

Energy analysis of the production line secondary heating system in a pulp mill

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Preface

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I want to start by expressing my gratitude to my thesis advisors Magnus Genrup and Daniella Johansson for their support and guidance throughout the process. I also want to thank Anders Åkesjö for his guidance in ExtenSim and pinch analysis. Robert Nilsson and Daniel Berg for helping me understand how the mill functions with specific process demand and limitations. Finally, I want to thank everyone at the mill that has both supported and shown interest in my thesis work.

*“The laws of thermodynamics, translated from Mathematics into English,
come out:*

You can’t win.

You can’t even break even.

Furthermore, you can’t get out of the game!”

-Dwight Wayne Batteau [1]

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Abstract

Products made from pulp are a part of everyday life. With end products like coffee filters, food packaging and tissue paper. These products are the result of wood being processed in pulp mills to produce the pulp from which the forementioned paper products are produced. The modern pulp and paper industry is energy intense and on a global perspective a large emitter of greenhouse gasses, accounting for 2% of industrial emissions. Large efforts have been made historically resulting in pulp and paper mill consistently reducing their emissions year by year. With projections of increasing paper demand comes increased importance in the energy efficient production of said pulp. It is therefore imperative that solutions to reduce emissions and for energy efficient solutions to be found. From installation of new units to optimisation and improvements of old. Pulp mills, while they are energy intense, are well known to produce great amounts of excess heat which can be recovered and used beyond the pulping process. Both district heating and electricity is produced, courtesy of the liquor recovery cycle and large cooling requirements in the mill.

This thesis covers mapping and analysis of the secondary heating system in a mill situated in the south of Sweden. The secondary heating system is an integral part of the mill providing heating and cooling to multiple processes in the mill. The mill has undergone several reconstruction efforts and system changes over the years, resulting in an energy analysis of the secondary heating system being sought after. The overall goal is to further the mill understanding of the secondary heating system in terms of efficiency and energy. With the target to enable increased efficiency in use of the current secondary heating system and provide a basis for future secondary heating usage. While simultaneously also replacing current steam heating wherever possible. Prime mover behind this thesis is the need for reduction of steam usage. Caused by a condensing turbine set to be installed by the mill, resulting in increased possible steam utilisation for electricity production. Consequently, it follows that increased importance is placed on ensuring that only processes which truly require steam receive it. Maximising the possible steam utilisation in the turbine while also increasing the use of internal heat recovered.

The pulp production line from the digesters to the bleaching section, as well as the scrubber, was mapped out and data was collected for use in analysis. Found in the study were potential immediate steam savings of 6.8 MW by changing processes or swapping current steam condensing units with heat exchangers using the secondary heating system. The pinch analysis performed indicated energy savings primarily in the black liquor coolers and the mill ventilation condenser, where steam is cooled by 12°C water, which alone represents 5.5 MW steam saved. In the process of mapping of the secondary heating system it was discovered that significant amounts of water at 85°C is available to the mill for use. One such case was analysed after suggestion from the mill. Potential use of either scrubber water or hot water in a bark dryer is analysed in which the hot water is preferred to scrubber water, as it at least reduces the dryer steam heating demand from 55% to 26%. Improvements to scrubber use in the current system was also found, where a heating system occasionally in use could always be, saving 1.3 MW.

Lifting the temperature of the secondary heating streams by using steam was also considered, As lifting the temperature of the hot secondary heating streams is shown to increase possible use cases, as higher temperature heating demands can be sufficiently achieved. Resulting in further possible primary heat savings of 0.3-2.8 MW. Since there is significant excess of hot water, if the use can be increased by lifting its temperature there are further energy savings possible that will have to be weighed against the heating requirement. This thesis opens up possible future research in improved utilisation of recovered heat in the pulping mill researched.

Keywords: Energy, Kraft process, pinch analysis, heat recovery, heat exchanger, steam savings.

Populärvetenskaplig sammanfattning

Produkter framställda från massa är en del av vardagen. Med produkter så som kaffefilter, förpackningar till mat och mjukpapper. Dessa är ett resultat av trä som behandlats i massabruk för att producera massa, som de tidigare nämnda pappersprodukterna är producerade från. Den moderna pappers och massaindustrin är energiintensiv och står för stora utsläpp utifrån ett globalt perspektiv, ansvarig för 2% av industriella utsläpp. Stora insatser har gjorts historisk vilket har resulterat i att pappers och massabruk stadigt minskat sina utsläpp år efter år. Med förväntad ökad efterfrågan på pappersprodukter följer en ökad betydelse av minskade utsläpp och mer energieffektiv produktion av massa. Därmed är det nödvändigt att nya lösningar för minskade utsläpp och energieffektiva lösningar hittas, både med förbättring av gamla och tillbyggnad av nya delar. Massabruk är, trots att de kräver mycket energi, också välkända källor av värmeenergi som kan användas i eller utanför produktionen. Både fjärrvärme och elektricitet produceras som resultat av brukets processer.

Denna avhandling täcker kartläggning och analys av det så kallade sekundärvärmesystemet på ett massabruk i södra Sverige. Sekundärvärmesystemet, som består av vatten vid olika temperaturer, är en mycket viktig del bruket och försörjer flertalet av brukets processer med värme, kyla och vatten. Bruket har genomgått flertalet till- och ombyggnader över tid och efterfrågar därmed en energianalys av det befintliga sekundärvärmesystemet. Den övergripande målsättningen är att öka kunskapen kring sekundärvärmesystemet i termer av energi och effektivitet. Med målet att utgöra en bas för energieffektivisering av nuvarande sekundärvärmesystem och framtida utökningar av restvärmeanvändning. Samtidigt som ånganvändning ses över och ersätts när möjligheten finns. Drivande bakom uppsatsen är brukets behov av minskad ånganvändning. Orsakat av en ny kondensator som ska installeras vilket resulterar i ökad möjlighet av ånganvändning till elproduktion. Därmed är det viktigare att endast de processer som absolut kräver ånga förses med det. Detta maximerar ånganvändning i turbin samtidigt som nyttjande av intern återvunnen värme ökar.

Efter att karteringen genomförts så undersöktes möjligheten att minska användningen av ånga i brukets produktion. Det visade sig att viss användning av ånga kan direkt ersättas eller upphöra utan att påverka produktionsprocessen. Detta kunde endast ske i redan befintliga delar av bruket vilket innebär att ingen ny installation kunde föreslås som direkt ersatte ånga i processerna. Det undersöktes även om ånganvändningen kunde minskas, men inte helt ersättas, i flertalet processer. Detta visade sig till viss del vara möjligt, men storleken på besparingen var kraftigt beroende av temperatur på vattnet i bruket. Slutsatsen blir att det finns energi tillgängligt i dagens sekundärvärmesystem och denna studie kan förstås som en utgångspunkt för framtida effektiviseringar och förbättringar av brukets sekundärvärmesystem.

Nyckelord: Energi, sulfatprocessen, pinchanalys, värmeåtervinning, värmeväxlare, ångbesparing.

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Notations

WP = Washing Press

F = Filter

HW = Hot water ($>50^{\circ}\text{C}$)

WW = Warm water ($<50^{\circ}\text{C}$)

WC = Cold water

WCC = Cold water (Chemically cleaned)

S03 = Steam at 3 bar (gauge)

S11 = Steam at 11 bar (gauge)

S14 = Steam at 14 bar (gauge)

LMTD = Log Mean Temperature Difference

l/s = Litre/Second

$\dot{m}$ = mass flow (kg/s)

h = Enthalpy (kJ/kg)

h_{fg} = Enthalpy of evaporation (kJ/kg)

HE = Heat Exchanger

D: Digester

OB: Oxygen Bleaching

B: Bleaching

C: Condensate

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1. Introduction

In 2022 IEA (International Energy Agency) reported that the pulp and paper industries were responsible for 2% of all industrial emissions [2]. Primarily from combustion in the recovery boiler, biomass boilers and lime kiln [3]. With paper production being predicted to increase in coming years it is important for energy and CO₂ intensity to be decreased in the pulp production. Production of pulp is energy intense, which IEA primarily attributes to the evaporation stages of the mills. Historically, the energy and CO₂ intensity has been decreasing over time, which according to IEA is due to improved energy sources [2]. In 2023 Sweden was the lead European producer of pulp, producing 33,4% of the total 32,7 Million tonnes of pulp produced by CEPI (Confederation of European Paper Industries) countries which comprises the vast majority of European pulp and paper producing countries [4]. Swedish forest industries reportedly represent 14% of the total electrical energy consumption of Sweden. Upwards of 40% of this consumption can be sustained by the forest industry itself, which is produced using 96% bio-energy [5]. The bio-energy in Swedish pulp mills is most commonly recovered from the mill itself, as the Kraft process results in black liquor which is used as a bio-fuel for heat and electricity production [6]. Primarily, the goal of the recovery boiler is not to produce electricity. Rather, it is an integral part of the liquor recovery cycle. Where black liquor is burned in order to remove unwanted chemicals and eventually recover white liquor for reuse in the pulping process [7]. The paper and pulp mills are also important suppliers of district heating in Sweden, serving an important role in the historical development of the district heating systems. As the high availability of heat from the pulp and paper mills facilitates large production of district heating [8], where Swedish district heating systems on average demand supply temperatures above 80°C [9]. Which pulp and paper mills are able to generate, covering large parts of local heating demand. Even in larger cities [8].

The mill in question for this report is located in the south of Sweden and has been in use since the 60's producing pulp. The mill uses the Kraft process and is therefore equipped with a recovery boiler, which serves as the primary heat source for the electricity production and the pulping process. There is also a secondary bark boiler. Currently there is a new condensing turbine being installed. There is also a heat recovery system in which supplies the local municipality with district heating. Being able to meet the vast majority of the local district heating demand. Currently the mill produces an excess of steam, which then can be utilised for heating purposes in various points in the process. The condensing turbine unit being installed is set to change the steam availability for the mill. In order to ensure steam availability in critical applications, processes that ultimately do not require steam should therefore be replaced by other heating systems. The goal of this report is to analyse part of the secondary heating system of the mill and determining where steam usage can be replaced by other means. Also, the current secondary heating system connected to the main production line will be analysed and mapped out. As due to several reconstruction efforts over the years, an energy efficiency review of the secondary heating system is needed [10].

Previous studies of energy systems in paper and pulp mills have been conducted. With some placing special emphasis on secondary heating system and energy savings therein. Mahmoud and Nihlmark in their 2017 master thesis at Södra Cell Mönsterås were able to find potential primary energy savings of 79 MW and also found a potential for production of 38.3 MW water at 114°C for the secondary heating system [11]. Eriksson and Hermansson found savings of 18.5 MW at Billerud Karlsborg with specifically 11 MW recoverable in the mill warm water system [12]. These studies showcase that there are possible energy efficiency savings to be found in the secondary heating system. While the mills will vary in terms of construction and age, the general trend seems to be that the secondary heating system can be utilised more

efficiently. In this report only a section of the mill is covered while the previously mentioned studies cover other sections of the mills. It follows that possible energy savings in this report can occur in different processes and be of different size. As some savings were found in mill sections not covered in this report, it could indicate that further analysis of the remaining systems of the mill may return further energy savings.

