d, 250 d/a)	h/a	3'000
Efficiency of fuel boiler	-	0.90
Maintenance factor (on capital costs)	-	0.04
Cost factor for planning & integration	-	2.0
COP ($COP = 52.94 \cdot \Delta T_{lift}^{-0.716}$)	**-**	**2.67**
Specific investment costs (HTHP)	**EUR/kW**	**840**

Output parameters		
Total investment costs	**kEUR**	**924**
Annual CO_2 emissions reduction	tCO_2/a (%)	361 (98%)
Annual energy savings	MWh/a (%)	1'214 (66%)
Annual fuel cost savings	kEUR/a	312
Annual electricity costs	kEUR/a	155
Annual heat pump maintenance costs	kEUR/a	37
Annual CO_2 tax compensation	kEUR/a	33
Annual cost savings	**kEUR/a**	**153**
Discount rate	%	5
Payback period	**a**	**6.0**
Discounted payback period	**a**	**7.3**

In the Reference Case (Ref) scenario, a 550 kW SGHP was considered using the waste heat from the NH_3 chillers as a heat source at 50 °C and providing 1.5 bar(a) (115 °C) low-pressure steam. A typical annual operating time of 3'000 h (12 h/d, 250 d/a) was assumed. The electricity price for medium-sized customers was set at 0.25 CHF/kWh (2023) and the gas price at 0.17 CHF/kWh (2022). This results in a favourable electricity-to-gas price ratio of 1.5. The purchased electricity mix is nuclear energy with a low CO_2 emission factor of approx. 0.012 kg CO_2/kWh_{el}. Due to the reduction in CO_2 emissions, a possible carbon tax rebate of 92.5 EUR/tCO_2 was assumed. A discount rate of 5% was used.

The economic calculation leads to a payback period of 6.0 years (see Table 5), which means that the SGHP integration would be cost-effective for Gustav Spiess AG under the current assumptions. However, it should be noted that the financial evaluation strongly depends on the individual case.

The case study shows significant annual energy savings of 66% and CO_2 emission reductions of 98% because of purchasing nuclear power. The COP varies between 2.4 and 2.9 depending on the HTHP technology applied. According to a COP-fit function ($COP = 52.94 \cdot \Delta T_{lift}{}^{-0.716}$) (Arpagaus et al. 2022a, b) a COP of 2.67 is calculated and used for the economic evaluation.

Further calculations shown in Table 6 lead to 3.2 to 14.2 years payback periods, depending on the assumed energy prices, cost factor for planning & integration, COP, and specific investment costs. In scenarios A and B, integrating an SGHP would be cost-effective and within the accepted payback period of 3 to 5 years.

Table 6: Preliminary evaluation of the payback period for the case study of Gustav Spiess AG.

			A	B	C	D	E	F
Company			Gustav Spiess	Gustav Spiess	Gustav Spiess	Gustav Spiess	Gustav Spiess	Gustav Spiess
Application process	Symbol	Unit	Sausage cooking	Sausage cooking	Sausage cooking	Sausage cooking	Sausage cooking	Sausage cooking
Heat sink outlet temperature	T_h_out	°C	115	115	115	115	115	115
Heat source inlet temperature	T_c_in	°C	50	50	50	50	50	50
Temperature lift	dT_lift	K	65	65	65	65	65	65
Heating capacity	Q_dot_h	kW	470	470	470	470	470	470
--- Fuel prices, CO2 tax, CO2 emission factors---								
Fuel price (gas, oil)	c_fuel	EUR/kWh	0.13	0.13	0.13	0.13	0.13	0.13
Electricity price	c_el	EUR/kWh	0.25	0.25	0.25	0.25	0.25	0.25
CO2 tax	c_CO2_tax	EUR/tCO2	0	0	0	0	0	0
CO2 emissions factor electricity	f_CO2_el	kgCO2/kWh	0.012	0.012	0.012	0.012	0.012	0.012
CO2 emissions factor fuel	f_CO2_fuel	kgCO2/kWh	0.201	0.201	0.201	0.201	0.201	0.201
CO2 emissions ratio el/gas	e_CO2_el/fuel	-	0.06	0.06	0.06	0.06	0.06	0.06
Electricity-to-fuel price ratio	p_el/fuel	-	1.92	1.92	1.92	1.92	1.92	1.92
--- Other input parameters---								
Annual operating time	t	h/a	3000	3000	3000	3000	3000	3000
Efficiency of fuel boiler	eta_fuel	-	0.90	0.90	0.90	0.90	0.90	0.90
Maintenance factor (on capital costs)		-	0.04	0.04	0.04	0.04	0.04	0.04
Cost factor for planning & integration	f_inv_hp	-	**1.0**	**1.5**	**2.0**	**1.5**	**1.5**	**1.5**
--- Fit curves ---								
COP (y=52.94x^-0.716)	**COP**	-	**2.67**	**2.67**	**2.67**	**2.40**	**2.40**	**2.40**
Specific investment costs (y=3157x^-0.322)	**c_inv_hp**	**EUR/kW**	**435**	**435**	**435**	**730**	**550**	**435**
--- CO2 emissions reduciton & energy savings ---								
Annual CO2 emissions reduction	**E_CO2_reduction**	**tCO2/a**	**309**	**309**	**309**	**308**	**308**	**308**
Annual CO2 emissions reduction	**E_CO2_reduction**	-	**98%**	**98%**	**98%**	**98%**	**98%**	**98%**
Annual energy savings	**E_savings**	**MWh/a**	**1038**	**1038**	**1038**	**979**	**979**	**979**
Annual energy savings	**E_savings**	-	**66%**	**66%**	**66%**	**63%**	**63%**	**63%**
--- Economic calculations ---								
Investment costs	**C_inv_hp**	**kEUR**	**205**	**307**	**409**	**515**	**388**	**307**
Annual fuel cost savings	**C_fuel**	**kEUR/a**	**204**	**204**	**204**	**204**	**204**	**204**
Annual electricity costs	**C_el**	**kEUR/a**	**132**	**132**	**132**	**147**	**147**	**147**
Annual heat pump maintenance costs	**C_maintain**	**kEUR/a**	**8**	**12**	**16**	**21**	**16**	**12**
Annual CO2 tax compensation	**C_CO2**	**kEUR/a**	**0**	**0**	**0**	**0**	**0**	**0**
Annual cost savings	**C_savings**	**kEUR/a**	**63**	**59**	**55**	**36**	**41**	**45**
--- Payback ---								
Payback period	**PP**	**years**	**3.2**	**5.2**	**7.4**	**14.2**	**9.4**	**6.9**

Figure 22 shows a sensitivity analysis of the payback period for the Reference case (Ref). All input parameters of the model were individually varied from -25% to +25% (factor 0.75 to 1.25), while the other parameters were kept constant.

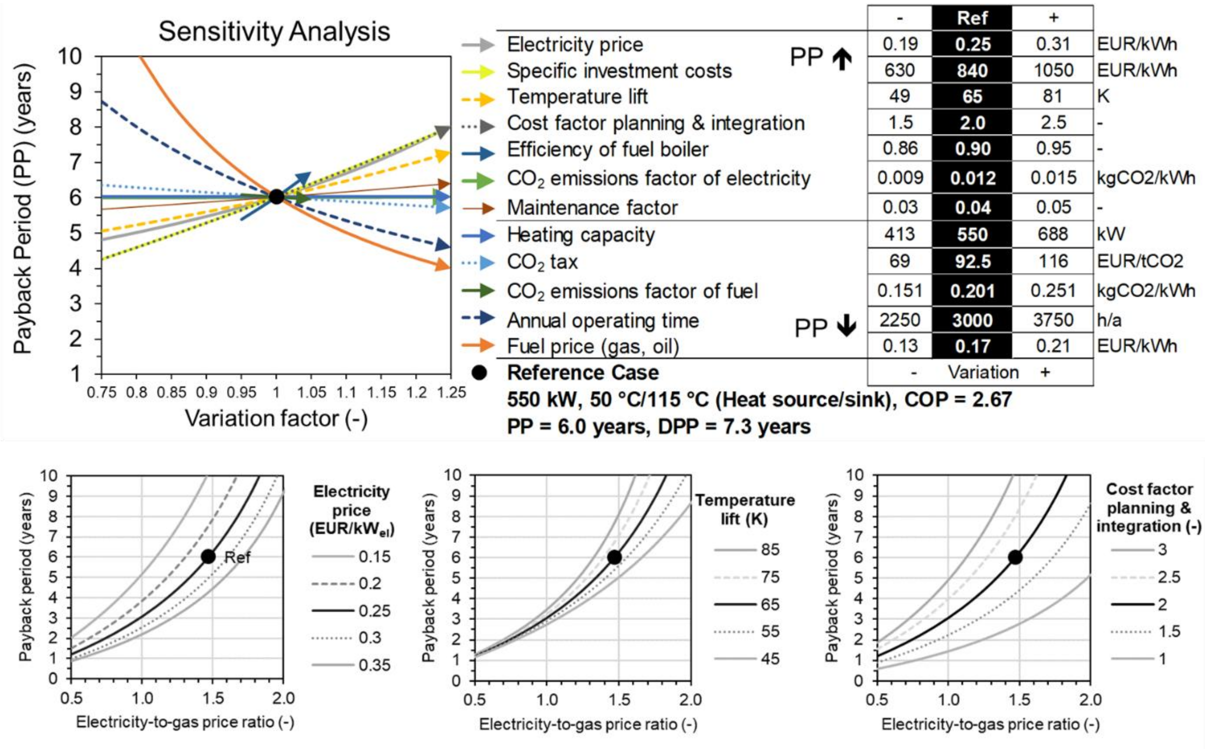

Figure 22: Sensitivity analysis of the payback period for the Reference Case (Ref) at 50 °C/115 °C heat source inlet/heat sink outlet, 550 kW heating capacity, and 1.47 electricity-to-gas price ratio. The graphs below show the impact of electricity price, temperature lift, and cost factor for planning & integration on the payback period as a function of the electricity-to-gas price ratio (Arpagaus et al. 2023, 2024b; Arpagaus 2024a).

The sensitivity analysis reveals that the estimated payback period of 6 years is strongly sensitive to a change in electricity and fuel prices, the temperature lift (i.e., COP, application), the specific investment costs, operating hours, and the cost multiplication factors for planning and integration.

Using waste heat from NH_3 chillers as a heat source shows great multiplication potential in other Swiss food processes, where refrigeration machines for cooling foods are state-of-the-art.

However, technical support is necessary for HTHP integration (e.g., know-how on the choice of refrigerant, HTHP in combination with gas boilers, cost transparency regarding investment, maintenance, energy costs and reduction of CO_2 emissions).

In the next step, the steam demand of the cooking cabinets is analyzed in more detail, and a Pinch analysis is performed with the support of the Swiss company Flimatec AG (Horw).

2.3 Steam Demand and Pinch Analysis

During the HTHP-CH project, monitoring sensors were installed to measure steam consumption and waste heat from the NH_3 chillers. The first measurement data was available for evaluation in 2024.

Figure 23 shows the measured steam profile for the production days from 6 to 7 February 2024. The analysis shows a strongly fluctuating steam demand between approximately 80 and 900 kW. It is assumed that several appliances of the cooking cabinets and the pasteurizer are operated simultaneously as batch processes. As a result, to avoid oversizing the SGHP and heat pump cycling a combination of SGHP integration and a steam accumulator should be considered.

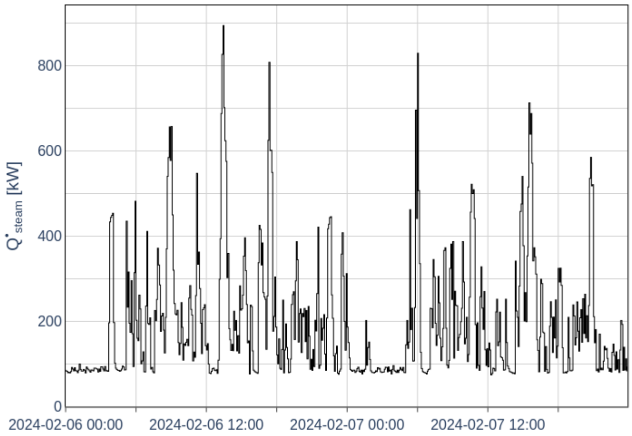

Figure 23: Measured steam profile on 6 to 7 February 2024 (Source: Flimatec AG, Horw).

Figure 24 illustrates the cumulative curve of the steam demand for 51 measurement days. The measured peak value is around 1’200 kW. Around 2/3 of the time, the steam demand is low. The measurements suggest an SGHP integration with a lower heating capacity than originally expected and fewer operating hours.

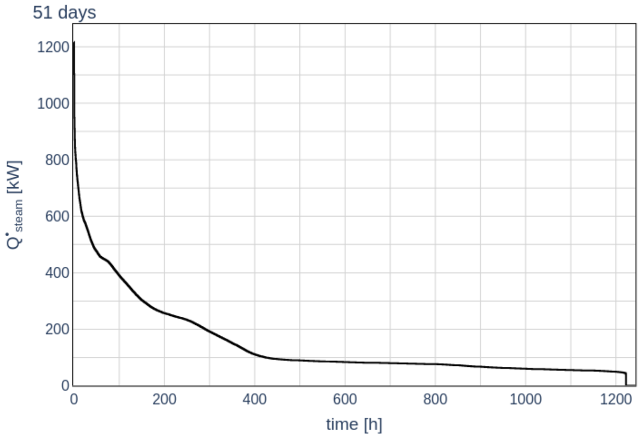

Figure 24: Cumulative steam demand for 51 measurement days (Source: Flimatec AG, Horw).