1.1 Aims and objectives

The aim of this report is to increase the knowledge and understanding of the mill secondary heating system enabling future improvements and energy savings in the system. This is done by mapping out the secondary heating system and analysing the current usage of it. Also constructing the secondary heating system in the simulation tool ExtendSim. The target is to increase energy efficiency of the secondary heating system and assuring that it is available for the processes that need it. The energy efficiency is sought to be improved as a whole, with one goal being to research possible reductions of the primary heating usage by replacing it with secondary heating when possible. To aid with finding possible sources of energy misuse, a pinch analysis will be performed on the section of the mill that this report concerns. Finally retrofit changes to the current system and possible future secondary heating use will be suggested.

- Mapping of the secondary heating system
- Mapping of the scrubber water system
- Data collection of primary and secondary heating system
- Evaluation of data collected
- Pinch analysis
- Retrofit suggestions
- Suggestion of secondary heating usage for future processes

2. Process description

This chapter will give some background on the pulping production of the mill, illustrated in Figure 1, as well as the primary and secondary heating system. The primary role of the mill is to produce pulp, meaning that the other systems are second to the pulping process. This is not an in-depth look into the pulping production methods and the chemistry of pulping. However, some basics have to be covered for the reader to get an overview of how the mill operates. The pulping process description is largely based on Gary A. Smook's Handbook for Pulp and Paper Technologists, which the reader is encouraged to consult for a more in depth look at the pulp and paper production process.

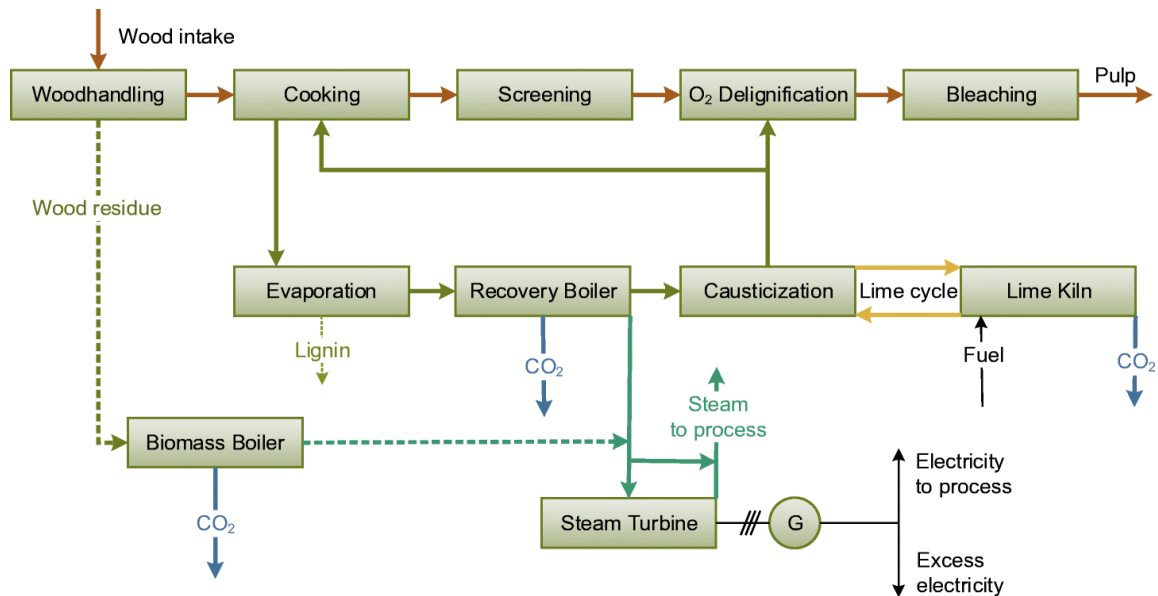


Figure 1: Kraft pulp mill overview with pulping, recovery cycles and electricity generation [3]. After the bleaching stage the pulp is ready to be dried. Note that washing stage and district heating is not shown in the figure, but is very much present in the mill analysed.

2.1 Kraft process and recovery cycle

Production of pulp at the mill is done by using the Kraft process which is the mainstream method for pulp production. The pulp itself is a fibre mass resulting from separation of the fibres from other substances in the raw wood. In simple terms, the pulp is produced by inserting woodchips and white liquor to a digester where they are heated. This causes the lignin to swell which causes the woodchips to rupture resulting in formation of pulp. The pulp at this stage still contains unwanted substances, including some remaining lignin. [13]. Lignin is an organic polymer which together with cellulose and hemicelluloses make up the largest part of the wood chemical structure. One of the functions of lignin is to act as the binding material of the wood cell structure, holding the cells together into a larger stronger structure [14]. The pulp is then sent for washing and bleaching which will be covered in the next section. The other product resulting from the cooking process is weak black liquor, which is composed of white liquor and the remaining organic products of the wood. An important stage in the Kraft pulping process is the recovery of white liquor for reuse in the digesters [13]. Following the recovery process shown in Figure 2 the next stage is evaporating the weak black liquor into heavy black liquor in order to improve the burning process. The heavy black liquor is burned in the recovery boiler which burns the organics present in the liquor, generating steam for use in the mill. The burning process results in a smelt which is then turned into green liquor by dissolving it in water. This can finally be treated with lime in the causticizing plant where the resultant is white liquor closing the cycle shown in Figure 2 [7].

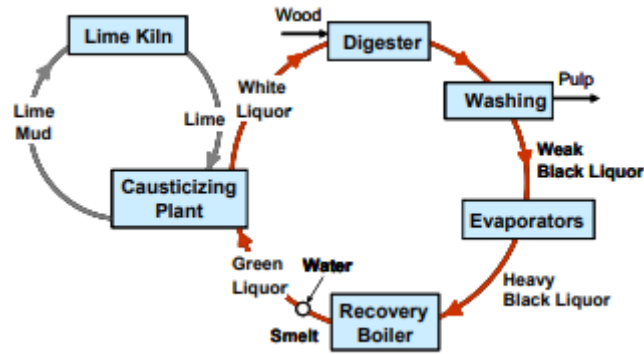


Figure 2: The Kraft recovery cycle [7] Note the presence of the washing stage after the digester.

2.2 Washing and bleaching

One part of the recovery cycle not yet covered is the washing stage. It is here where the cleaning process of the pulp begins. But prior to the washing stage is the treatment of the mass exiting the digesters. This mass may contain knots, meaning irregularly large pieces of pulp or chips that have not sufficiently reacted. Therefore, screening of the pulp and removal of unwanted pieces of pulp is done. It is set up in two stages, as some of the rejected pulp could be of acceptable properties which should then be returned to the normal pulp stream. Then the accepted pulp enters a washing stage where liquor and spent chemicals are removed. The degree at which the mill can successfully remove unwanted substances in this stage directly reduces chemical treatment requirements downstream. As well as reduces the addition of new liquor required by increasing the amount of recycled liquor. The first washing stages uses liquor as washing medium whereas the latter stages use water. The washing stages uses a counter-current washing system, by which the cleanest pulp is cleaned by the cleanest washing liquid. This liquid is then used in the previous (with regards to the pulp flow) washing stage, continuing until the first washing cycle in the washing stage. Water use at this stage is a balance act for the mill to consider, it is added as the initial washing medium in the final washing stage or added to dilute the dirty washing water. Increased water addition will result in cleaner pulp, but more water present in the pulp increases evaporation demands later in the process. After washing the pulp, it enters the bleaching stages.

There are two bleaching stages in the mill. After the washing stage the pulp is still brown in colour, caused by residue lignin in the pulp. As the aim of the bleaching stages is to remove the final lignin and achieve a bright white pulp, the bleaching stages are also called delignifying stages. Varying chemicals are added in this stage to aid with the delignification, with specific demands in temperature and concentration to optimise the reactions. The first bleaching stage uses oxygen to oxidise the lignin present in the pulp. After a series of oxygen bleaching stages, the pulp enters the bleaching section. In this final bleaching stage, a counter current washing stage is once again used, this is to remove the final unwanted substances and chemicals from the pulp flow. After the bleaching stage, the pulp is an acceptable colour but contains significant amounts of water which needs to be removed.

2.3 Drying

To remove the water content from the pulp it is passed through a drying section. Here the pulp is pressed in multiple steps. It is also heated using steam, making it an important steam consumer, and passed through a fan section. As noted earlier, the water content of the pulp entering dictates the energy demand from the drying section [13].

2.4 Primary heating system

Before discussing the secondary heating system, which is of most concern for this report, the primary heating system needs to be properly defined. The primary heating system consists of steam at different pressure and temperature levels. Steam is, as previously mentioned, generated using primarily the recovery boiler where heavy black liquor is combusted as part of the recovery cycle. There is also a bark boiler which is used when the primary heat demand cannot be fulfilled by the recovery boiler. The primary role of the recovery boiler is to burn heavy black liquor into green liquor, with the secondary role of producing steam for use in the pulping process. The third role of the recovery boiler is to supply primary heating to the turbines for generation of electricity, with a new condensing turbine unit currently being installed. Steam is also currently used for increasing the district heating temperature when required. As mentioned previously, there is currently a condensing turbine being installed. This is expected to reduce the excess steam availability, meaning that steam must only be used in the most significant applications. Steam utilisation in the future will be directly impacting possible electricity generation capabilities, which directly affects the revenue of the mill.

2.5 Secondary heating system

The secondary heating system consists of the hot water (HW) and warm water (WW) systems of the mill. Both HW and WW are resultant of cold water (WC) being heated in different processes. HW is declared to be mechanically cleaned water at temperatures above 50°C whereas WW is mechanically cleaned water below 50°C. A more accurate alternative, description, aiding in understanding of the systems, for is to denote HW as water at around 80°C and WW around 40°C. The heating of the mechanically cleaned water is provided either by direct use of primary heat, or it is heated in the mill processes. Both HW and WW are required at various steps in the pulp production process. The pulp process demand both heating and cooling in various stages along the pulp production line, making the secondary heating system important in regulation of temperature in the pulp process. HW and WW is also used in cleaning purposes. In the washing stages the secondary heating system provides clean water for use in the washing stages, both in regular operation and for when back water (washing water) is unavailable. For example, HW is used during start-up of the mill after maintenance stops when washing water is not yet available. Also, it is used for chemical balancing in dilution of pulp or chemical additives used in the mill. The secondary heating system has significantly changed over time. Previously the system suffered from a lack of hot water and an excess of warm water. Currently this has been reversed, but the mill is still subject to future changes both in processes and constructions. Therefore, there is no guarantee that there will always be an excess of HW.

3. Theory

3.1 Energy calculations

Forming the basis of this report is the energy calculations performed with the flow data collected at the mill. For this, the theory behind the thermodynamic concepts used will be introduced. As well as the heat exchanger equations, as heat exchanging features prominently in this report. This section concerns the theory behind the calculations and analysis methods used in this report.