Figure 25 shows an example of Composite Curves over 11 hours (0:00 to 11:00) with average steam demand and waste heat from refrigeration (i.e., simplified with 2 streams). In this illustration, the installed heat recovery systems in the new production building of Gustav Spiess AG have been deducted.

The process requirement for steam generation and unused waste heat from refrigeration remains. The steam demand is around 130 kW. The unused waste heat from refrigeration is about 190 kW. Overall, there is simultaneously more unused waste heat available throughout the day than steam demand. Only during short periods, there is not enough unused waste heat available.

In summary, the measurement data and the Pinch Analysis evaluation show that the waste heat from the NH_3 chillers has a sufficiently high capacity and availability. The analysis of steam demand shows periods with interruptions. A steam accumulator is therefore recommended to balance the fluctuations.

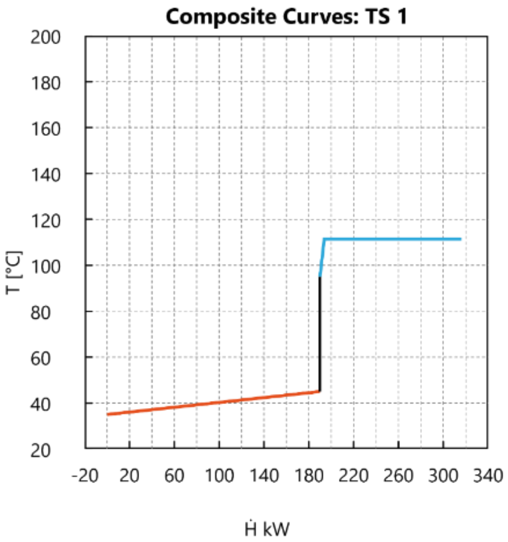

Figure 25: Composite Curve (Source: Flimatec AG, Horw).

According to Flimatec AG, a steam accumulator of approximately 5 m^3 at 4 bar(a) combined with an SGHP of around 250 to 300 kW heating capacity should be sufficient to cover the steam demand of Gustav Spiess AG.

As an outlook, it is recommended to verify the dimensioning and sizing of the equipment to maximize the utilization of steam-driven processes and conduct a detailed cost calculation by a specialist planner (e.g., SGHP, steam accumulator, installation).

2.4 Conclusions

The case study of Gustav Spiess AG has demonstrated that integrating an SGHP with a steam accumulator is technically feasible. Various SGHP technologies are available on the market, and sufficient waste heat is available from the NH3 chillers. Energy costs and CO_2 emissions can be reduced by integrating an electrically driven SGHP. However, there are economic challenges, including high temperature lift (i.e., low coefficient of performance, or COP), high investment costs, low operating hours, and high energy prices.

2.5 Lessons learned

The main lessons learned of the case study are (Arpagaus 2024b):

- For accurate dimensioning of the SGHP system (i.e., heating capacity, operating hours, steam accumulator, and installation) and cost calculation, the measured steam profile and the cumulative steam demand for a measurement campaign must be known.
- Data collection and measurement of gas consumption for heating the cooking cabinets are essential for decision-making and dimensioning (i.e., fluctuations, peak demand).
- The Pinch Analysis supported decision-making and clarified potential integration points regarding temperatures and heating capacity.

3 Case study ELSA

3.1 Introduction

ELSA (Estavayer Lait SA) is Switzerland's largest dairy on a single site, processing around 260'000 tons of milk per year into a wide range of fresh dairy products, such as UP/UHT milk, yogurt, quark, and cream. As a large industrial dairy, it was to be expected that ELSA would present different opportunities for HTHP integration. ELSA had several applications in mind.

Considering the large number of products (>300) and corresponding processes and processing conditions, it was not possible to collect all data in the frame of the HTHP-CH project. In fact, a Pinch Analysis was conducted in 2012, and the data and the report were made available by their author at the beginning of the project in 2022. From the discussions with ELSA, it appeared that, compared to 2012, many changes took place, including:

- Evolution of the production breakdown
- Implementation of new process units to replace existing ones
- Improvement of CIP units and their operation
- Implementation respectively improvement of heat recovery projects
- Installation and operation since 2016 of a wood chip-fired saturated steam boiler supplying base load steam and merging of the 2 steam networks
- Redesign of chillers for ice water production and optimization of ice water distribution
- Improvement of the HVAC systems

It also appeared that heat requirements for CIP were probably underestimated in the Pinch Analysis in 2012, partly explaining the large "unknown" gap in the steam consumption balance. However, there was no follow-up on the changes and no update on the Pinch Analysis. ELSA didn't want to invest time updating the Pinch data. Another difficulty was the lack of a big picture of the site (including buildings, location of process units, position of utility units, layout of networks, space constraints, etc.).

ELSA wanted to focus on "local" integration solutions for this project (as the project evolved, different options were defined). Therefore, contrary to the analysis approach presented in the document *"Guidelines for the implementation of HTHPs in industrial processes"* (Final Report: Appendix 9) and since ELSA didn't want to invest time in the update of Pinch data carried out beforehand, the potential integration solutions were analyzed in a local/isolated perspective.

As part of the HTHP-CH project, most of the effort (i.e., measurements and analyses, feasibility study) was focused on integrating heat pumps into CIP systems. The other options proposed by ELSA and briefly analyzed included:

1. HP with a 65 °C condensation temperature to supply two new yogurt pasteurizers requiring 500 kW of pre-heating from 5 to 28 °C (the much higher 65 °C condensation temperature is because heat would/could not be supplied directly but indirectly through a network operated at 65 °C supplying other more temperature demanding heat consumers).
2. Pre-heating make-up water for SU and AC tanks up to approx. 45 °C, by optimization of heat recovery of UP processes cooling loop (hence without integrating an HP).

These two options are not considered later in this report.

As for the Cremo case study, the presentation of this case study endeavors to trace the various stages when aiming at the integration of HPs, the difficulties encountered, the possible concepts, the practical constraints, the decisions made, and the results obtained for the concept chosen. The process leading from the various theoretically possible concepts to the actually relevant concept being evaluated is important and highlighted.

Particular attention is paid to the description of the CIP process, the analysis of measurements, the understanding of its specific features (e.g., variability in intensity and time, heating by steam injection, etc.), and the way to handle the corresponding challenges for the HP system sizing and integration. Again, these specific features and the practical constraints explain the gap between the initial theoretical concept and a technically feasible, if not profitable, solution.

3.2 Company and Site Activities Overview

3.2.1 Company and products

ELSA, located in Estavayer-le-Lac (see sky view in Figure 26), has 640 employees. The most important thing for ELSA is the production of milk products. The focus is the production of milk-based fresh products (i.e., neither hard cheese nor powder production), yet featuring a wide variety of products. Table 7 summarizes the ELSA industrial dairy site's key mass and energy figures.

Table 7: Key mass and energy figures of the ELSA industrial dairy site.

Figure	Value	Comments
Production		
Processed milk	260'000 t/a	30 trucks/day, 7 days/week
Other ingredients	3'600 t/a	Fruits, sugar, etc.
UP / UHT milk	160'000 t/a	
Yogurt	52'500 t/a	Estimation (350'000'000 units/a)
Cottage cheese	4'000 t/a	About 19'500 t/a milk
Curd	6'000 t/a	About 21'500 t/a milk
Cream	420 t/a	Small cups of coffee cream
Energy consumption		
Electricity	42 GWh/a	162 kWh/t processed milk
Steam from wood chips	71.6 GWh/a (275 kWh/t processed milk)	4 trucks/day (65 m^3 each) About 80% of steam produced (t/a) (not directly related to production capacity)
Steam from natural gas		
City water	1'800'000 m^3/a	5'000 m^3/d
Capacity of utilities		
Process cooling	4 MW @ 0°C (NH_3) 6.6 MW @ -7°C (NH_3)	
Tunnel and storage cooling	3 MW @ -10 (NH_3)	
HVAC cooling	2 MW @ +3°C (NH_3)	
Steam (from wood)	12 t/h @ 12 bar(g) (base load)	Moving grate-saturated steam boiler sized and operated for the baseload of steam
Steam (from gas/fuel)	46 t/h	(Peak) cumulated production capacity of the steam boilers already present before the wood steam boiler was built (around 2016)

Figure 26: Skyview of the ELSA industrial dairy site with administration, utilities, and production buildings (top, "above" railway line); high bay warehouse (bottom, "below" railway line).

3.2.2 Production processes, supporting side processes, and steam production

In dairy processing, heating and cooling requirements stem from the various thermal treatment processes: pasteurization, sterilization (UHT or UP), with intermediate temperatures defined and optimized for steps like separation (i.e., centrifuge), homogenization, incubation/fermentation (for yogurt), etc. Several successive heating treatments are applied depending on the product and the constraints of production planning. For example, Figure 27 shows the production process for stirred yogurt.

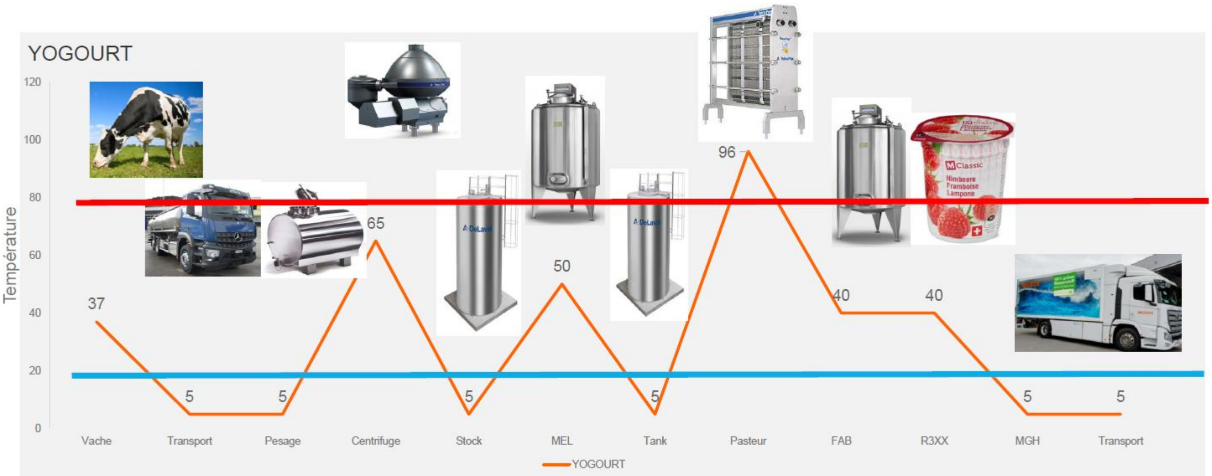

Figure 27: Simplified yogurt production process with a focus on thermal treatment.

Note that, unlike the production of UHT milk, allowing efficient counter-current heat recovery (e.g., small temperature driving forces, typically 5 K), the incubation at 40 °C to produce yogurt restricts the heat recovery (in state-of-the-art process facilities) because of a large temperature driving force of 35 K (5 °C milk flowing in, 40 °C milk flowing out to the incubation tank). Hence, the stirred yogurt process has significant potential for improvement.

To harvest this potential, a process engineering company recently proposed a heat integration concept resorting to a CO_2 HP for the simultaneous production of ice water and hot water for post-heating milk to 96 °C before cooling to 40 °C for incubation. Although theoretically sound, the proposed concept suffers from increased complexity in heat transfer with the product and the need for a 7-temperature layer stratified heat storage. In addition, experience with similar systems shows that operating such heat storage is difficult, if not unreliable.

Furthermore, regarding applying the concept at ELSA, the process area where the yogurt production facilities are located is packed with skids and piping, and there is no room for heat storage. The latter should be placed outside the building, with multiple pipe connections between the storage and the center of the building, which is almost technically impossible.

Relevance and issues of Cleaning-In-Place (CIP)

Besides production processes, CIP processes require large quantities of water (515’000 m^3/a) and heat in the form of steam (3.5 bar(g) with the current design of the units). There are 6 CIP units available at ELSA (CIP for trucks, CIP 0 / 2 / 3 / 4, as well as a small CIP unit for Tofu and Mayonnaise production, not considered here), located in 3 different places:

- Location 1: CIP for trucks
- Location 2: CIP 0 (RLM = réception lait matières), CIP 3 (Laiterie 3), CIP 4 (Laiterie 4).

- Location 3: CIP 2. This CIP unit is brand new and includes a hot water tank (while the other CIP units do not).

Each CIP unit supplies several circuits (e.g., CIP 0 / 3 / 4 supplies 37 circuits, whereas ELSA has 53 CIP circuits in total). However, the actual heat consumption of the CIP facilities is not measured (i.e., it cannot be measured with the existing PLC system) and is a "hot" topic of concern and debate. The practical evidence regarding total water volume seems to contradict benchmark values. Therefore, the CIP and the potential for integrating an (HT)HP are discussed in more detail in Section 3.3.

Heating, ventilating, and air conditioning (HVAC)

HVAC involves large air flow rates to ensure hygienic conditions in the production areas (running with 100% outside air). However, HVAC consumes virtually no heat since the air handling units (AHU) include heat recovery on exhaust air to preheat outside air, and the internal heat gains from process facilities are large. Hence, the production zones require cooling and supply air to a setpoint temperature of 14 °C. In addition, the AHUs include a coil on the supply air side, connected to a water-glycol cooling loop. At outside air temperature below 12 °C, this air is preheated by the water-glycol loop, cooling the water-glycol loop and avoiding or limiting the operation of chillers on this loop (free-cooling operation).

Steam production

At ELSA, the production of saturated steam is carried out in 3 different plants:

- 1 wood chip steam boiler,
- 2 steam boilers (gas-fired), and
- 2 steam boilers (producing "food-grade" steam, e.g., for UP units operated with injected steam) (see Table 7).

The first two steam plants originally supplied a "general steam" network, separated from the "food-grade" steam network. However, since the analysis of steam from the "general steam" has demonstrated a quality as good as that of the "food-grade," the two networks have been merged into a single network, allowing the simplification of piping, energy savings, and an increase of the share of wood-based steam production beyond 80%. Hence, 80% of steam is, on average, CO_2-free.

Ice water/glycol water production

Production and storage of fresh milk products consume large quantities of ice water/glycol water. The NH_3 chiller capacities are correspondingly very large (see Table 7). Part of the condenser heat is used for hot water production, but much of the heat is dissipated by cooling towers.

Note that the capacity of the cooling towers is somewhat undersized, so that in summer, the condensation temperature drifts, resulting in over-consumption of electricity. Overall, electricity consumption for cooling is a major financial issue, and ways of reducing it are being sought.

3.2.3 Conclusions and need for measurements

To save energy and money, ELSA is interested in integrating steam-generating HTHP(s) that use waste heat from the NH_3 chillers (about 23.7 GWh/a at 40 °C, currently discharged through cooling towers) or CIP wastewater (about 515'000 m^3/a at about 50 °C) as a heat source to replace some of the steam required for the CIP processes (about 22.7 GWh/a steam in 7'200 h of operation corresponding to

3.15 MW). Although the heat sources and sinks must be confirmed[5], Figure 28 sketches ELSA's initial potential HTHP integration points for the CIP plants (corresponding to a black box model).

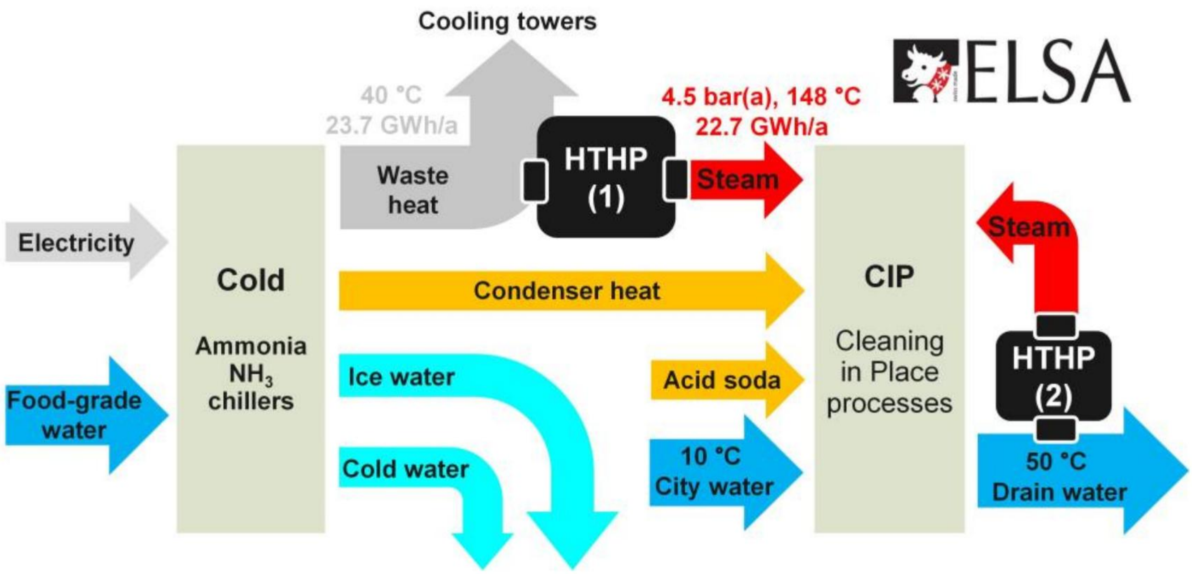

Figure 28: ELSA's initial potential HTHP integration points for the CIP plants.

However, unlike typical production processes, whose streams feature fixed supply and target temperatures and an easy-to-define schedule of operation (e.g., either ON or OFF), CIP processes feature complex use profiles and streams. According to the *"Guidelines for the implementation of HTHPs in industrial processes"* (Final Report: Appendix 9), the CIP processes could be modeled in two ways:

- Black Box (BB): Modeling by existing utility requirements. This is easier to set up but has some drawbacks:
  (1) Ignoring the potential for internal heat recovery, if any, and
  (2) Requiring utility (steam) at "high" pressure (not looking at ways to reduce it), hence low COP and potentially poor profitability.
- White Box (WB): Modelling the actual process heat transfer requirements. This requires detailed measurements and analysis, but with the likely benefit of a larger energy efficiency and potentially better profitability, although the HP system is generally more complex.

The temperature lift required when applying the BB approach (approx. 100 K) would severely impair energy efficiency and profitability. Hence, in line with the principles of Pinch Analysis, the WB approach has been applied. Measurements and conclusions are described in Section 3.3.

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[5] The values mentioned above are ELSA's estimates

3.3 The CIP facilities: description, measurements, results

3.3.1 Typical CIP procedure

ELSA applies CIP typical procedures as depicted in Figure 29 (left), including the following 5 successive steps [6] (see also Figure 30):

1. **Pre-rinse** (first with fresh water to recover product, then with water recovered from the final rinse of the previous CIP cycle, stored in the "recycled water" tank, ER tank on Figure 30)): Circulation of water in the circuit (return water flows to the drain, i.e., it is not recovered).
2. **Caustic (NaOH)**: The diluted solution (at approx. 75 to 80 °C) from the soda tank (SU tank in Figure 30) is circulated in the circuit to be cleaned. The return flow to the soda tank is usually colder than the set point temperature, requiring temperature holding of the soda tank and/or heating from the "inline" heat exchanger before flowing to the circuit again.
3. **Intermediate rinse**: Flow of recycled water from ER tank (if available; otherwise, fresh water from EF tank, heated as needed to reach a minimum temperature to avoid thermal and mechanical stress) to remove any remaining soda in the circuit.
4. **Acid** (**HNO_3**): The diluted solution (at approx. 60 °C) from the acid tank (AC tank in Figure 30) is circulated in the circuit to be cleaned. The return flow to the acid tank can be colder [7] than the set point temperature, requiring temperature holding of the acid tank and/or heating from the "inline" heat exchanger before flowing to the circuit again.
5. **Final rinse**: Freshwater (from EF tank) is circulated in the circuit (during the first phase, the freshwater is heated to a lukewarm temperature, then flowing "cold" [8]). Return water is recovered in the ER tank for a pre-rinse or intermediate rinse of the next CIP cycle.

In addition, the soda tank and the acid tank solution need to be "regenerated," and their losses need to be compensated by make-up fresh "cold" water. Both make-up water heating to tank set point temperature and temperature holding of tanks is achieved by circulating the solution in an external "heat exchanger" supplied by 3.5 bar(g) steam. In fact, contrary to the symbol used on the supervision screen in Figure 30, this is a steam injection and not a heat exchanger.

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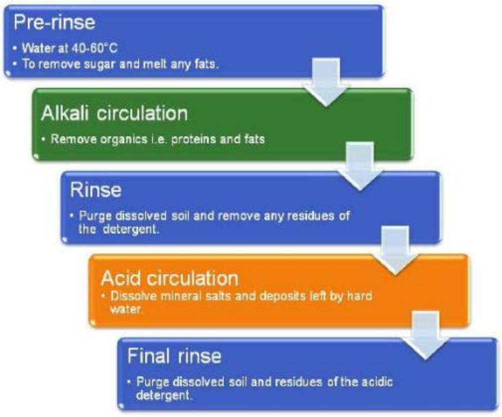
[6] Depending on the circuit to be cleaned and in case of an intermediate CIP (and not a final CIP at the end of the day), the AC wash step may be omitted. In fact, there are even more numerous types of CIP cycles.
[7] In practice, however, in the case of the CIP unit measured (CIP 0), it appeared that the return flow is often hotter than the forward flow, ensuring heating of the acid tank. This is because during the acid phase, certain process facilities (e.g., pasteurisation heat exchangers) are heated.
[8] In fact, freshwater is presently preheated to about 20 °C by heat recovery on the condensation of NH_3 chillers.



Type of detergent	Temperature range (°C)	Cleaning objects
NaOH	60-80 °C	Milk collection tankers, tanks and pipes
	70-90 °C	Milk pasteurizers
	90-140 °C	UHT plants
HNO_3	60-65 °C	Tanks, pipes, milk pasteurizers
	80-85 °C	UHT plants

Figure 29: Left: Typical CIP procedure, right: Cleaning temperature ranges (Source: Tetra Pak, Cleaning in place handbook).

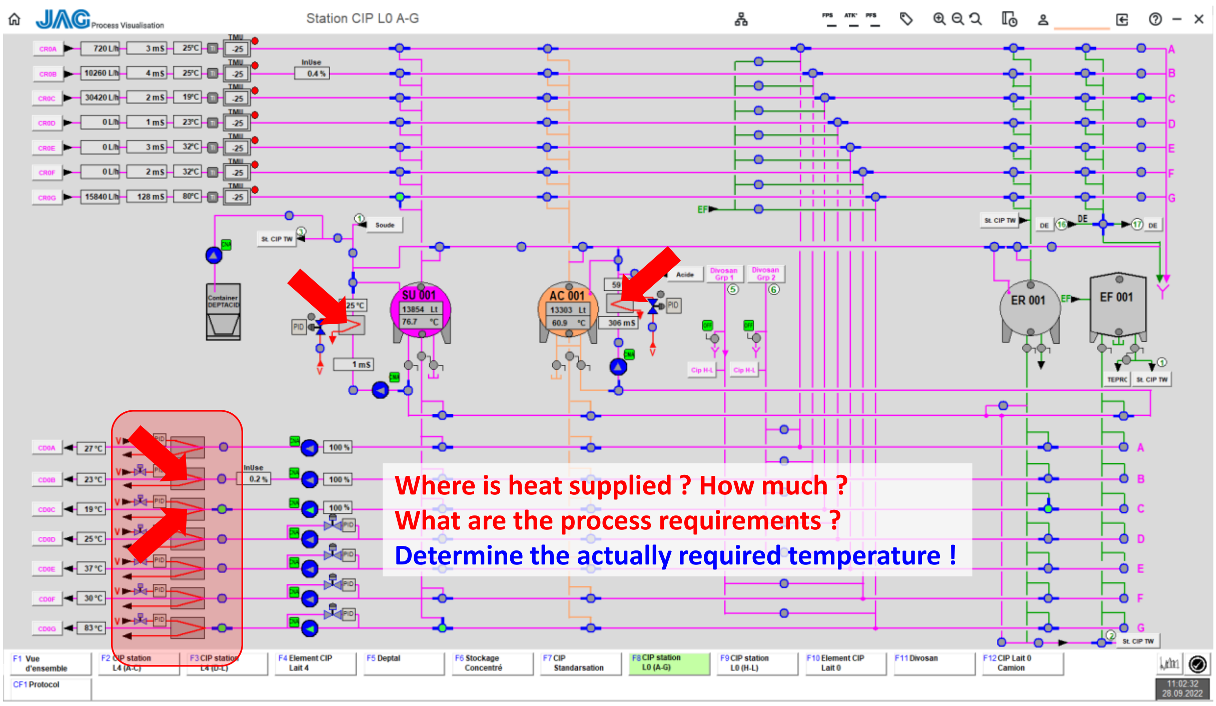


Figure 30: CIP 0 facility showing the external steam "heat exchanger" on both soda and acid tanks, as well as the "inline" reheating steam heat exchanger for each of the 11 CIP circuits (here, only 7 are shown).

3.3.2 Measurements of CIP 0

To define a WB model, CIP heating requirements at their actual lowest temperature must be determined. As part of this task, the volume of make-up water in the SU and AC tanks must also be calculated (considering the volume of injected steam in these tanks). Currently, heat is supplied to SU and AC tanks (injected steam) and to 11 CIP circuits (heating steam). Data to determine the energy and mass balance of the system are largely missing.

Therefore, the following measurement campaigns were carried out:

1. **CIP circuit B [9]:**
   (1) Mass flow,
   (2) Inlet and outlet temperature of the steam-heated inline heat exchanger, and
   (3) Return flow temperature.
2. **CIP circuit C:**
   (1) Mass flow,
   (2) Inlet and outlet temperature of the steam-heated inline heat exchanger, and
   (3) Return flow temperature.