3.1.1 First law of thermodynamics

The first law of thermodynamics states that “energy can neither be created nor destroyed during a process; it can only change forms”. From this it follows that the total energy change in a system, consisting of the total change in kinetic, potential and internal energy, is equal to the difference between in- and output of energy, consisting of the difference between heat, work and mass transfer, into the system in accordance to equation 1. The equation is also valid for energy transfer rate as stated in equation 2:

$$E_{in} - E_{out} = \Delta E_{sys} \quad (1)$$

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys} \quad (2)$$

3.1.2 Second law of thermodynamics

From the first law it is possible to determine whether or not a process is in balance in terms of energy, but it does not guarantee that the process by which energy transfer happens is possible. The second law of thermodynamics concerns the direction, quality and quantity of energy flow in processes. The law states that energy flows and processes will happen in one direction, and not the opposite direction. As an example, it is possible for heat to be transferred from a hot to a cold medium but not the opposite. For further energy analysis it is also important to introduce the concept of heat sources and sinks. A source is a supplier of heat, whereas a sink is a heat absorbent. It then follows that heat flows to a sink from a source, with the reverse being an impossible process. In the second law the definition of entropy is also introduced, which can be thought of as a measurement of disorder in a system. Entropy always needs to remain unchanged or be increased during a process and is defined in equation 3 as:

$$\Delta S = S_2 - S_1 = \int_1^2 \frac{\delta Q}{T} + S_{gen} \text{ where } S_{gen} \geq 0 \quad (3)$$

3.1.3 Conservation of mass

While it may sound trivial, it is still important to introduce the conservation of mass. More specifically, the processes treated in this report are for the most part treated as steady flow processes, where the control volume does not experience any mass change. With the mass flow only passing through, the steady flow conservation of mass balance can be stated as:

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \quad (4)$$

$$\dot{m} = \frac{\dot{V}}{v@ (T, P)} \quad (5)$$

$$IV = C - PH + 2 \quad (6)$$

This relation can also be extended to volumetric flow (m^3/s) relations, under the condition that the medium can be assumed to be incompressible. Conversion between volumetric and mass flow is done by using the specific volume, v (m^3/kg), at specified flow pressure and temperature as stated in equation 5. The definition of the medium's physical state can be determined with the Gibbs phase rule, expressed in equation 6. By which the number of variable independent properties, IV , is determined from number of components C and phases PH . For a medium in a thermodynamic equilibrium single phase, both pressure and temperature can freely be varied [15].

3.1.4 Heat transfer

An integral part of this report is the analysis of heat exchangers and heat transfer. The basics is that heat exchangers enable transfer of heat between two mediums without mixing. The most efficient option is to use counter current flow where hot and cold mediums enter on opposite ends of the exchanger unit. As can be seen in Figure 3.

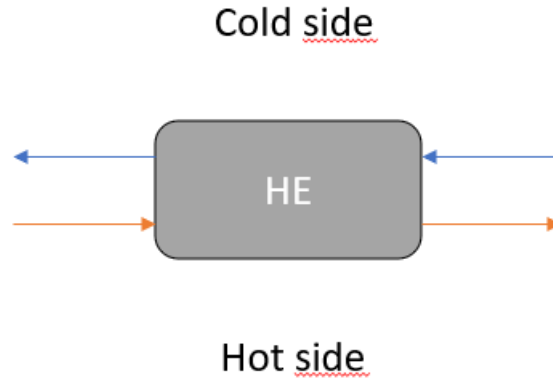


Figure 3: Illustration of a counter flow heat exchanger.

Three methods of calculating the heat transfer rate of the heat exchangers of the mill are needed. First, there is the energy balance for steady flow situations, as stated in the section on the first law of thermodynamics. When possible, these energy balance calculations are performed using the change of enthalpy in the respective process. Enthalpy is defined as the total sum of flow energy and internal energy. Here it is assumed that the heat exchanger units are perfectly insulated. Which if the first law of thermodynamics is applied results in the cold and hot medium experiencing equal rate of heat transfer. A special case is made for the heat transfer in condensers, as the heat transfer capacity for a condensing medium is approaching infinity. The heat transfer rate for condensers can therefore be considered to be exclusively based on the specific enthalpy of vaporization, h_{fg} , as shown in equation 8. Finally, the Log Mean Temperature Difference (LMTD) is used as shown in equation 9 where A (m^2) is the heat transfer area, U (kW/m^2K) is the overall heat transfer coefficient and ΔT_{LMTD} as shown in equation 10. This relationship comes from solving the relation of temperature change rate and heat transfer rate with heat capacity rate in fluids. The temperature change rate with regards to the heat transfer rate is shown in equation 11. This method takes into consideration the change in temperature difference between the cold and hot side along the length of the heat exchanger. Where ΔT_1 and ΔT_2 are the temperature differences between cold and hot medium on each side of the heat exchanger [16].

$$\dot{Q} = \dot{m} \cdot [h@(T_1, P_1) - h@(T_2, P_2)] \quad (7)$$

$$\dot{Q} = \dot{m} \cdot h_{fg} \quad (8)$$

$$\dot{Q} = U \cdot A \cdot \Delta T_{LMTD} \quad (9)$$

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \left(\frac{\Delta T_1}{\Delta T_2} \right)} \quad (10)$$

$$\frac{dT}{\delta\dot{Q}} = \frac{1}{\dot{m}c_p} \quad (11)$$

Important to consider when discussing heat exchanger units is the fouling impact on heat transfer efficiency. Most commonly these inefficiencies are caused by gradual deposition of material in the exchanger units resulting in increased thermal resistance. Both on the area of heat transfer and the exchanger pipe connections. Fouling is associated with increased operational costs both caused by halted operations and cost of cleaning the exchangers [16]. Pulping mills are seasoned in handling fouling in heat exchanger units, as the properties of black liquor frequently results in operational disturbances. Black liquor contains large amounts of both solvable and insoluble solids of both organic and inorganic composition and is exuberated by increased black liquor temperature [17]. Generally, fouling rate is increased with high temperatures and low velocities [16].

3.2 Pinch

Pinch analysis is a method which aims to optimise energy use in industrial systems, both for new constructions or retrofitting to existing industries, by optimising its heat exchanging systems. It treats the heat addition and removal from industrial processes including optimising internal use of heating and cooling sources by choosing the most reasonable heating or cooling source. When performing pinch analysis, it is useful to define hot and cold streams, according to which all streams in the analysis are to be categorised. Hot streams include all streams that require cooling, and will therefore heat any cooling medium. Cold streams instead represent heating demand from the process streams. In separating hot and cold streams, a minimum temperature delta that can be achieved in a heat exchanger, $\Delta T_{\min}$ [18]. The choice of $\Delta T_{\min}$ sets the position of the pinch point in the composite curve system and affects the resultant economic demands for the construction of the heat exchanger system. It also determines the heat recovery possible in the system, as it is this value that sets the limit on which streams can be utilised for each specific purpose. A conventional choice of $\Delta T_{\min}$ is commonly set to 10K for processes with temperatures above ambient. Depending on which type of process is analysed, values between 5-20K are normal.

3.2.1 Composite curves and heat exchanger networks

With data collected and separated into hot and cold streams, it is possible to plot the flows as a line from one temperature to another against the subsequent change in enthalpy. Each stream forms a single curve which when joined together they end up forming the composite curve as seen in Figure 4. The curve will display different heating or cooling capacities, $CP = \dot{m}c_p$, as streams can feasibly provide different amounts of heating or cooling [19] for use in equation 12 for calculations of heat transfer rate, with the temperature change rate relation shown in equation 11 and can be observed in figure 4 [16].

$$\dot{Q} = \dot{m} \cdot \Delta h = CP \cdot \Delta T \quad (12)$$

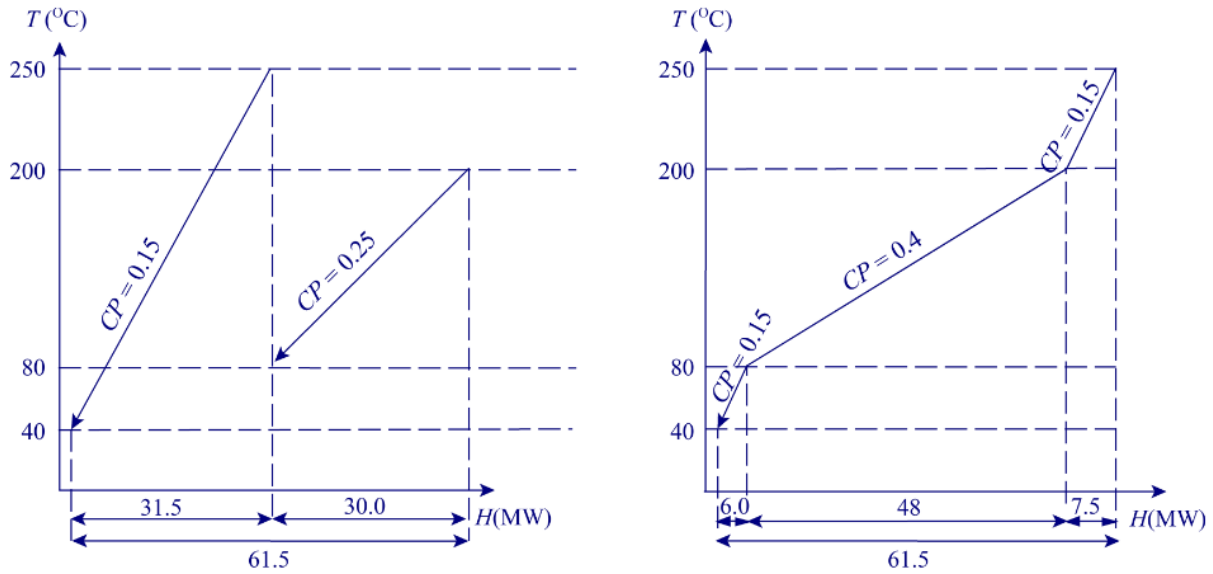


Figure 4: Individual streams and the composite curve formed from them [19].

Placing both the hot and cold composite curve in a single diagram, the system can now be analysed and target minimum hot or cold utilities, or energy targets. The hot utility, Q_{Hmin} , is the difference in enthalpy between the highest temperature hot and cold stream, while the cold utility, Q_{Cmin} , is the enthalpy difference between lowest temperature hot and cold stream. These represent the heating and cooling demands respectively, that cannot be satisfied with internal heating and cooling streams, thus requiring external addition of heating or cooling. The heating and cooling demands that can be satisfied by recovering heat internally, Q_{REC} , is the enthalpy difference between the start points of the hot and cold streams respectively. From the graphs the pinch temperature can also be found, where the distance between the two curves is at a minimum as seen in Figure 5. When designing the heat exchanger networks the goal overall is to minimise the utilities while maximising the recovery. Not all heat transfer processes occur by heat exchangers, in the industry streams are often mixed at different temperature. Mixing of streams is considered to be isothermal heat transfer, resulting in two streams reaching the same temperature. This is acceptable as the heat transfer is not done through a heat exchanger, rather it is directly occurring in the two united streams. Meaning that one stream experience heating while the other is cooled [19].