   The aim is to make sure that the results for CIP circuit C are reasonably similar to that of CIP circuit B, allowing later extrapolation to 11 circuits with greater confidence.
3. **SU tank external recycling circuit:**
   (1) Mass flow, and
   (2) Temperature upwards and downwards of steam injection (with additional state data from PLC: state of valves "around" the tank, notably that of fresh water for make-up; CIP step number, …).
4. **AC tank external recycling circuit:**
   (1) Mass flow, and
   (2) Temperature upwards and downwards of steam injection (with additional state data from PLC: state of valves "around" the tank, notably that of fresh water for make-up; CIP step number, …)
5. **CIP tanks outlet temperature and wastewater temperature**.

These measurement campaigns led to the following observations and conclusions.

3.3.3 CIP 0 circuit B: Results and conclusions

Measurements on CIP circuit B aimed at determining when (i.e., during which CIP step) and how much heat is supplied by the inline heat exchanger during a typical CIP cycle.

Figure 31 shows that the inline heat exchanger reheats recycled water (ER) and AC solution, as well as freshwater (EF), during the first phase of the final rinse. This occurs at each CIP cycle. This observation leads to the conclusion that, if the same occurs for the other CIP circuits, it is possible to shift a significant part of the heat presently supplied by inline heat exchangers to the corresponding CIP tanks by modifying (i.e., increasing) their respective set point temperature.

This conclusion is particularly relevant because it can make the integration of HP easier and "cheaper": instead of implementing 37 new inline heat exchangers (in total for CIP 0+3+4, and all the required piping connections), changes to the heat supply system needed to integrate HP can be "focused" on

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[9] Before the HTHP-CH project started, ELSA was already seeking ways to achieve heat and water savings in CIP processes. To this end, CIP circuit B of CIP 0 had been fitted with sensors to monitor the turbidity and to decide when to end a step based on measured parameters instead of based on a duration. In this frame, ELSA set up the extraction of a large set of parameters from the PLC (CIP step, position of valves, …) to analyse the operation of the system and calculate saving potentials. With this data extraction system already in place, Circuit B was an obvious preferred candidate for measurements and analysis.

CIP tanks only. Furthermore, it is not only a CAPEX and piping layout issue but also a space issue. There is presently no space to implement new inline heat exchangers.

Measurements have also shown that the mass flow features a very variable profile during a CIP cycle.

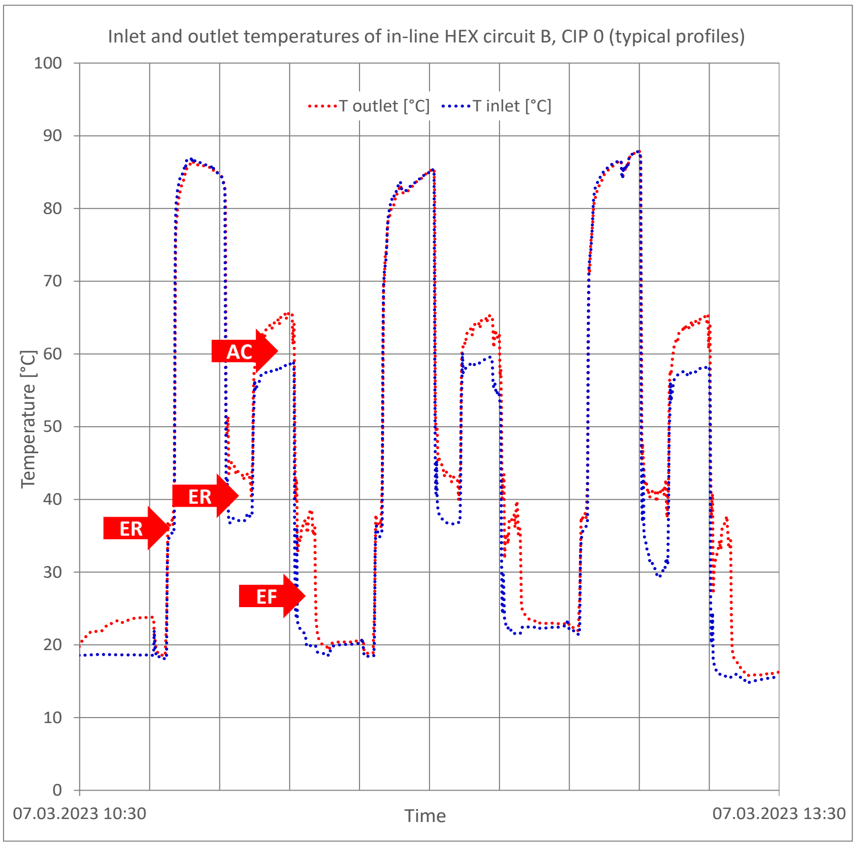

Figure 31: Temperature profiles at the inlet and outlet of the inline heat exchanger of circuit B during three typical CIP cycles.

3.3.4 CIP 0 circuit C: Results and conclusions

Measurements on CIP circuit C lead to the same general conclusions as those on CIP circuit B, as can be seen by comparing Figure 32 with Figure 31. However, slight differences in outlet temperatures can be observed:

- Supply (outlet) temperature during the SU step is higher for CIP circuit C
- Supply (outlet) temperature of ER during intermediate rinse seems higher for CIP circuit B
- Supply (outlet) temperature during the AC step is slightly higher for CIP circuit C

This means that not 100% of the heat supplied by inline heat exchangers can be shifted to CIP tanks. A “fine-tuning” of supply (outlet) temperatures of the CIP circuits to their respective set points remains necessary.

A check on the other circuits would be necessary to confirm the above conclusions. Another approach would be to read the supply set point temperatures in the PLC system and review the necessary values with quality managers.

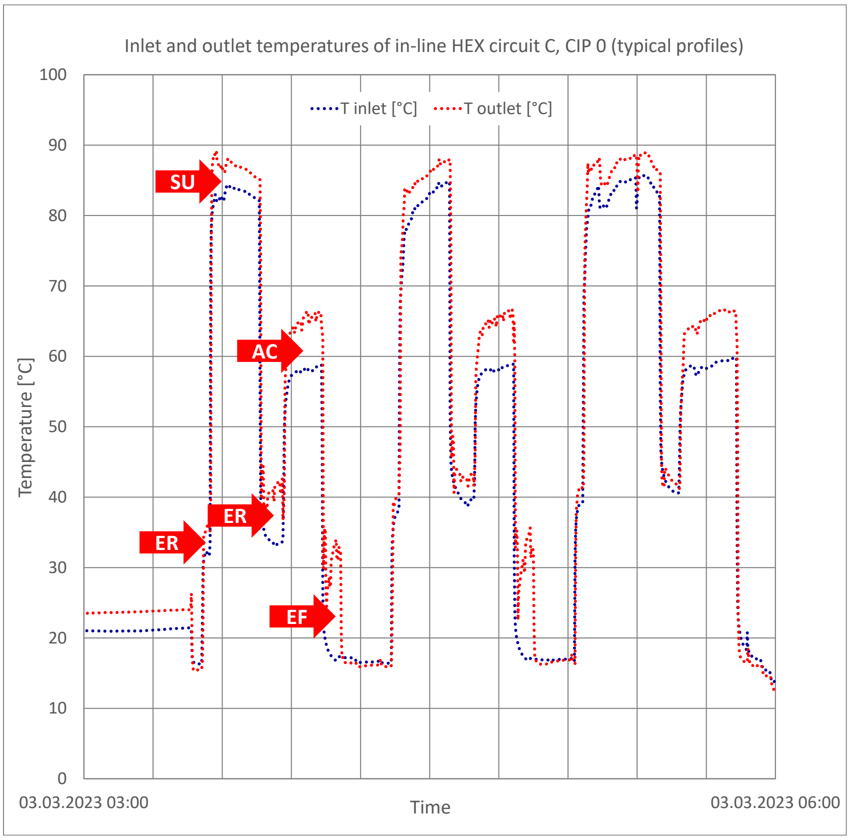

Figure 32: Temperature profiles at the inlet and outlet of the inline heat exchanger of circuit C during three typical CIP cycles

3.3.5 CIP 0 SU tank: Results and conclusions

Measurements on the SU tank were used to determine:

- the quantity of fresh make-up water (and the heat required to heat it),
- the quantity of steam injected, and
- the heat required for SU tank temperature holding.

The values are summarized with those of the AC tank in Table 8 and Figure 34 (values extrapolated to CIP 0+3+4). It is interesting to note that the measured values, even if accurate to within +/- 10 to 15%, deviate significantly from the values announced by ELSA. These values should be checked with the quantity of concentrated soda consumed.

3.3.6 CIP 0 AC tank: Results and conclusions

Measurements on the AC tank were used to determine:

- the quantity of fresh make-up water (and the heat required to heat it),
- the quantity of steam injected, and
- the heat required for the AC tank temperature holding.

The values are summarized with those of the SU tank in Table 8 and Figure 34 (values extrapolated to CIP 0+3+4). Unlike the SU tank, the return flow temperatures to the AC tank are, on average, larger than the supply temperature, meaning that there is no net heat required to maintain the AC tank temperature. In fact, a significant part of the fresh make-up water heating is heated by the positive balance due to return temperatures being larger than supply temperatures. In other words, the quantity of injected steam supplies “only” 68 MWh/a, while 230 MWh/a would be necessary to heat the whole fresh make-up water quantity.

As for the SU tank, the measured values deviate significantly from the values announced by ELSA. These values should be checked with the quantity of concentrated acid consumed.

3.3.7 CIP 0 tanks temperatures: Results and conclusions

The temperatures were measured on large-diameter, uninsulated supply pipes to the large manifolds. Due to the resulting inertia and delay effects, the measured temperatures can neither be directly related to the tank temperature nor to the inlet temperature of operated inline heat exchangers.

Similarly, the wastewater temperature was measured at the bottom of the pipe in free flow (i.e., unfilled pipe, not allowing a continuous monitoring of the wastewater flow). The measured temperature ranges from 20 to 80 °C, but the distribution of the total volume as a function of temperature could not be calculated.

However, based on the return temperature and flow of CIP circuit B, considering the position of the valve to the wastewater pipe, Figure 33 could be determined. Whether or not this temperature distribution can be extrapolated to the whole CIP 0 with eleven circuits is still uncertain. However, the average temperature of wastewater estimated by ELSA (50 °C) is very likely too optimistic. According to Figure 33, it should rather be approximately 32 °C.

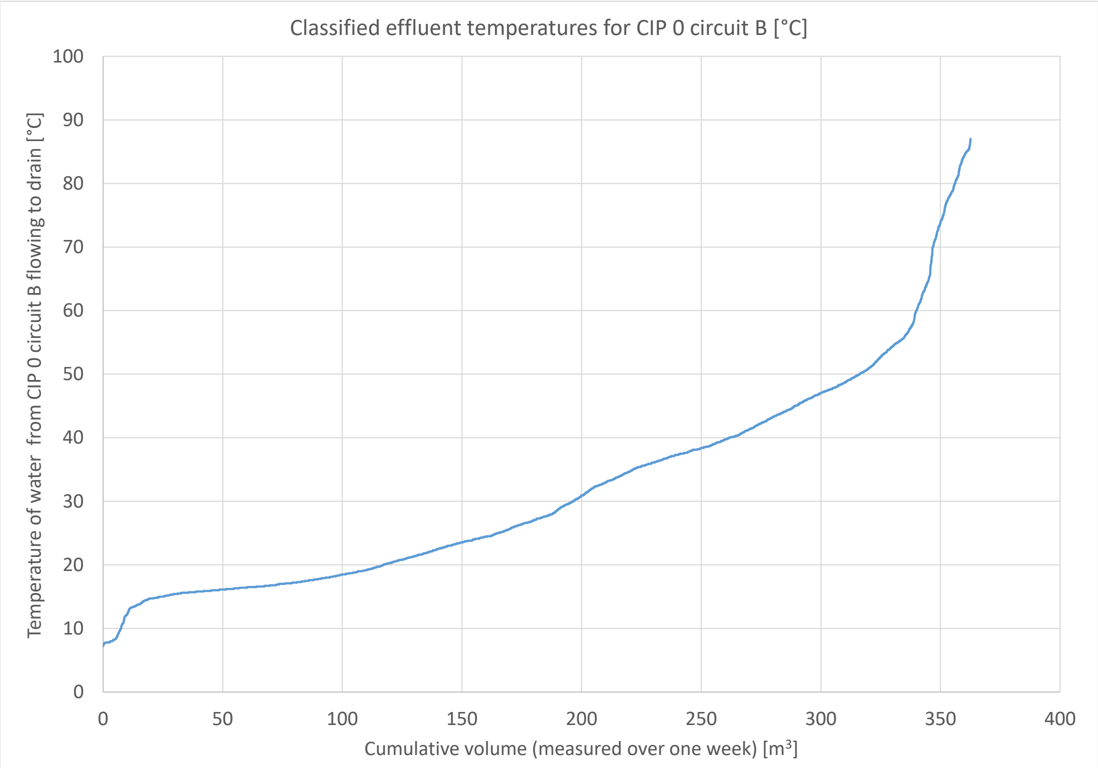

Figure 33: Typical temperature distribution of wastewater (measured for CIP circuit B for one week).