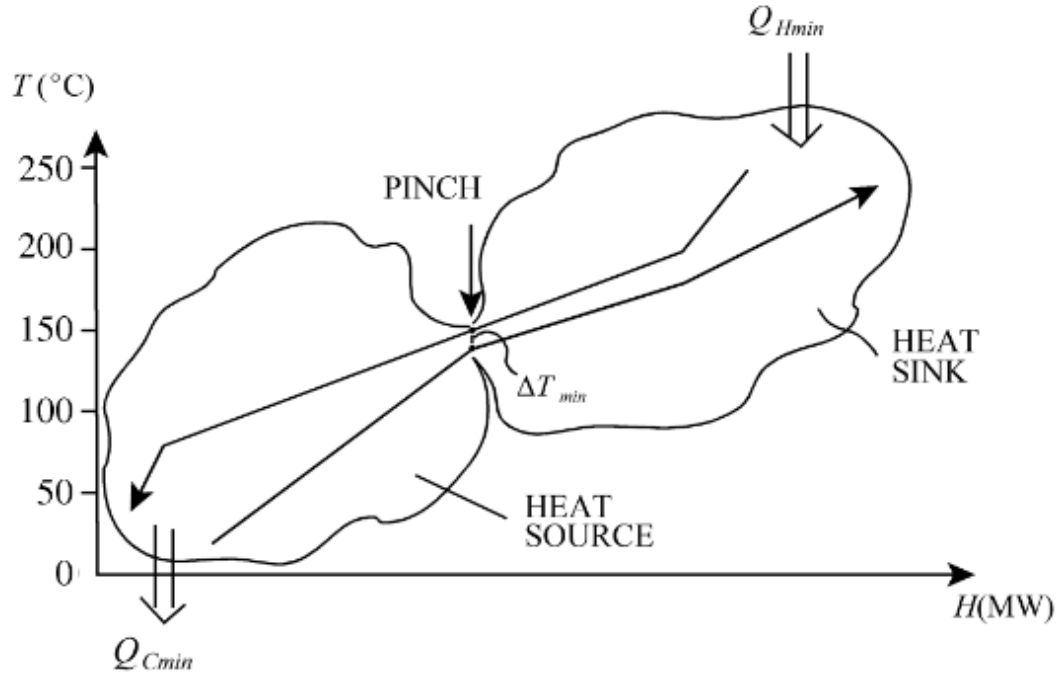


Figure 5: Composite curves and the pinch point separating the sink and source [19].

3.2.2 Grand composite curve

From the analysis of the composite curves, an optimisation of heat input, recovery and removal from a system can be achieved. However, it does not showcase the processes that require external sources of heating or cooling and where energy can be recovered internally. For this the grand composite curve was developed in order to showcase the possible areas for heat recovery and the choice of utilities. The grand composite curve is created by plotting the problem table cascade with shifted temperature, T^* , plotted against enthalpy. Shifted temperature means that hot streams are shown as $\Delta T_{\min}/2$ cooler whereas cold stream are shown $\Delta T_{\min}/2$ as seen in Figure 6. This is done to ensure that the constraint of $\Delta T_{\min}$ between hot and cold streams is fulfilled.

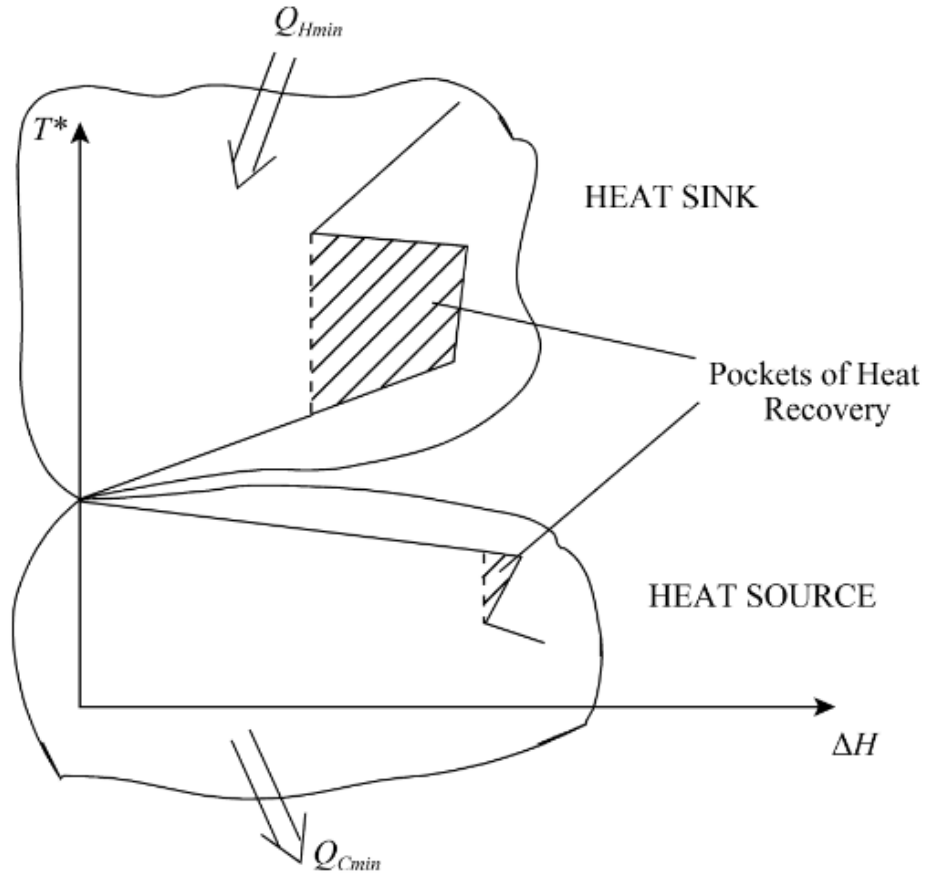


Figure 6: The grand composite curve, with energy recovery possible shown [19].

3.2.3 Retrofit

Lastly, the concept of retrofitting needs to be treated. As the word indicates, retrofitting concerns analysis and improvement of an already constructed heat exchanger network. This presents some different challenges when compared to pinch-analysis of new construction, as modifying current designs can be challenging or downright impossible. In order for pinch-analysis to be useful when retrofitting, one has to take into consideration the possible solutions for improvement, not only presenting the ideal solutions. Also, the economical aspect needs to be taken into account. Retrofitting can be done by increasing possible heat transfer between matching streams, changing the use of different streams to better match heating and cooling demands or reconstruction of certain parts of the system in order to optimise certain sections. [19].

4. Methodology

4.1 Data Collection

The mill runs as a batch cookery, meaning the cooking process is not continuous. Production of pulp on the other hand is continuous through the mill. This affects the sub-systems connected to the production, which will be running in accordance with the cooking cycles. The production itself also varies depending on each cooking cycle, as different qualities of pulp is produced. This results in different demands from the sub-systems in the mill. From this it follows that flow data is going to be varied, with some flows being near constant, some will be cyclic and others will be sporadic in nature. Analysis and calculations are going to be highly dependent on accurate long-term data being collected in order to find representative values for the flow.

A crucial part of energy efficiency calculations and pinch analysis is the collection of data from measurements in the mill. For this paper there are three tiers of data collected, based on how representative it is assumed to be with regard to normal operation of the mill. This is due to the different availability of measurement units and data logging systems in the mill. The first tier is data based on numerical trend values logged continuously at the mill on a minute basis. From this, an hourly average value is attained and collected between 2023-01-01 00:00 and 2024-01-01 00:00 unless otherwise stated. The operation during 2023 is considered to be normal, with no incidents that could cause the data collected to be especially non-representative for the mill. The second tier consists of data points that are measured and logged continuously, however only saved for the last three months, with average values calculated by the operations system. The date for each data extraction has been logged, and under most circumstances these data points are assumed to be of equal value to the yearly values. Although it should be noted that the values collected are representative of winter and spring conditions. Summer and autumn conditions are therefore unrepresented in these cases.

Finally, there are flows that lack measurements. Depending on the specifics of the flow, they will be dealt with in different manners. If a process lacks adjacent temperature measurements, more distant measurements can be used instead. If, as an example, the flow has its origin in a cistern. The flow is assumed to have equal temperature to the cistern when arriving at the specific process. Depending on the piping path, this can be inaccurate as systems adjacent to the pipe can both heat and cool the fluid flowing through. However, the temperature of the cistern is the closest. If there is a lack of measurements and the flow is assumed to be sporadic in nature, which is true for some washing and diluting flows, they can be omitted from the study. The flows are only omitted after discussing the nature of the flow with workers at the mill. However, some unknown flows cannot be ignored, as they will have a noticeable impact on calculations. If there are specifications for the size and temperature of the flow, or if there are previous measurements available, these will be used and assumed to be accurate. If possible, flow data will be calculated using available measurements or specifications.

There is normally one mill maintenance shutdown each year, where normal production is stopped. It follows that measurements taken during that time will not be representative of normal plant operations. If possible, the flow data collected during maintenance can be filtered out and not used in energy calculations. This is done by not using the flow and temperature values for calculations when the mill is stopped, by checking w. The flows that can be filtered out clearly approach zero when there is a stop and, unless an unforeseen stop happens during normal operations, never approach zero, or some other value that indicates that the mill operations are halted. If the flow is not affected by stops or the flow is such that filtering out the mill maintenance shut down impacts the accuracy of average calculation, the data will have to be accepted as it is without any filtering.

4.2 Extendsim

Extendsim is a simulation tool used for simulating the production of the mill. As the secondary heating system, specifically the HW and WW cistern networks, is currently not implemented one of the goals of this report is to construct it. This is done by using setting up all the streams found in the mapping section. Missing HW and WW usage points are also covered by adding them which prepares them for implementation into the ordinary mill simulation system. While not ready for simulations yet, the construction of the system graphically illustrates the mapping progress performed as part of this study.

4.3 ProPi

Pinch analysis was performed using Pro_pi2, an extension to excel. Here stream data found in the data collection is added. With temperature difference and the heating or cooling demand

added, the extension separates the streams into hot and cold streams. From the data collected the composite curves and grand composite curves can be created, with a set global temperature difference. Here the programme standard of 10K as global temperature difference was used.

4.4 System boundaries and assumptions

The systems analysed in detail in this report concerns the main pulp production line. This starts with the digester section and ends with the bleaching section, meaning that the drying section is not covered. This does cover most connection to the HW and WW cisterns, flows connected to other sections of the mill are present in the cistern analysis. However how these streams are used in those sections will not be covered in detail. There are also other types of water streams that have not been covered. This report only concerns the mechanically cleaned water, as part of the secondary heating system, and steam, the primary heating system. Other water systems exist and further savings may be found within them, but they will not be part of this report. The heat exchanging processes covered all use either steam or mechanically cleaned water as heating or cooling medium. This means that other heat exchangers have been left out, where possible energy savings may still be present. Also covered is the scrubber section which is mapped out and analysed from an energy perspective. This is considered separated from the other HW systems due to the scrubber water being unclean. This is not covered in the pinch analysis however, rather energy savings are found by manual analysis of the system. The pinch analysis will cover the primary and secondary heating usage from the digester to the bleaching section.