3.3.8 Extrapolation of measurement results of CIP 0 circuit B to CIP 0+3+4

As a best guess, to extrapolate the results measured on CIP circuit B to CIP 0 as a whole, extensive values measured for CIP circuit B are multiplied by the number of circuits (11 circuits). It is also assumed that the 1-week measurement campaign is a typical week that can be readily extrapolated to one year.

Then, to extrapolate extensive data for CIP 0 to CIP 0+3+4 as a whole, one must first define a quantitative indicator closely related to the CIP activity. Regarding energy and mass balances of CIP 3 and CIP 4, the only known data are the ¼-h freshwater consumption values and, hence, the annual consumption. CIP 3 and CIP 4 are conceptually similar, although the former has only one external reheating circuit (used alternatively for the SU and the AC tanks) instead of two circuits (one for each tank), as in CIP 0.

However, these differences are ignored, and the extrapolation of energies from CIP 0 to CIP 0+3+4 is based on the total freshwater consumption, which should be the appropriate indicator of CIP activity. Considering the respective freshwater consumptions (from 8.2.2023 to 8.2.2024) of CIP 0 (230'320 m^3), CIP 3 (145'850 m^3), and CIP 4 (139'570 m^3), the multiplication factor to extrapolate CIP 0 values to get values for CIP 0+3+4 is 2.239.

3.3.9 CIP 0+3+4 Overall energy balance (extrapolated from CIP 0)

The measurements previously described and the extrapolation method to CIP 0+3+4 sketched above allow the determination of the heat balance of Figure 34. It shows, at present, how much heat (heating steam, respectively. injected steam) is consumed and where / to what purpose. In addition, the water balance of SU and AC tanks is shown in Table 8 (approximate values).

Table 8: CIP 0+3+4 overall water balance (extrapolated).

Water quantities (m^3/a)	SU tanks	AC tanks
Fresh make up water	9'820	10'765
Injected steam	5'555	180

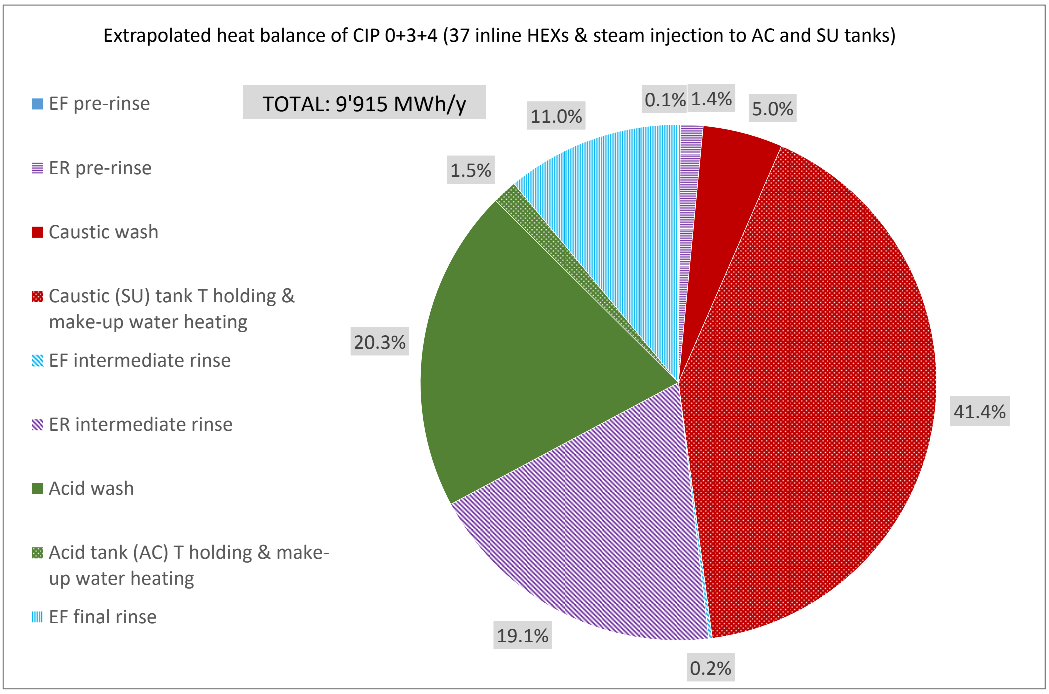

Figure 34: Extrapolated heat balance of CIP 0+3+4 split into individual CIP steps.

Referring to the BB and WB models:

- Heating steam and injected steam quantities can be easily calculated
- Knowing the temperature at which the heat contributions are actually required, an ideal WB model can be set up.

The corresponding composite curves are presented in the following sections.

3.3.10 Approach to the sizing of HPs

As mentioned, CIP operation is stochastic in both time and intensity, which makes HP sizing difficult. It involves a trade-off between HP capacity, heat storage capacity, and heat savings. Figure 35 highlights the variability of CIP activity and of its intensity. The intensity generally peaks shortly before midnight and drops to a minimum during the morning.

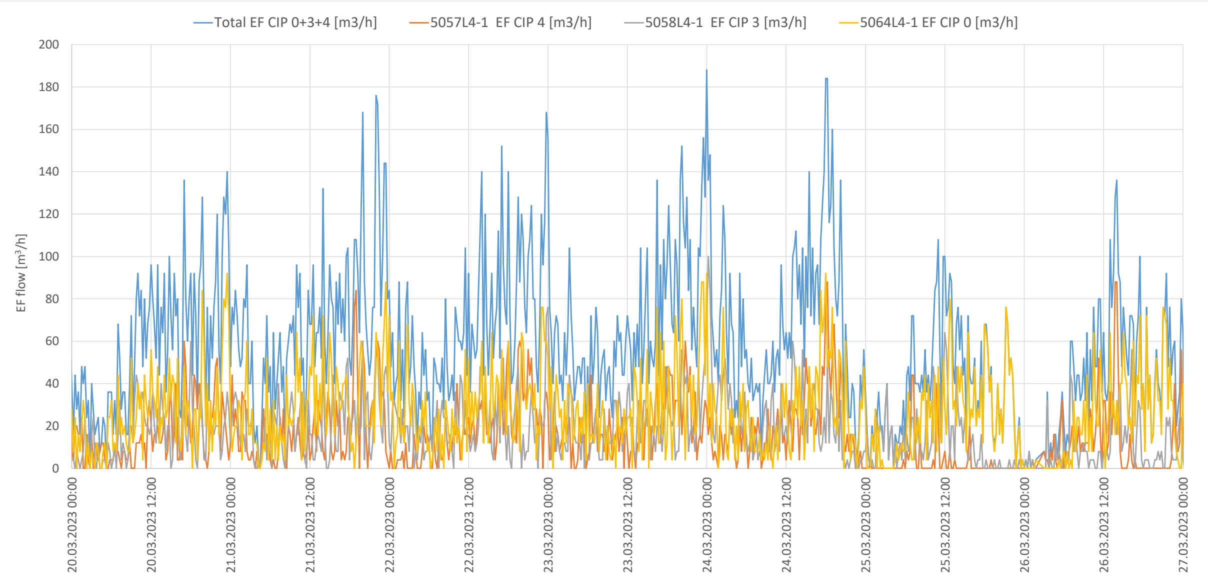

Figure 35: Freshwater (EF) consumption profiles of CIP 0, CIP 3, CIP 4, and CIP 0+3+4 during a typical week.

For sizing the HP, the classified curves of Figure 36 are more relevant. The influence of the running average duration on HP sizing can be assessed. The larger the duration (i.e., the larger the storage capacity at HP(s) condenser side), the larger the savings for a given HP capacity (i.e., the smallest the area between the corresponding classified curve and the EF flow that the HP(s) can "supply" [10]).

Note that the average annual flow rate is 58.8 m^3/h, which corresponds to a yearly average heat rate of approximately 1'130 kW (total annual heat: 9'915'000 kWh/a (see Figure 34), duration 8'760 h/a). A 1'130 kW HP system would, at best, supply 76% of total requirements with storage rated for 15 min RAD and 81% with storage rated for 90 min RAD. If the HP system is 20% oversized (i.e., 1'360 kW heat rate), the potential increases to 84% for 15 min RAD and 89% for 90 min RAD.

[10] Remember that the EF flow is an indirect indicator of the intensity of the CIP activity, and hence of the required heat to by supplied. Several CIP circuits may be in cleaning at the same time, but not necessarily at the same CIP step.

Hence, due to the peak flow rates, heat storage can hardly increase the heat savings. Rather, the appropriate storage capacity would be determined by constraints related to the electrical drive and compressors (minimizing the number of starts, etc.).

In addition, to comply with these constraints, splitting the total capacity of the HP system into at least two units may be necessary to ensure safe and sustainable operation during periods of low CIP intensity.

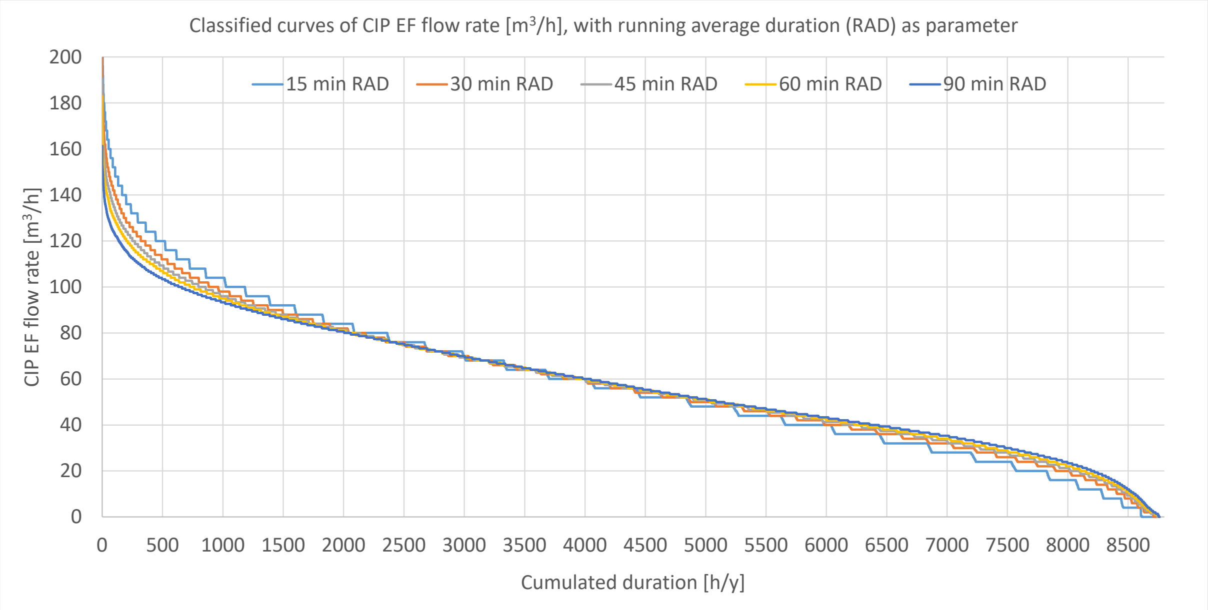

Figure 36: Classified curves of freshwater consumption of CIP 0+3+4 with running average duration (RAD) as a parameter.

The above considerations are focused on the heat demand and its variability.

The availability of the heat source and its synchronization with the heat demand must also be verified. This would require a detailed analysis. However, since the necessary numerical data were not made available, only qualitative observations can be made here.

Figure 37 plots the power consumption profile of the chillers during 5 workdays (in red: chillers with 0 °C evaporation temperature, in orange: chiller with -7 °C evaporation temperature). The chillers tend to operate at a minimum at the end of the day when the CIP heat demand is the largest. The HP system heat rate could, therefore, be smaller than its design rate during these periods.

Furthermore, at present, part of the condenser heat is recovered so that the actually available remaining heat is smaller than what could be calculated from the profile of Figure 37.

Figure 38 plots the power consumption profile of condensers (wet cooling towers). Although the operation of the condensers is related to the remaining heat to be rejected to the ambient, it cannot be used to quantify the remaining heat unless the ambient temperature and the characteristic *electrical power = f (wet bulb temperature, rejected heat)* is known, which is not the case.

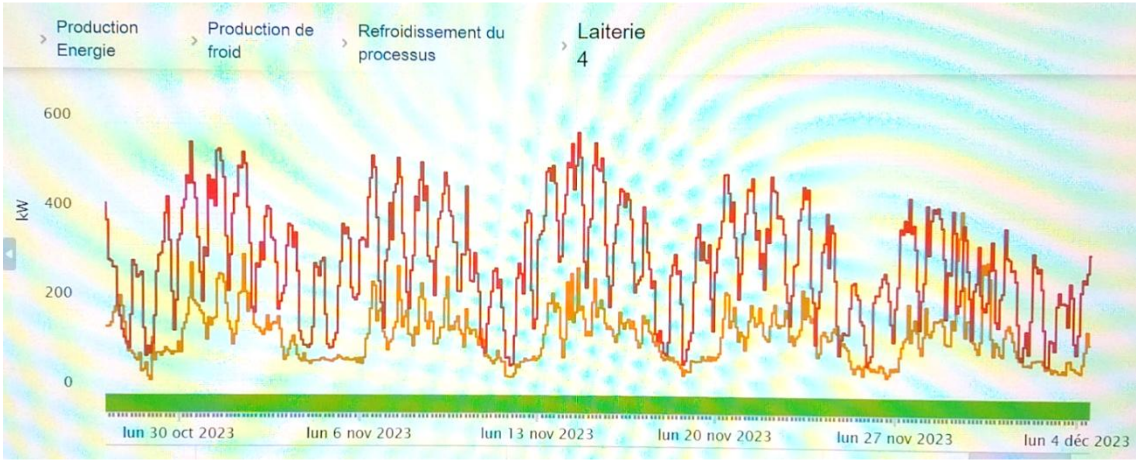

Figure 37: Electrical power consumption of chillers (red: 0 °C; orange: -7 °C. Low power consumption can be observed at night.

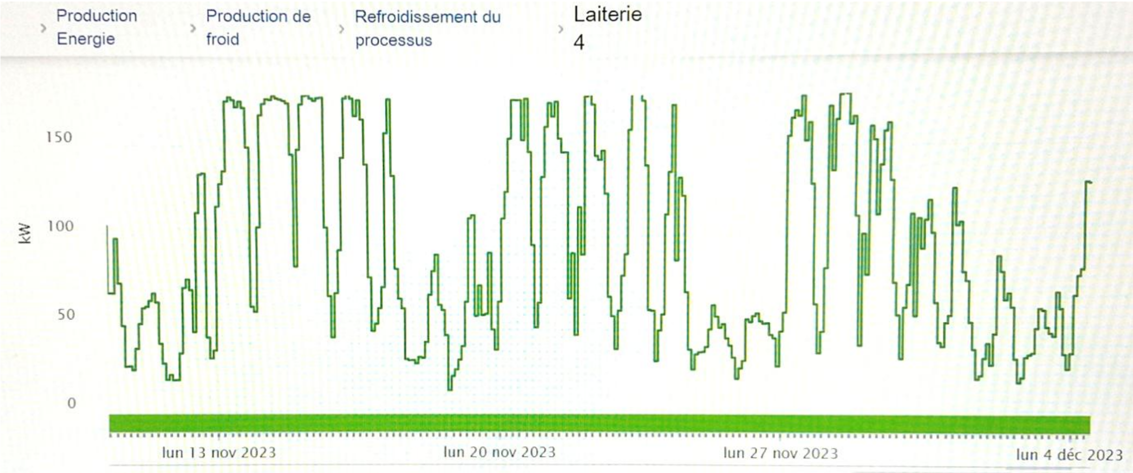

Figure 38: Electrical power consumption profile of the wet condensers (cooling towers) of the chillers.

3.4 Energy integration and (HT)HP concepts

In retrofit situations, hard constraints must be identified early to avoid spending too much time on concepts that are obviously not applicable in practice. Therefore, constraints are first considered before the composite curves and the corresponding possible (HT)HP concepts are presented.

3.4.1 Constraints and limitations

The following constraints and limitations apply:

- Tight space in both the CIP and chiller rooms:
  - In the CIP room, there is no way to implement 37 additional inline HEXs to lower the supply temperature (hot water instead of 4.5 bar(a) steam).
  - There is a lack of / limited space for piping and heat/water storage as well as external HEXs for the tanks holding heat supply.

- Space and excessive CAPEX for adding a “hot EF” manifold and all corresponding valves for the first step of the final rinse.
- Footprint for heat pump(s) and storage tanks.

- Access path and location (i.e., dimensions, load-bearing capacity, maintenance, etc.) for required equipment.
- Mandatory use of NH_3 condensation heat instead of wastewater heat.
- There is a need for “continuous” operation of CIP (no CIP = no production); hence, the equipment and their fittings must be analyzed. Check for pending connections/tappings on existing tanks and circuits to allow easy implementation of a heat integration concept with no/minimum downtime (e.g., the ER tank has no T-connection that would make installing an external loop reheating easy).
- There is a need to control CIP circuits temperature individually. Hence, there is no ideal set point temperature for tanks, meaning that it is impossible to shift 100 % of inline HEX heating to tank heating and that a remaining consumption of 4.5 bar(a) steam is needed anyway.
- Large range of variation of CIP activity and related heat demand; HP(s) cannot be sized according to peak load, meaning that a fraction of the heat demand remains to be supplied by 4.5 bar(a) steam.
- Check the power supply spare capacity (to avoid large extra costs for installing a new transformer).

3.4.2 Heat Requirements Models, Composite Curves and Grand Composite Curves

Heat requirements (streams) and composite curves are modeled as time averages, i.e., assuming constant CIP heat demand and constant availability of heat source over the year (8’760 h/a). Sizing of HP(s) and heat storage(s), as well as electricity consumption and heat savings, can then be estimated.

The BB model, involving the production of injected steam for SU and AC tanks and of heating steam by evaporation of condensate for inline heat exchangers (both at 4.5 bar(a)), can be readily calculated from data from Table 8 and Figure 34.

The ideal WB model (IWB), defining the heat demand at the actually required (lowest) temperature levels, implicitly assumes that a retrofit of all existing heat transfer equipment can be made and implementation of new heat exchangers (e.g., to heat the make-up water) is possible. Further, the variability and availability issues are ignored. This model includes:

- Heating of make-up water to AC and SU temperature, respectively (total quantities according to Table 8, including injected steam).
- Heating of EF, especially during the final rinse (17 °C to approx. 33 °C on average at the outlet of inline heat exchangers of circuits B and C), the EF heating requirement during pre-rinse and intermediate rinse being negligible (see Figure 31, Figure 32, and Figure 34).
- Heating of ER tank from its present average temperature (approx. 35 °C to approx. 45 °C on average at the inline heat exchangers during pre-rinse and intermediate rinse, as can be seen in Figure 31 and Figure 32).
- Heat needed for acid wash, plus temperature holding of AC tank, minus the contribution, in the latter, due to heating of present make-up from 17 °C to approx. 65 °C (see Figure 34).
- Heat needed for caustic wash, plus temperature holding of SU tank, minus the contribution, in the latter, due to heating of present make-up from 17 °C to approx. 90 °C (see Figure 34).

Unlike the ideal WB model, the practical WB (PWB) model takes the variability and availability issues into account, as well as the constraints preventing any retrofit of the inline heat exchangers. For this model, the assumptions are as follows:

- Only 75% of present heating by inline heat exchangers to CIP-circuits specific set-point temperature during ER rinse, caustic and acid wash can be “shifted” to ER, AC & SU tanks heating. Hence, 25% of present heating, as well as 100% of EF heating during the final rinse still supplied by steam-heated inline heat exchangers.
- 30% of heat needed for AC tank heating must be supplied by injected steam, because the HP cannot be sized for peak heat demand and that around midnight, the NH_3 heat source may be too limited for the peak of CIP activity.
- Make-up water for AC tank heated to 65 °C.
- Make-up water for SU tank heated to 87 °C.

It should be noted that heating by steam injection creates a close dependency between water and energy balances, making it more complex to calculate make-up water quantity as a function of make-up water temperature. Figure 39 shows the composite curves corresponding to the BB, PWB, and IWB models, respectively. Figure 40 shows the corresponding Grand Composites Curves, highlighting a large gap in required supply temperatures.

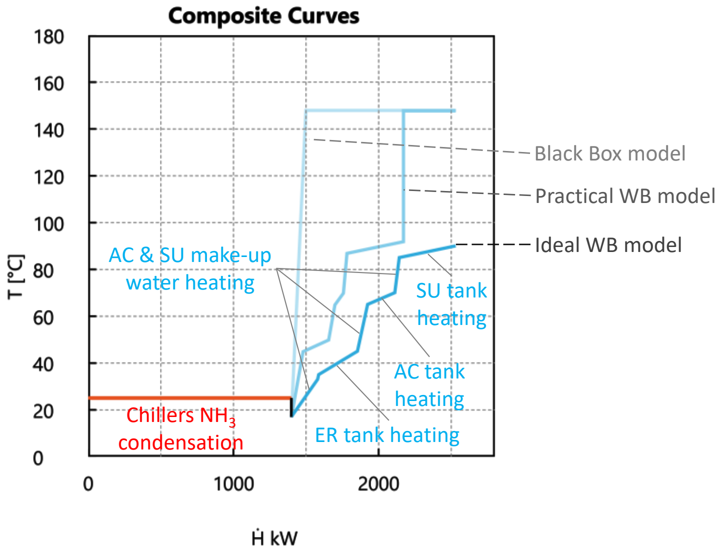

Figure 39: Time-averaged composites curves of the CIP 0+3+4 facilities corresponding to Black Box (BB) model, Practical White Box (PWB) model, and Ideal White Box (IWB model respectively.

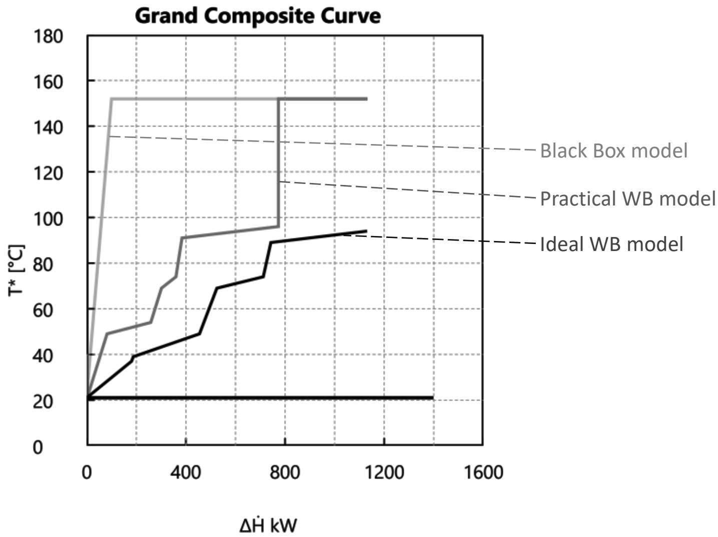

Figure 40: Time-averaged grand composite curves of the CIP 0+3+4 facilities corresponding to the Black Box (BB) model, Practical White Box (PWB) model, and Ideal White Box (IWB) model, respectively.

3.4.3 HP integration concepts

Based on the BB and PWB models, several HP integration concepts have been roughly analyzed:

1. A 4.5 bar(a) steam generating heat pump (SGHP) for utility level integration (BB model): its integration is simple in principle, but in practice, the variability of the CIP steam demand would be a killing factor, unless expensive steam accumulator could be used (with additional temperature lift). In addition, the profitability is low, if any (the low COP makes it very sensitive to the electricity-to-fuel ratio).
2. A single condensation temperature HP to supply the lowest temperature part of the PWB grand composite curve, namely for make-up water heating and ER tank heating.
3. An HP system consisting of a CO_2 trans-critical heat pump to heat make-up water to AC and SU tanks (to 75 °C) and dual condensation temperatures HP for ER tank heating and AC tank heating. The rated heat duty of the latter would be small and hence involves a greater complexity of the HP system for a small contribution to savings.

Although the SU tank heat demand is large and a corresponding HP integration would bring significant savings, the required temperature lift would result in a low COP of approx. 2.4. And since space is tight, HP concepts with smaller footprint and larger COP would be preferred.

Figure 41 shows the composite curves with HP integration Concept 3, the corresponding schematic diagram is sketched in Figure 42. Table 9 summarizes key figures of the three HP integration concepts and compares their respective benefits and drawbacks.

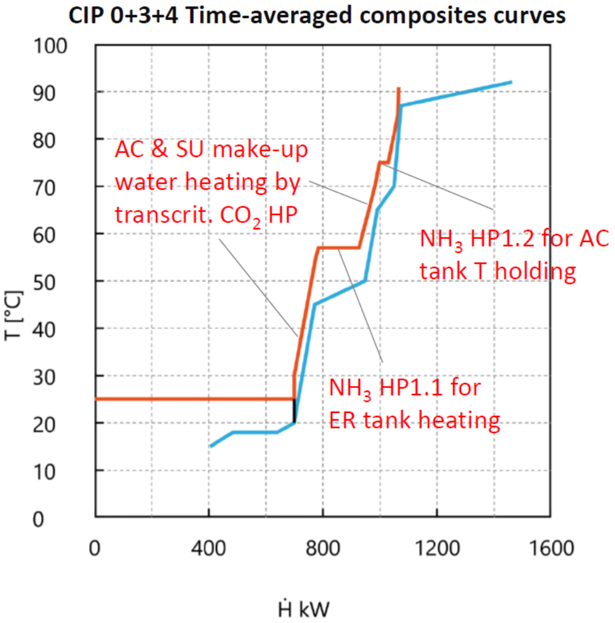

Figure 41: Composite curves of HP integration concept 3 (focused on the relevant part of the PWB; refer to Figure 42).