As for assumptions, the secondary heating system is assumed to hold at 4.5 bars pressure, which will only partially be true throughout the mill. Multiple pumps are present in the system, as well as different flow paths and processes resulting in dropped pressure at various points. The digesters are assumed to hold at 7 bars pressure, the pulp flow is assumed to hold at 6.5 or 7 bars depending on what is observed in the visual inspection of pressure measurements nearby the process. The energy calculations are mainly affected when the pressure change dictates which phase the fluid in question is in. Heat transfer in mixing processes is assumed to be isothermal, as was stated in the pinch theory section.

Some streams have been omitted from the study, as covered in the section on data collection. While this results in missing representation of flow, the impact should be kept to a minimum as most flows that are set to be omitted are small and would have limited impact on the calculations.

4.5 Sources of error

As stated in the data section the yearly maintenance stop is filtered out of data when possible. However, this presents the issue that some data extracted will include data points taken during the shutdown. This means that the data sets used will be of different size. Also, the removal of the shutdown data points can also, for better or for worse, remove unplanned shutdowns during other times of the year. A solution to this problem is to extract data between two maintenance shutdowns, as then no removal of unrepresentative data points is necessary, as the average can always freely be extracted, while the seasonal variations will remain captured. This was realised to late and therefore the method of filtering out of the maintenance stop is used in this study. Also, the data collected is from the year 2023, meaning that certain processes may have changed since, meaning that some data collected may not be representative for current mill data.

The accuracy of data extracted is also dependent on measurement tools being available and correctly calibrated. Unless otherwise stated, the measurement tools are assumed to be accurate. Even when measurement tools are known to possibly show inaccurate values, the

result may still use the values gathered unless calculation can be done in some other manner. Measurement of steam flow is known to be challenging and thus flow meters can report inaccurate readings. When possible, the heating requirement is calculated by other means than using the steam data. This is not possible for all instances in the mill and therefore steam flow data will be used when needed.

The consuming flows, meaning flows that are added to processes in the mill and therefore do not return to any of the cisterns, are assumed to achieve the temperature of the flow in which it is added. This is done in order for these streams to capture the heating or cooling demand. Which is needed for these flows to be able to be part of the pinch analysis. However, another option is to analyse the energy from the secondary heating systems perspective. Where instead the energy demand is considered to be that which went into heating the waters initially. Seeing as the stream needs to be replaced by new addition of water, the method used in this report can underestimate the impact of the consuming flow on the system as a whole.

5. Results

5.1 Mapping of the secondary heating system

Mapping of the secondary heating system was performed by researching the mill flow sheets and operations system layout. An illustration of the system can be seen in Figure 7. Finding individual streams and following them from start to finish, noting which processes are connected and what individual part makes use of the flow. The demand from each process on average is extracted from the data. Both in terms of the HW and WW flow and temperature demand, but also the change in temperature sought after by the process. The final destination may be a return to the HW- or WW-cisterns, waste water treatment or consumption by processes. The HW- and WW-cisterns are seen as nodes in the secondary heating system, from which HW and WW flows in and out being utilised in different section of the production line.

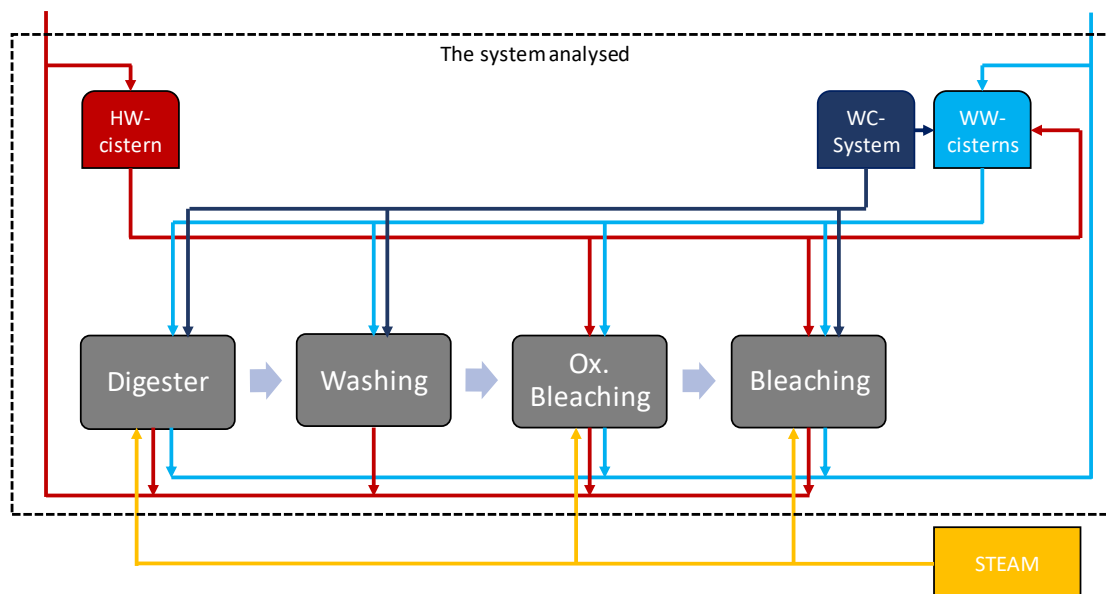


Figure 7: The water streams in the system analysed

5.1.1 Primary heating system

Primary heat is used in various processes in the mill and has been previously mapped out. Lowering steam usage directly facilitates greater production of electricity and ensures availability of steam for processes that absolutely require it. In the main pulp production line steam at gauge pressures of 1.4, 1.1 and 0.3 MPa are used and are henceforth denoted S14, S11 and S03. Higher pressure steam here holds a higher average temperature, meaning that the heating potential is greater for higher pressures. Steam addition to the pulp flow is done for various reasons throughout the mill, it is mainly added for temperature control reasons. As certain processes can be heavily temperature dependent. As can be seen in Table 1, most processes of the area analysed use 0.3 MPa steam. In processes that directly add the steam to the process it is consumed by the respective process, meaning that a corresponding amount of water has to be cleaned for safe use in boilers and turbines. The heat exchanger and condensation processes instead return condensate which can be reused, provided that it has not been contaminated in the process. The steam heat exchangers analysed in this report exclusively utilise steam to heat other flows in the mill. In this section the current steam usage will be showcased and potential misuses of steam are noted.

Digesters

S14 is added to steam mixers in which the steam controls the temperature and aids in the addition of chemicals to the pulp. Continuing with S11, it is used in the digesters where it is passed through the digester calorisers to add heat to the cooking process. Some S11 is also directly added to the digesters. It is also used in the oxygen bleaching where it is used for heating pulp to around 98°C and also helps in the addition of pulp treatment chemicals. S03 is used in the digesters where it is directly added to the processes. Final of the S03 consuming processes analysed in this report is the bleaching system where it primarily is used to heat the pulp. The digesters represent significant consumers of steam, it is both added into the digesters themselves and used for heat exchanging in connection to the digester. Steam added to the digesters is assumed to attain the digester pressure, which is assumed to hold at 7 bar. The start temperature, right before steam addition, is manually extracted from analysing the cooking cycles. Target temperatures are set to the reported target temperatures of the mill digesters. This is an attempt to more accurately capture the impact steam has on the digester process. Continuing there is a set of two white liquor heaters. Heat exchanger HE:D7 uses S03 to heat white liquor which is then stored awaiting further use. From the storage cistern, the liquor is either directly used in the digesters or sent to a second heating stage. Being heated in HE:D6, using S11, before the white liquor is used in the digesters.

Washing and bleaching

Continuing, steam passed through HE:B1 is used for heating HW, which is required for it to be used in bleaching washing press WP:B1. It technically consists of two units but can be treated as a single, unit, as they are of the same type and share inlet and outlet. While the temperature increase of the HW may seem insignificant, reportedly the temperature increase of the HW is not large enough. Meaning if no other heating source can be utilised, an increased amount of steam will need to be utilised to meet demand. S03 is used to heat washing water in HE:B7, for use in the bleaching filters. The bleaching stage in question is of special interest, as it is a process that both heats and cools two different washing water streams prior to use. The values for HE:B7 are based on a manual analysis of short-term data and the specification of the heat exchanger. According to the available data, the temperature increase required of the washing water is 5°C whereas the exchanger is specified to be able to support a temperature increase of 15°C. For calculation purpose it is assumed that the heating requirement is 1/3 of specification. The temperatures collected are seemingly quite constant and are therefore assumed to be representative of normal mill operation. On the surface, F:B2 represent possible

misuse of either primary heat, secondary heat or possibly both. However due to the specification of F:B2, the cooling prior and heating afterwards are both required. Pulp production and controlling its quality is, after all, the main priority of the mill. The cooling demand is due the specifications of F:B2, while the subsequent steam heating is due to the remaining bleaching processes demanding higher temperatures. HW for heating HE:B7 could possibly be considered to a certain degree, possibly in combination with a small amount of steam in order to lift the HW temp when required.

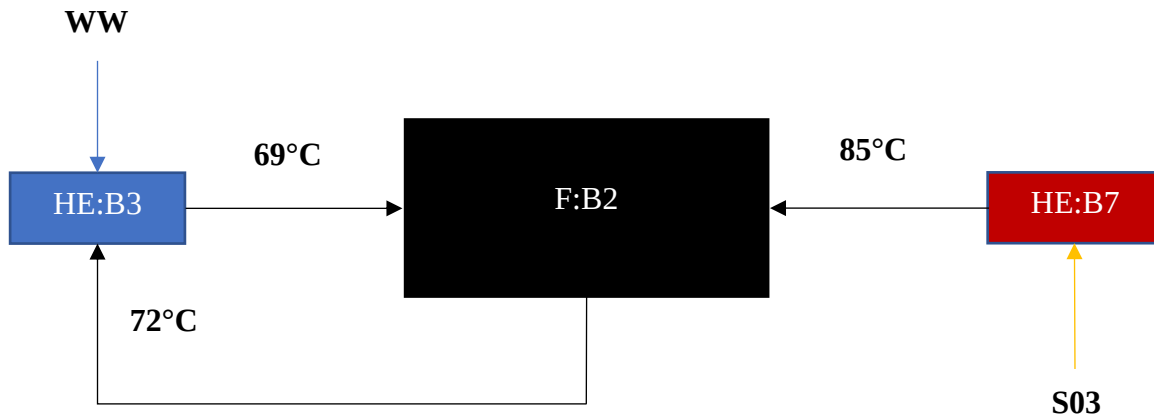


Figure 8: Illustration of the bleaching filter washing water streams. The washing water in HE:B7 is heated using steam while the washing water stream in HE:B3 is cooled with WW.

Ventilation condenser and remaining heaters.