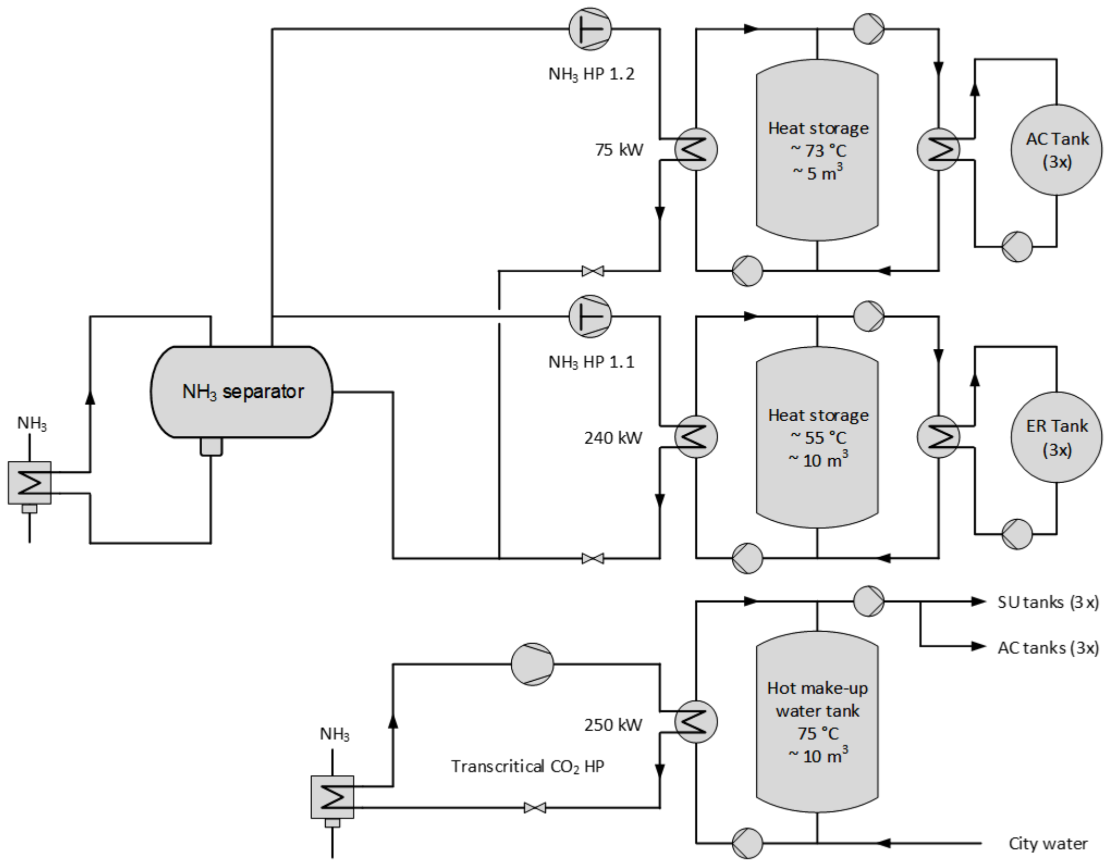

Figure 42: Schematic diagram of a combined trans-critical CO_2 and a dual temperatures NH_3 HP system (integration concept 3).

Table 9: HP concepts rated heat duties, performances, savings of 3 HP integration concepts, and their comparative evaluation.

HP concept	Design data ($Q_{rated} \cong 1.5 \times Q_{mean}$)	COP [1]	Savings [2, 3]	Evaluation
Concept 1 Steam generating HP 4.5 bara	$Q_{rated} \cong$ 1'200 kW @ 4.5 bara	≅ 1.6	≥ 6'000 MWh/y ≥ 309 to CO_2/y	++ Largest savings ++ Simple integration, «no change» - No storage capacity on stean side - - - Poor profitabilty, if any
Concept 2 1-T NH_3 HP Make-up water to 60°C ER tank heating	$Q_{rated} \cong$ 400 kW	≅ 4.0	≥ 2'365 MWh/y ≥ 122 to CO_2/y	++ Standard technology + High COP (low OPEX) + Large savings + Limited CAPEX (mutualisation of HP capacities, but 2 storages) - Unclear implementation feasibility
Concept 3 CO_2 + NH_3 2-T HP Make-up water to 75°C ER tank heating AC tank T holding	CO_2 HP : $Q_{rated} \cong$ 250 kW NH_3 HP1.1 : $Q_{rated} \cong$ 240 kW NH_3 HP1.2 : $Q_{rated} \cong$ 75 kW **Overall**	≅ 4.4 ≅ 4.6 ≅ 3.0 **≅ 4.3**	≥ 1'460 MWh/y ≥ 75 to CO_2/y ≥ 1'420 MWh/y ≥ 73 to CO_2/y ≥ 324 MWh/y ≥ 17 to CO_2/y **≥ 3'204 MWh/y ≥ 165 to CO_2/y**	+ Standard technology + High overall COP (low OPEX) + Large savings (CO_2 + NH_3 HP1.1) - HP1.2 for AC tank not worth - High CAPEX - Unclear implementation feasibility

[1] Not including the electricity savings resulting from reduced load of cooling towers (lack of data regarding their operation)
[2] Based on conservative assumptions, energy savings (and CO_2 emissions reduction) can be up to 30% larger
[3] CO_2 emissions reduction calculated assuming saved steam stemming 20% from gas and 80% from wood, and CO_2 free electricity

3.5 Feasibility study

3.5.1 Heat pump selection

It can be reminded here that the initial HTHP >100°C investigated for the present case study proved not to be necessary and that more conventional HP systems could be implemented to provide heat to the CIP stations.

Concept 3 illustrated in Figure 42 offers the largest energy and CO_2 saving potential along with high overall COP. It best fits the optimal temperature levels for heat supply following the composite curves obtained. The respective heat capacity of each heat pump proposed for this concept is summarized in Table 9. As a reminder, the heat needs for the CIP 0-3-4 have been evaluated based on the global water consumption known at 1/4h values due to lack of more precise data. The obtained classified curve hence contains large uncertainties. The heat pumps are not foreseen to cover 100% of the heat production (see 3.3.10), the complement and finetuning temperature control is made by mean of the existing inline steam HEX.

The make-up water heating by means of a CO_2 HP system with high efficiency confirms that it is well suited for this type of application. Indeed, its trans-critical thermodynamical cycle is particularly adapted for large temperature lifts like here with a source at 20°C and a production temperature of 75°C with a COP of 4.45. The COP would further rise with a reduction of the production temperature.

A thermeco$_2$ HHR260 CO_2 HP could be used to provide the 250 kW capacity needed and heat city water up to 75°C. The technical specifications can be found in Appendix 2.

The dual temperatures NH_3 HP system, as shown on the upper part of Figure 42, is technically feasible and can be custom-made to work optimally at the two specific fixed temperature outputs levels. The circuits for each temperature level would be independent and able to modulate individually to follow the heat demands.

3.5.2 Practical considerations

Unclear aspects remain related to the technical feasibility of the ER tank and make-up water hydraulic connections and equipment, which if achievable would probably lead to poor profitability. Preliminary constrains exposed in 3.4.1 are unfavorable to a such project. The complexity of the CIP system and heat demand profile variability constitute an adverse context for a cost-efficient system retrofit. Moreover, the timing of the make-up usage is stochastic and limited in time, further impairing the profitability.

Would the feasibility allow for the project, the following practical considerations apply.

Given the available space in the chiller room for the machines and beside the CIP tanks for the accumulator, it would not be feasible to install both the CO_2 and NH_3 HP systems with their respective heat storage tanks, which constitute Concept 3. Keeping the make-up water production would be the most reasonable option for the following reasons:

- Technically feasible with standard products
- High COP for the service provided
- Less hydraulic modifications to the existing CIP system

The 260 kW CO_2 heat pump has a size of approximately 2.6 m in length, 1.4 m in width, and 2.3 m in height. The introduction of the assembled machine to the technical room would prove problematic and require that it would be assembled on location. Indicative space requirement (without insulation) for a 10 m^3 hot make-up water tank is 4 m x 2 m x 2.5 m. There is sufficient available footprint and height in the premises for HPs and heat storage tanks.

On the heat pump source side, whereas the reduction in the cooling towers load is welcome by ELSA, the availability of heat from the chillers is not guaranteed at all time. However, it is assumed sufficient. Hydraulic connection to supply the evaporator side can be realized using the emergency condenser connector. An intermediate decoupling water loop on the source is needed to supply the HP evaporator with water. Besides, it is preferable for safety reasons to avoid any possible NH_3 migration to the production units in case of leakage although this implies a reduction in the overall efficiency of the system.

There is reserve for the maximum electrical power absorbed by the CO_2 HP.

The margin on the emergency ventilation in the technical room is considered sufficient by ELSA.

3.5.3 Challenges faced

Limited space around the existing CIP tanks for storage tanks, heat exchangers and piping. Moreover, the ER tanks do not feature existing connections for temperature holding hydraulic circuit.

Lack of information leads to an inability to design a valid specific hydraulic concept.

As they are always in use the CIP stations shouldn’t be stopped, making modifications to the system difficult.

3.5.4 Environmental impact

CO_2 heat pumps work with a natural refrigerant fluid (R-744) which has an ODP = 0 and GWP = 1. It has a high thermodynamic efficiency applied in the context of high temperature lift. Besides, the refrigerant is listed in the A1 group, it is non-toxic, non-flammable and non-corrosive.

As the heat pump solution would mainly replace steam supplied by a wood boiler, the positive impact in terms of CO_2 emissions reduction is mitigated as compared to replacing a fossil fuel steam boiler. The steam production is currently at ~80% from wood chips and 20% from gas for an average of 0.064g CO_2-eq/kWh.

3.5.5 Energy consumption and emissions reduction

Based on conservative assumptions and green CO_2-free electricity, the following savings have been evaluated. Given the uncertainties, 30% larger values could be achieved:

- CO_2 HP yearly energy savings of 1'460 MWh/yr and CO_2 emissions reduction of 75 to CO_2/yr
- Dual temperatures NH3 HP system:
  - HTHP1.1 (240 kW, supplying 55°C storage tank) yearly energy savings of 1'420 MWh/yr and CO_2 emissions reduction of 73 to CO_2/yr with a COP of ~4.6
  - HTHP1.2 (75 kW, supplying 73°C storage tank) yearly energy savings of 324 MWh/yr and CO_2 emissions reduction of 17 to CO_2/yr with a COP of ~3.

Electricity savings resulting from reduced load of the cooling towers aren't considered in the above values due to lack of data.

3.6 Conclusions

This case study is focused on the use of waste heat available from the chillers to supply a heat pump system to supply the CIP system. In the process of the case analysis, the need for steam showed to be avoidable and could be replaced by lower temperature heat supplied by conventional HP. The concept however hasn't been proven feasible and suffers from an unfavourable context.

In the present case, the usual driver of decarbonating process steam usage by switching to a renewable alternative isn't as much of an argument for process steam at the ELSA site is already mainly produced by a wood chip boiler.

Obtained baseline data are insufficient and the evaluations cumulate assumptions in order to extrapolate the heat needs to CIP 0-3-4 based on limited measured data.

3.7 Lessons learned

In addition to the above-mentioned conclusions, the following observations and recommendations can be made:

1. Pinch Analysis first: despite the complexity of the processes and the effort needed for data collection / extraction, convince the client to perform a Pinch Analysis. There are broader issues and opportunities to be addressed (however, the scope and time frame of the project did not allow it).
2. By their very nature, the heat requirements of CIP systems are highly fluctuating in terms of heat rate and temperature, unlike the semi-continuous production processes of dairies. This does not meet the prerequisites for profitable heat pump operation. Heat storage can level out the heat demand to some extent and stabilize heat pump operation (but heat storage capacity is limited by both the space constraints and the related costs). However, the equivalent running time at full load remains limited for efficient heat pump operation.
3. Challenges to define accurate HP specifications: in the frame of this project, the efforts made in measuring and analyzing data to determine the heat requirements on the tanks of a CIP station and only 2 circuits (out of 37 in total) would have been considered prohibitive if the company

should have paid for these. The lack of detailed energy-related data from the PLC control system should be considered redhibitory in practice for integrating HPs in CIP systems at the process level. In this case, integration of steam generating HPHT at the utility level may be easier and more flexible, though much less energy efficient and profitable, and plagued by the large variability of steam demand for CIP

4. For the reasons mentioned under Section 3.3.10 and 3.4.2, only part of the heat currently supplied by steam could be replaced by HPs. As a result, their profitability is penalized. Additionally, the smaller the savings by the HPs, the lower the tolerable complexity of the heat pump system. In other words, “complex” HPs systems ideally matching the composite curve of actual heating requirements would only be relevant for significantly larger heat requirements without limitation regarding the availability of free space.

4 Global conclusions

These case studies didn’t all lead to expected or desired results. However, the lessons learned are valuable. In themselves, the case studies enable the communication of the possibilities offered by the emerging HTHP technologies, which can supply heat exceeding 100 °C, to a large public. The success of the events organized within the framework of this research project demonstrated the significant interest from industries in HTHPs. In fact, these technologies provide durable solutions allowing for the reduction of energy consumption and CO_2 emissions in the industrial sector.

A challenge common to all three case studies lies in the availability of baseline data. Measurement campaigns were conducted to address this issue and establish the necessary work basis. Besides, the plans provided weren’t all up to date, involving complementary clarifications or site visits. Information was sometimes made available or updated over time, explaining some evolution in the work.

5 Literature references

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Appendix

Appendix 1 EPCON MVR-HTHP datasheet for the Cremo case study

Appendix 2 Thermeco$_2$ product datasheet for the Elsa case study

IHP-MVRi-2S-8

GENERAL

Project nr: 24062-40104
Customer: CSD
Source: Hot water
Ref customer: Nicole Calame
Ref EPCON: Amund Norland
Date: 20.08.2024

APPLICATION

The MVR-HP utilizes surplus heat from various industrial processes in direct, indirect, or closed heat pump systems. It employs water vapor or other process vapors as working fluid, featuring serial compression driven by electricity, for flexible system design and optimized COP.

ADVANTAGES

An MVR-HP from EPCON will provide:
*Low operational and maintenance cost.
*Access to 24h aftersales support.
*Optimized process integration and high COP

DESCRIPTION

The MVR-HP will recover heat from a hot water loop. Cooling will be provided to the hot water by evaporating water in a heat exchanger. The evaporated water will be compressed in two serial connected MVR-blowers to the required pressure and temperature.

The plant is designed as an indirect heat pump system, where the condensate from the consumers is being evaporated in the heat exchanger. An open-loop system has also been considered, but in consultation with the client it was decided to proceed with an indirect loop. As the system is operating partly under vacuum, minor air leaks may occur. Given that the clients steam network is made of stainless steel, this is considered acceptable.

The system will be delivered turnkey including electrical installation and automation. It will be delivered in two prebuilt skids, ensuring simple plant installation.

TECHNICAL DATA

Source flow rate	49	Nm3/h
Source inlet temperature	98	°C
Source return temperature	90	°C
Inlet sat. temperature MVR 1	88	°C
Inlet pressure MVR 1	650	mbarA
Supplied steam temp.	117	°C
Supplied steam pressure	1,8	barA
Feed water mass flow	810	kg/h
Latent energy to sink	500	kW
Total energy consumption (±10%)	92	kW
$COP_{\text{incl. losses (heat, motor, VSD)}}$	5,4	-
Power	400-50	V-Hz
Operating range	30-100	%
Instrument air	6	barG
Footprint (L x W x H)	5x1,8x2,4	m
Noise level	110	dB(A)
Weight skid 1	2-3	ton
Weight skid 2	2-3	ton

SCOPE OF SUPPLY

The table below shows EPCONs scope of supply (x).

INCL	DESCRIPTION
X	MVR fan(s) w/motors and frequency converters
X	Heat source heat exchanger
X	Other heat transfer equipment necessary
X	Flash vessels and/or droplet separator(s)
X	Drain, recirculation and DS system
X	Necessary instruments (4-20mA)
X	Necessary valves
X	Prefabrication of skids
X	Piping and fittings
X	Automation (Siemens PLC and programming).
X	Operator panel or PC
X	Electric distribution system, frequency converters and MCC
X	Electric installation
X	Documentation for electrical equipment
X	Pneumatic fittings and installation
X	Prefabrication of piping
X	Foundation and support drawings
X	Mechanical installation
X	Commissioning of the plant
X	Training of the personnel, limited to 15 hours
	Containers for outdoor installation on concrete foundation
	Buildings, foundations and supports
	The use of equipment for lifting purposes
	Connection to existing process
	Distribution system for individual steam consumers
X	Insulation of the plant
X	Documentation of the plant
	Components or features not described in this table

ATEX

The plant is foreseen located in Non-Ex-zone.

MATERIALS

All materials in contact with the liquid, condensate and the vapor are AISI316L/1.4404. Material in structural components is Painted CS, AISI304, or according to agreement.

FINISH

Internal finish of evaporator boiling pipes is Ra<0.8µm. Other internal finish according to industrial standard. External surfaces are pickled and passivated. Piping and fittings for the liquid are DIN2458 - ISO tubes/DIN2642 or similar.

PRICE ESTIMATE

Price estimate (±20%): EUR 1.100.000,- excl. VAT and tax.

TERMS OF DELIVERY

The plant is delivered DAP client site according to NLM19-E. Guarantee period is 12 months after startup, max 18 months from delivery.

Delivery is normally 12-14 months after order.

DELIVERY SCHEDULE RESERVATIONS

IMPORTANT: The commercial data submitted in this document is only valid within the EEC area!

All technical data are preliminary and may be subject to change. The price estimate is based on EPCON's current information, and additional clarifications are necessary for a binding proposal.

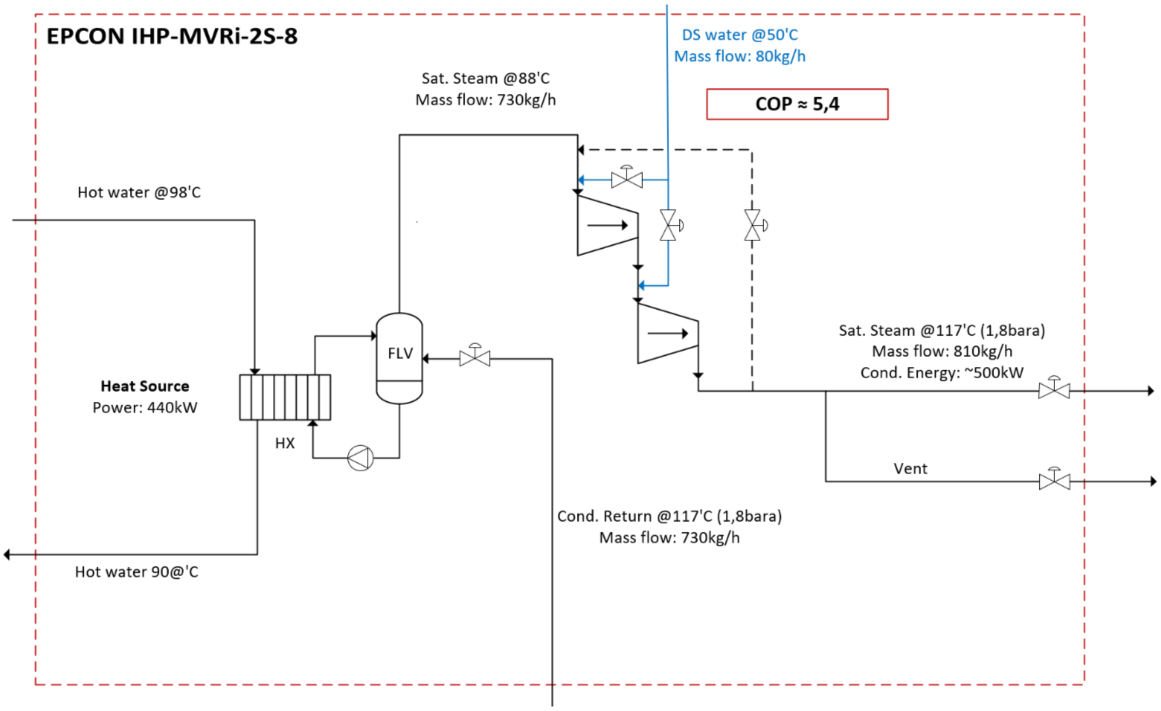
MAINTENANCE RECOMMENDATIONS

One annual service in addition to a semi-annual inspection while plant is running is recommended. EPCON offers 24-hours after sales service that includes trouble-shooting, spare parts, preventive and corrective maintenance, as well as inspection of installations. A separate proposal for Service Agreement could be submitted.

COMMENTS

- The outlet steam pressure could be reduced to match the actual steam pressure necessary to optimize COP. To be discussed.
- Desuperheating (DS) water will be taken from water network at site. If 50°C is not available, internal preheating could be arranged.

PRELIMINARY FLOW DIAGRAM



PRELIMINARY LAYOUT

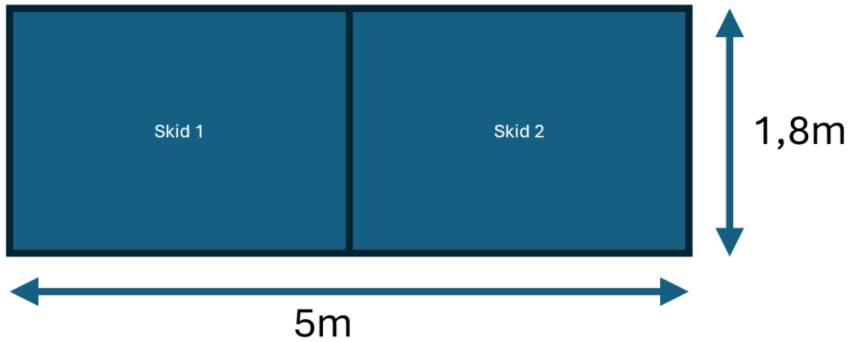


Figure 1: Possible arrangement in closed building, total preliminary footprint (L x W x H): 5m x 1,8m x 2,4m

Pos. 1.1 Pompe à chaleur à haute température CO2 thermeco2 HHR90

Caractéristiques techniques :

créé avec Selectum version 3.06.133 , base de données .26.07.2024 , valable pour une machine

Points de fonctionnement		
Niveau de puissance, compresseur	1 de 1 compresseurs	
puissance électrique requise	kW	21,8
Refroidisseur de gaz		
Puissance thermique	kW	92
Fluide caloporteur / concentration	eau	
débit (volumique)	m³/h	1,5
temp. d'entrée fluide caloporteur	°C	20,00
temp. de sortie fluide caloporteur	°C	75,00
pertes de charge totales	bar	0,03
facteur d'encrassement	m²K/W	0,000044
évaporateur		
puissance de refroidissement souhaité	kW	70
Fluide frigoporteur / concentration	eau	
débit (volumique)	m³/h	12,1
température d'entrée fluide frigoporteur	°C	20,00
température de sortie fluide frigoporteur	°C	15,00
pertes de charge totales	bar	0,68
facteur d'encrassement	m²K/W	0,000018
COP		4,22
EER		3,21
SCOP		3,59
Cogénération chaleur-froid COP		7,43

Les valeurs de puissance indiquées sont soumises aux tolérances et aux précisions de mesure suivantes.

Temp. sortie évaporateur :	Norme	Tolérance COP	Tolérance Qc
<-7,5°C	DIN EN 12900 Appl. du compresseur M	12,5%	7,5%
>-7,5°C	DIN EN 12900 Appl. du compresseur H	10%	5%

Temp. entrée refroidisseur de gaz :	Précision de mesure des températures des circuits de fluide caloporteur
<55°C	selon DIN EN 14511
>55°C	±0,25 K

Dimensions, poids et volumes de remplissage			
L x l x h*	mm	2506 x 1331 x 2167	
Poids à vide	kg	1300	
Poids en service	kg	1335	
Remplissage du fluide frigorigène	kg	25 **(Fluide frigorigène non compris dans la livraison)**	
**) Ces indications sont des données maximales. Veuillez consulter la fiche des cotes pour des données détaillées. Les poids peuvent augmenter avec les options.*			
Régulation variable de débit			
Fluide frigoporteur minimum	m^3/h	0,87	
Fluide frigoporteur maximum	m^3/h	14	
Fluide refroidisseur de gaz minimum	m^3/h	1,47	
Fluide refroidisseur de gaz maximum	m^3/h	14	
Une modification de débit par rapport aux valeurs nominales peut provoquer une modification des performances de l'installation.			
Données électriques			
Tension/fréquence	V/Hz	400V/50Hz	
Puissance électr. absorbée max.	kW	29,0	
Courant de démarrage spire partielle/direct	A	125/209	
Classe de protection armoire électrique	-	IP 54	
Conditions d'installation		Minimum	Maximum
Altitude d'installation	m	1	1000 au-dessus du niveau de la mer
Température ambiante	°C	10	40
Caractéristiques acoustiques			
Niveau de puissance acoustique selon DIN EN ISO 3744	dB(A)	76	
Niveau de pression acoustique moyen des surfaces de mesure en 1m de distance en champ libre via une surface réfléchissante selon DIN EN ISO 3744	dB(A)	68	
dans les conditions à pleine charge conformément à Eurovent			
Limites d'utilisation		Minimum	Maximum
Temp. sortie évaporateur :	°C	12,00	18,00
Temp. entrée évaporateur :	°C	17,00	23,00
Temp. sortie refroidisseur de gaz :	°C	75,00	78,00
Temp. entrée refroidisseur de gaz :	°C	20,00	23,00
Pression du système dans le circuit d'eau du refroidisseur de gaz à la température de refoulement. <= 90°C	bar	2,5*	10
Pression du système dans le circuit d'eau du refroidisseur de gaz à la température de refoulement. > 90°C	bar	5*	10
** Sur demande : circuit intermédiaire pour assurer une pression minimale du système.*			
GWP (Global Warming Potential) et équivalent CO2			
GWP selon le rapport AR4 du GIEC et le règlement (CE) n° 517/2014 sur les gaz à effet de serre fluorés			1
Équivalent CO2 (AR4) (dans 1000 kg)			0,001 to par éqCO2/kg
GWP selon le rapport AR5 du GIEC			1
Équivalent CO2 (AR5)			0,001 to par éqCO2/kg

Remarque : conception du circuit de l'évaporateur et du refroidisseur de gaz
Afin d'éviter tout apport d'oxygène et la corrosion qu'il provoque, le circuit de l'évaporateur et du refroidisseur de gaz doit être réalisé de manière à être étanche à l'air.
Il est en outre nécessaire de maintenir une pression statique minimale dans le circuit du refroidisseur de gaz en raison des températures élevées du CO2, afin d'empêcher toute ébullition.
Le client doit en outre assurer l'amorce et la marche à vide de la pompe sur l'évaporateur (protection antigel) et le refroidisseur de gaz (protection anti-ébullition).