As there is an excess amount of steam during the writing of this report, there is a significant amount of steam ventilation. The ventilation condenser is used to produce HW which, as the report is able to show, is largely unnecessary at the moment. As there are several processes that already provide large quantities of HW. While it is preferable if the condenser is not used, it can be important as back-up should there be a sudden lack of HW. The impact of not using the condenser is twofold. Not only is less HW produced, resulting in less HW overflow, but also less WC needs to be provided to the mill. The benefits of reducing additional production of WC has been stated in earlier chapters. HE:C2 and HE:C3 both use small amounts of S03 to heat condensate above 80°C, similarly the HE:WCC uses S03 to lift the temperature of WCC. While the temperature changes in these exchangers seems to be small on average, the amount of condensate and WCC that requires heating is large, thus there is not an insignificant heating demand from the units. When looking into the possible replacement of steam with HW for the previous three exchangers the amount of HW needed and temperature requirements in comparison to the availability is going to be carefully considered. This will be covered more in section 5.3.

Process	S14 (MW)	S11 (MW)	S03 (MW)
T [°C]	207	193	155
Digesters	-	13.4	6.6
Washing and bleaching	6.3	2.4	5.6
WCC	-	-	2.5
Condensate	-	-	2.0
White liquor Heating	-	6.2	2.9
HW production	-	-	5.5
Total [MW]	6.3	22.0	25.1

Table 1: Steam consumers analysed in the report.

5.1.2 Digester system

The digester system has been found to require a significant amount of cooling, as is seen in Table 2. A majority of the digester processes that require cooling use WW, resulting in the digester system also being an important source of HW for the mill. The digester section also consumes significant amounts of steam as was shown in the previous section. White liquor cooler HE:D1 is required to cool a significant amount of white liquor dropping its temperature from 87.8 to 81.0°C, resulting in WW being heated to consequently become HW. The use of HE:D2 will be initialised in 2025, therefore no data currently exists which means that the heat exchanger specifications will have to be used. Its role is the same as HE:D1, with the exchanger set to cool white liquor from 90 to 75°C by using WC. It is worth noting that the expected temperature of the cooling water is higher than its current average temperature. The cooling water temperature does vary over the year and the design WC temperature is considered representative of the summer months.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:D1	WW	24.2	41.8	80.8	-
	White Liquor	146.8	87.9	81.0	-
HE:D2	WC	23	20	45	HE spec.
	White Liquor	40	90	75	-
HE:D3	WW	66.8	40.7	92.9	-
	Black liquor	73.9	135.6	85.1	-
HE:D4	WW	77.8	41.9	88.0	-
	Black liquor	72.9	136.7	86.1	-
HE:D5	WW	76.9	39.8	93.9	-
	Black Liquor	74.8	136.8	84.4	-
Turpentine water trap	WW	0.3	41.4	-	-
	Turpentine	-	-	-	-
Prim. Turpentine Condenser	WC	1.5	11.6	82.3	-
	Turpentine	-	100.7	80.7	-
Sec. Turpentine Condenser	WC	1.5	11.6	41.5	Assumed
	Turpentine	-	80.7	58.4	-

Table 2: Digester secondary heating streams.

The black liquor coolers HE:D3-5 are connected to the warm water cisterns through two pipes from the WW-cistern. All exchangers are tube heat exchangers and can use either pipe as they are connected to one another. Enabling the three units to be treated as one. As the temperature difference between each of the WW-cisterns is extremely small, whichever pipe is used should

not be of any concern with regards to temperature. Water from the first cistern averages 41.5°C while the second one averages 41.8°C. The first liquor exchanger uses on average 66.8 l/s, the smallest average flow of the three, at an exit temperature of 94°C. The second exchanger uses a flow of 77.8 l/s and achieves a temperature of 88.0°C, the coldest outlet temperature of all the heat exchangers. Finally, the third heat exchanger has a flow of 76.9 l/s with an exit temperature of 93.9°C. During normal operations, one of the three exchangers is inactive, with totally 30MW of cooling required. Subsequently resulting in the same amount of heat being supplied to the secondary heating system, where it is a considerable source of HW with an average of 150 l/s at 90.6°C is supplied from the three units. The reason for running just two out of three units is because normal cooling demands from the mill can be fulfilled by just two units. Running all three reportedly reduces the black liquor flow to unacceptably low speeds, causing increased risk for blockage induced halting of production. Finally, we have three processes connected to the turpentine handling. The first is a water trap which uses a very small amount of water. The other two processes are turpentine condensers, which are connected in series and cool the turpentine in two steps. In total the turpentine is cooled from 100.7 to 58.4 with HW resulting from the primary condenser and WW from the secondary. The secondary turpentine condenser lacks flow measurement on the water side, but is assumed to use the same amount of WC as the primary.

5.1.3 Washing and bleaching system

Washing stage

The washing stage primary contributor to the secondary heating system is the black liquor cooler HE:W1. This black liquor has been used in a washing press stage and stored in a cistern. From there it is sent to the exchanger and cooled before being stored in another cistern. The heat exchanger is a tube exchanger using on average 21.3 l/s of warm water from the WW-cistern to cool weak black liquor. The WW used for cooling is heated, whereby it is classified as HW and is then sent to the HW-cistern. Both the temperature difference and flow size are kept decently constant over a year and the stop can be clearly filtered out from the results. The two remaining processes are WW and WC addition to the reject cisterns where the unwanted material that has been removed in the pulp filtering process is stored. Noteworthy is that reject tank 2 is a mixed stream of both WC and WW, hence the large difference between the cisterns.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:W1	WW	21.3	40.9	73.7	-
	Black Liquor	45.7	87.5	70.8	-
Reject tank 1	WW	0.2	41.5	-	-
Reject tank 2	WW/WC	6.1	-	-	WC/WW

Table 3: Washing stage secondary heating streams.

Oxygen bleaching

As covered in Table 4, heat exchangers OB1/2 are used for white liquor heating by use of hot water, which is returned to the warm water system. HE:OB1 uses 11.4 l/s with temperature dropping from 83.7 to 78.2°C whereas HE:OB2 uses 15.7 l/s with a temperature drop from 83.6 to 75.3°C. According to the operations system, these flows are then joined, together with water from heat exchanger HE:B3, and sent to the WW-cistern. These two heat exchangers represent an opportunity to achieve more efficient energy use, since the exchanger outlet temperature is significantly higher than the WW-cisterns. This will be covered in section 5.35.3.2. Heat exchanger HE:OB3 is used to cool white liquor by having it exchanged against WC at 13.0°C, which then is sent to the water processing section at 42.6°C. The exchanger unit consists of two exchangers that share inlet and outlet streams, and have therefore been treated as a single unit. The average flow through the exchangers is 56.0 l/s.

The remaining hot and warm water flows directed to the oxygen bleaching system are used for diluting and washing processes. These are all consumed by their respective processes and thus do not return to the secondary heating system. The hot water streams consumed by the oxygen bleaching system includes dilution of mass flow between the multiple washing stages and dilution of backwater and liquor. The dilution of the mass flow consumes 0.58 l/s on average over a year. This flow is only sporadically in use, as taking the average value for when it is in use results in an average flow of 14.7 l/s. The same follows for the dilution of backwater and liquor, with an average yearly consumption of 0.78 l/s, but on average 15.7 l/s when in use. Both flows are assumed to have a temperature of 84.4°C, the same temperature as the water in the HW-cistern.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:OB1	HW	12.4	84.7	79.1	-
	White liquor	39.8	73.8	78.0	-
HE:OB2	HW	17.5	85.1	76.8	-
	White liquor	48.8	74.0	78.6	-
HE:OB3	HW	56.0	13.0	42.6	-
	White liquor	56.4	63.2	40.4	-
WP:OB1 – dilution	HW	0.6	84.4	-	-
	washing water	-	-	-	-
WP:OB1	HW	0.8	84.4	-	-
	washing water	-	-	-	-
WP:OB2	HW	0.6	84.4	-	-
	washing water	-	-	-	-
WP:OB2-dilution	HW	0.8	84.4	-	-
	washing water	-	-	-	-
White Liquor Reactor	WW	3.5	41.5	60.6	-
	(Oxidised) White Liquor	-	-	100.7	-
HE:OB4	WW	0.3	41.5	66.3	-
	Oxidised White Liquor	0.9	100.7	80.7	-
HW: Oxygen vaporiser	HW	0.5	84.4	62.3	-
	Oxygen	-	-	-	-
MgO/MgSO4	WW	0.4	41.9	-	-
	MgO/MgSO4	-	-	-	-

Table 4: Oxygen bleaching secondary heating system.

When there is a lack of backwater available for WP:OB2, for use directly in the washing stage and the pulp dilution stage, HW is used. These flows are calculated using the total flow to the washing and dilution stage and the opening degree of the HW valve connecting the HW to the washing water. The resultant flow of HW to WP:OB2 is similar in size to WP:OB1 which can indicate that the calculated flow is accurate. HE:OB4 and the White Liquor Reactor both use WW for cooling oxidized white liquor. The reactor has a cooling system within itself and the heat exchanger function as a cooler for the resultant oxidized white liquor. While the heat exchanger is easy to model in terms of heating and cooling, the reactor itself is more challenging. The white liquor in the reactor is both simultaneously heated, by the reactions occurring, and cooled by the reactor cooling system. For future pinch calculation purposes, the temperature change of the liquor is set to a drop of $\Delta T=10^{\circ}\text{C}$ in order to capture the fact that the reactor requires cooling. Calculating the actual cooling demand is done using the WW,

which means that the cooling demand will be accurately calculated despite the assumption regarding the reacting white liquor temperature change.

Bleaching

The two heat exchangers HE:B1 use condensation of S03 to heat HW which is then connected to the pulp flow after WP:B1 in two stages. The total flow of water to the heat exchangers is 26.8 l/s at an inlet temperature of 84.4°C assumed to be the same as the temperature in the HW-cistern. The HW exits at 87.7°C, resulting in an average temperature increase of 3.3°C. This is reportedly not enough, as the target temperature of the HW is 92°C which would either require more steam, or heating by use of another stream. HE:B2 is used for heating ClO₂ which is to be mixed into the pulp. This is the only instance in this study that WW is being directly for heating in the production line, meaning that this flow requires a sufficiently high temperature of WW in order to function properly.

The next unit in Table 5 below, HE:B3, represents an interesting case in terms of energy saving potential. The exchanger is designed to cool washing water from filter F:B2, which is then added to the pulp headed to the filter. According to the operations system there are 5 connections that can supply washing water to the pulp, but only one of the streams is cooled prior to addition. The temperature step of the backwater is also small, sitting at only 3.3°C on average. Steam is also added to the pulp both before and after adding the cooled washing water. A glance at the operations system indicates that this steam heated backwater flow holds a temperature around 85°C. This results in a peak temperature difference of on average 16.2°C between the different streams of backwater entering F:B2.

HE:B5 is a degassing condenser used as part of a bleaching tower. The condenser use is seemingly not according to original specifications. As the expected WC temperature is higher than the real temperature of WC. It is also set to be heated to a higher temp than is achieved today. This could speak of inefficiencies present or just a change of demands from when the condenser was dimensioned. Finally, there are the flows that are consumed by the pulp bleaching process. F:B1, WP:B1 and WP:B2 all use HW for washing out unwanted substances from the pulp. The HW is going to be reused as washing water after the processes, but will then be considered outside the scope of this report. WW is used for dilution of acids, also set for use in the main line process. The HW use here amounts to 97 l/s, meaning that such an amount needs to be produced to replace it, initially by producing new WC.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:B1	HW	34.1	85.4	87.3	-
	S03	-	155.3	155.3	Spec.
HE:B2	WW	14.9	41.5	37.2	-
	ClO ₂	3.9	21.8	35.6	-
HE:B3	WW	19.2	40.7	49.3	-
	washing water	84.0	72.1	68.8	-
HE:B4	WC	4.6	11.6	-	-
	washing water	Finns	Saknas	Finns	-
HE:B5	WC	16.7	11.6	32.9	-
	Evac. Gas	-	100	90	Spec.
F:B1	HW	33.8	88.0	-	-
	Pulp	-	-	-	-
WP:B1	HW	29.6	85.0	-	-
	Pulp	-	-	-	-
Bleaching stem	WW	8.2	41.5	-	-
	Spare acids	-	-	-	-
WP:B2	HW	33.6	85.6	-	-
	Pulp/washing water	-	-	-	-

Table 5: Bleaching section secondary heating streams.

5.1.4 HW and WW cisterns

The HW and WW cisterns serve as a hub for the secondary heating system, being the link between production and consumption of HW and WW. The cisterns also serve as backup for when there is a disruption in production of either HW or WW, where normal operation can be kept to a certain degree even during disturbances in individual systems. There is one HW cistern and two WW-cisterns, with the HW-cistern being able to heat the water in the WW-cisterns. The calculated total inlet and outlet flow of the cisterns relies on accurate information being available. Both regarding flow size and flow charts showing correct piping paths. Currently there are two different net flow calculations for the HW-cistern, they vary greatly from each other in the resulting value and are possibly misrepresenting the net flow from the HW-cisterns. This therefore means that operation have to rely on possibly inaccurate information. Ideally, this report can provide the groundwork for better information on the secondary heating system to be available for the operations team.

There is an excess of HW produced by the mill resulting in the HW-cistern frequently overflowing. On average the cistern receives 370.7 l/s while letting out 238.5 l/s for use. Meaning there is an availability of 132.2 l/s for use in the mill. As it stands now, the overflow is either used in the production of WCC, but if the HW production is too large it will simply be sent to the waste water treatment system. This not only means that the energy content of the HW is wasted, it also negatively affects the waste water treatment system by increasing temperatures to unwanted levels. Furthermore, the HW is ultimately perfectly clean for its current usage, sending it to treatment means that new freshwater needs to be extracted and cleaned. Minimising overflow represents not only an economical improvement, by lowering water cleaning costs, but also a reduction of the mill freshwater consumption. While the data indicates an average temperature of 84.4°C in the cistern, seemingly there has been an increase

in temperature since 2024 toward approximately 90°C on average. The effect of higher temperature HW will be discussed further in section 6.

Inlet flows	Average flow [l/s]	Temperature In[°C]
Prim.Turpentine condenser	1.5	82.3
HE:D3	66.8	92.9
HE:D4	77.8	88.0
HE:D5	76.9	94.0
White Liquor Oxidation	3.8	60.1
HE:D1	24.2	80.8
HE:W1	21.3	73.7
Ventilation condenser	19.3	79.8
Average Inlet	370,7	-
Outlet flows	Average flow [l/s]	Temperature Out[°C]
WP:B2	33.6	84.4
O2-production	0.5	84.4
Evaporation system	20.9	84.4
WW-cistern	35.5	84.4
Space heating	0.1	84.4
CIO2 reactor	0.29	84.4
F:B1	33.8	84.4
WP:B1	29.6	84.4
HE:OB1	12.4	84.4
HE :OB2	17.5	84.4
WP:OB2	0.58	84.4
WP:OB2-dilution	0.78	84.4
HW-Stems	Average flow [l/s]	Temperature Out[°C]
Stem 1	33.8	84.4
Stem 2	71.9	84.4
Stem 3	33.6	84.4
Stem 4	29.9	84.4
Average Outlet	238.5	84.4

Table 6: HW cistern flows.

While the HW-cistern frequently overflows, the WW system instead suffers from a lack of water. It is imperative that there is WW available for use in the factory, since one of the most important uses of warm water is to satisfy the mill cooling demand. Therefore, there is significant flow of both WC and HW directly to the cistern in order to sustain WW availability and keep it at correct temperature. As can be seen in Table 7, the average inlet amounts to 174.7 l/s while the outlet is 213.4 l/s resulting in a delta of -38.8 l/s. This indicates that there is a lack of WW available for the mill. There are streams that currently could be deposited in the WW system, helping keep the availability of WW high to meet cooling demands of the mill. These two streams come from HE:OB3 and the evaporation section of the mill respectively and are both used for WCC production. The evaporation section water was thought to run the risk of being contaminated to such degree that it would not be useable in the secondary heating stage. However reportedly this is not true, as the mill measures the cleanliness of this water and have found it to be good enough for the secondary heating system most of the time. These two streams amount to an average flow of 130 l/s of WW which would result in a lower requirement of new production of WW from WC. However, since the flow is also used in WCC production,

a decreased flow to WCC would result in more WC needed to facilitate the WCC production requirements. As the mill consumes certain amounts of water in the processes, it follows that new addition of freshwater will to a certain degree be required. The HW overflow is also sent to the WCC section, which can be seen in the mill data as significant temperature increases of the WCC.

Inlet flows 1	Average flow [l/s]	Temperature In [°C]
WC to WW-Cistern	110.5	11.7
HW to WW-Cistern	35.5	84.4
HE:B4	4.6	
HE:OB1	12.4	79.1
HE:OB2	17.5	76.8
HE:C1	20.5	53.3
HE:B5	16.7	32.9
Inlet flows 2	Flow [l/s]	Temperature In [°C]
Sec. Turpentine condenser	0.14	41.5
HE:D2	23	45
Average Inlet (Both Cist.)	174.7	-
Outlet flows 1	Average flow [l/s]	Temperature Out[°C]
HE:B2	14.9	41.5
MgSO ₄	0.4	41.5
Stem. Bleaching 1	8.2	41.5
Ox. White Liq. /HE:OB4	3.2	41.5
Stem. Bleaching 3	19.2	41.5
HE:W1	21.3	41.5
Reject Tank 2	6.1	41.5
HE:D3-4	144.6	41.5
HE:B3	19.2	41.5
Outlet flows 2	Average flow [l/s]	Temperature Out[°C]
Reject Tank 1	0.2	41.4
HE:D5	76.8	41.4
HE:D1	21.7	41.4
Turpentine Water Trap	0.3	41.4
Average Outlet (Both Cist.)	213.4	-

Table 7: WW cistern flows

5.1.5 Scrubber system

The one component analysed was the flue gas scrubber, seen illustrated in Figure 9. Since the scrubber is to a certain extent an isolated sub-system in relation to other sub-systems it was analysed early on as an introduction to the systems of the mill for the author. The reason for its isolated HW system is that the scrubber significantly contaminates the water used, as it comes into direct contact with flue gasses. The primary role of the scrubber is to wash flue gasses using cold water in three spray stages. Only the first two are considered as the third stage is part of another water system, thus not considered a part of the scrubber secondary heating system. The first stage is split into two spray water spray stages. The water has been measured at 37°C and an average flow of 155.7 l/s. This water is then collected, removed from the scrubber and sprayed into the scrubber once again at an average flow of 118.8 l/s. The water is once again recollected and sent to a water tank. From the water tank, some water is recirculated into the scrubber. The rest remains either stored in the cistern, or pumped out for use.

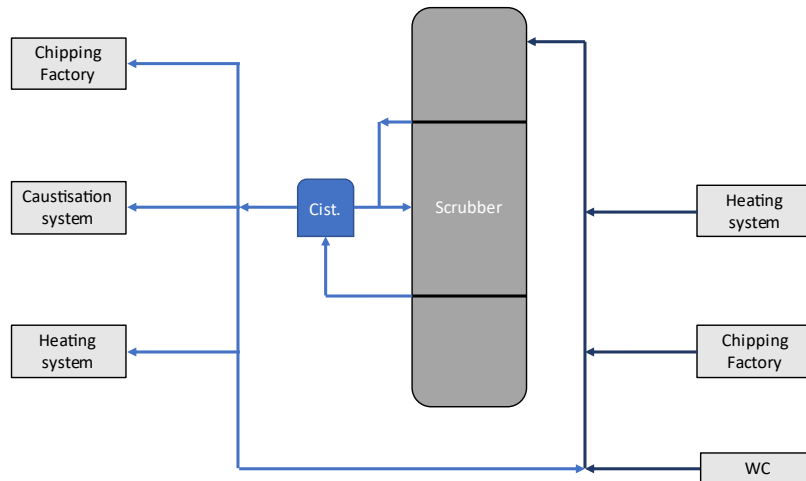


Figure 9: The Scrubber water system

Exiting the scrubber water tank, the flow is split into three stems with one pump per stem. The first stem supplies water for the space heating system through two heat exchangers. The first exchanger, is used to heat a water-glycol mix from target temperatures 38 to 55°C and is active with a flow of 32.3 l/s passing through. The second one is reportedly only used during stops, when excess steam is unavailable for heating, heating a water-glycol mix from target temperatures 45 to 60°C. As the excess steam is set to decrease, it was suggested that this exchanger can be used more frequently. The scrubber system is currently able to supply 37.8 l/s which is more than the calculated max flow demand from the exchanger at 23.9 l/s. The exchanger demands water at 70°C, slightly warmer than the scrubber is currently able to supply. Overall, the scrubber system should be able to supply 1.4MW of heat. The second stem treats the heating of chipping factory, causticizing and recirculation to the scrubber. The flow to the chipping factory consists of two pipes with an average total flow of 64.0 l/s, which is returned to the scrubber inlet flow at an expected 29°C. This flow is used for heating in the chipping factory. A flow of 43.9 l/s is directed to the causticizing which is connected to multiple other systems but, according to the operations system, all of the flow is directed to the causticizing system. The remaining flow of exiting the cistern 37.8 l/s is now returned to the scrubber inlet flow.

Inlet flows	Average flow [l/s]	Temperature In [°C]	Notes
Chipping factory heating	64.0	29	Spec.
WC	21.8	11.6	-
Scrubber recirculation	118.8	-	-
Heating system	32.2	38	Spec.
Total Scrubber Inlet	155.7	35	Measured
Outler flows	Average flow [l/s]	Temperature Out [°C]	Notes
Chipping factory heating	64.0	67	-
Caustisation	43.9	67	-
Recirculated to WC	37.8	67	-
Heating system	32.2	67	-

Table 8: Scrubber water.

5.2 Pinch analysis

With data points collected, the pinch analysis can now be performed. The streams have been separated into hot and cold streams, in essence separated by whether the stream requires heating or cooling. This is shown in Table 9. With these the composite curve can be created showcasing the hot and cold streams, shown in red and blue respectively, and graphically showing the minimum hot and cold utilities. The section analysed has minimum cold utility of 7 MW and respective minimum hot utility of 14 MW. The total recoverable heat between the hot and cold streams amounts to 42 MW of which to a certain extent is already being recovered, in some parts via the secondary heating system. The pinch point occurs at the end of the hot stream curve, at circa 132°C. Observed here is the large influence from HE:D3-5 which is a dominant part of the hot streams. Unless specific streams are matched, as is the ideal solution of the pinch analysis, utilising the intermediary HW and WW streams is more feasible. Meaning that reasonable recovery is limited to a smaller range where the HW and WW streams can feasibly be used.

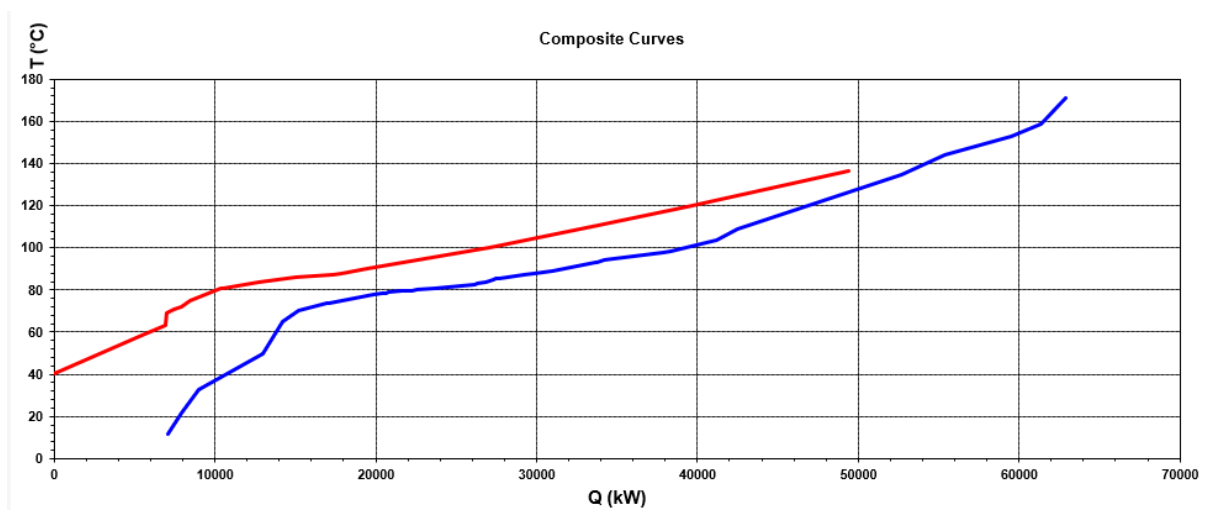


Figure 10: The composite curves.

Also created is the grand composite curve, which more clearly shows the pinch point at 132°C while also showcasing areas of potential energy savings. There are pockets of energy savings indicating that there are possible energy savings in the mill. Looking at the bottom of the grand composite curve, the first pocket of saving occurs in the heating of the coldest streams. One large stream to consider here is the heating of WC using a steam condenser, which will be covered in the following section. There are also pockets in the 60-70°C and one large section between 80-120°C region. In this last section, the heat from the black liquor coolers is available to be recovered which will be covered more in the retrofitting section. The 60-70°C interval, and to a certain extent the 80-90°C segment indicates specific smaller amounts of heat recovery possible. This is a temperature interval where several streams are present, meaning that many small streams could be optimally matched to one another. However, when considering realistic efficiency optimisations, some savings might not be feasible. Looking at the curve, the pockets of heat recovery show possible internal heat recovery of upwards of 12 MW. Which can be recovered by exchanging streams internally in the mill, or disconnecting of certain heating and cooling streams. Possible energy efficiency savings and the feasibility of them will be covered in the next section.

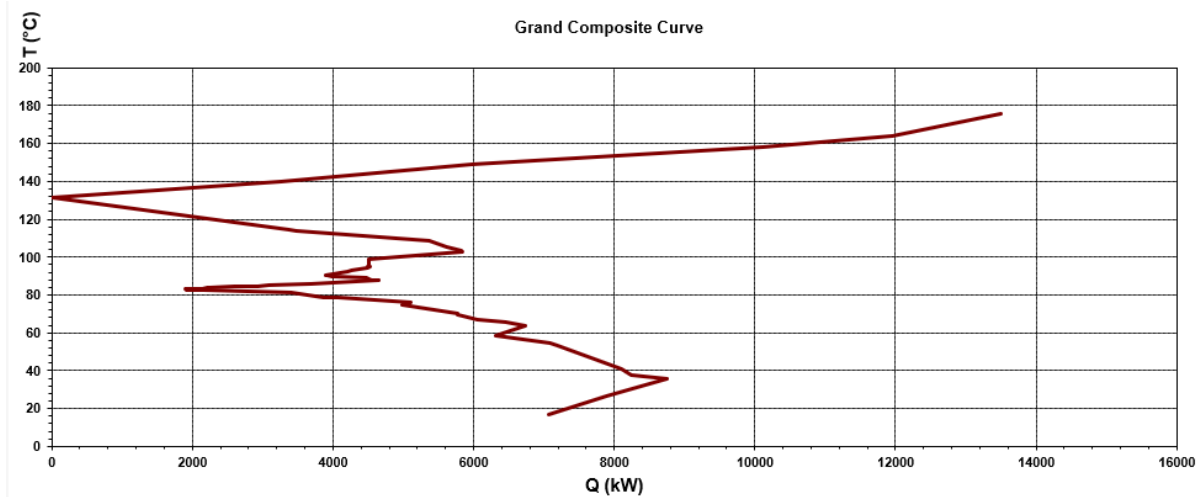


Figure 11: The grand composite curve.

As for the pinch violations, there are several instances of pinch violations present, however the possibilities of matching these streams can be questioned. For the hot streams the black liquor cooling process represents the main pinch violation by heat transfer through the pinch. The temperature of black liquor entering HE:D3-5 sits just above the pinch temperature and due to the large demand from the black liquor cooling system it is hard to see possible individual stream matching solutions. The main possible solution is then to utilise some of the heat available, slightly cooling the black liquor. The steam usage in the pulping process largely comes down as pinch violations as well, due to the heating of 85-100°C streams to temperatures both above and below the pinch. In the case of the digesters the target temperature is above the pinch temperature whereas for the pulp heating the temperature is below the pinch. Further analysis of these streams will be discussed in section 5.3.4.

Name	Hot/Cold	Start T (°C)	Target T (°C)	Demand (kW)	Medium
HE:D1	Hot	87.9	81	3916	WW
HE:OB3	Hot	63.2	40.4	6927	WW
HE:B3	Hot	72.1	68.8	684	WW
HE:W1	Hot	87.5	70.8	2898	WW
HE:D3-5	Hot	136.7	86	30048	WW
Prim. Turpentine condenser	Hot	119.7	83.5	548	WC
HE:OB4	Hot	100.7	80.7	31	WW
White Liquor Reactor	Hot	110.7	100.7	277	WW
HE:B5	Hot	100	90	1488	WC
HE:D2	Hot	90	75	2400	WC
Sec. Turpentine condenser	Hot	83.5	58.4	187	WC
HE:OB1	Cold	73.8	78.0	282	HW
HE:OB2	Cold	74.0	78.6	590	HW
HE:B1	Cold	85.4	87.3	264	S03
HE:B2	Cold	21.8	35.6	265	WW
Ventilation condenser	Cold	11.6	79.8	5504	S03
HE:C1	Cold	32.9	49.9	2587	HW
HE:WCC	Cold	70.1	78.4	2547	S03
HE:C2	Cold	78.8	80.7	741	S03
HE:C3	Cold	79.4	83.8	1212	S03
HE:D6	Cold	109.2	153.1	6157	S11
HE:D7	Cold	64.9	93.4	2946	S03
HE:B7	Cold	80	85	408	S03
S14:Mixer 1	Cold	83.0	89.7	1292	S14
S14:Mixer 2	Cold	85.7	103.9	5045	S14
Mixer (S11)	Cold	85.1	89.2	509	S11
S11: Oxygen Bleaching 1	Cold	93.3	98.6	477	S11
S11: Oxygen Bleaching 2	Cold	94.2	97.9	1386	S11
S03: Bleaching	Cold	78.0	82.7	3626	S03
S11: Digester	Cold	144	159	2766	S11
S11:Digester - Calorisator	Cold	88	171	10672	S11
S03:Digester	Cold	85	144	1942	S03
S03:Digester	Cold	85	135	4613	S03

Table 9: Hot and cold streams for pinch analysis, including the medium used for heating/cooling.

5.3 Utilisation and energy savings

As can be seen in both in the mapping section and in the pinch-analysis, there are energy savings available in the current system. The feasibility of swapping heating or cooling medium to a more efficient option will be of great concern. In ideal scenarios, two streams could be perfect to exchange in terms of flow and temperatures. However, the streams could be in completely different parts of the facility, making it an unfeasible alternative. The role of the secondary heating system can be considered as the link between the process streams. There will be limitations to this as well, as secondary heating streams cannot always perfectly matched either depending on where heating or cooling is done in the mill. A limitation is then caused to the mixing of different temperature HW and WW streams in the cisterns, resulting in them attaining a shared temperature. Meaning that some are cooled, which is affecting the HW system negatively, whereas others are heated, negatively affecting the WW cistern. This section will attempt to showcase some reasonable options for primary heat replacement and improved secondary heat usage. While also showing options that currently may not be feasible, but could be in the future.

5.3.1 Primary energy savings

Primary energy savings directly corresponds to steam savings, meaning that availability for turbines and processes that require steam is ensured. There is an economical aspect to saving steam, as the electricity produced with steam result in monetary gains for the mill. The profit from the reduced process steam consumption is dependent on electricity price development, as reduced process steam increases electricity generation possible. Showing the savings in terms of MW will represent a more permanent measurement of energy saved, although changes to the pulping process will result in subsequent changes in the HW and WW system.

Ventilation condenser

The ventilation condenser creating HW from WC is set to not be used once the new condensing turbine has been installed. This will result in savings of 5,5MW of primary heat while also reducing HW production by 19.3 l/s which is currently not of any concern for the mill HW system. As shown, there is significant excess of HW at the moment with more than 100 l/s available, from which it follows that there are other HW producers in the mill well able to cover this deficit.

5.3.2 Secondary energy savings

Black Liquor Heat Exchangers

Shown in the pinch analysis is the significant recovery possible by utilisation of the black liquor coolers. The primary concern for the mill is however is ensuring that the temperature of the black liquor reaches its target and that the kraft recovery cycle operates without disturbances. This means ensuring that consistent cooling of the black liquor can be provided. As the three black liquor heat exchangers provide a significant amount of HW at somewhat higher temperatures than the other HW streams. It could be feasible to use these for district heating which, as previously mentioned, is an important role of the mill. The mill currently uses another system for district heating. But as the mill can be subject to changes in the future keeping other alternative sources of district heating in mind can be important. As only two of the three exchangers are in use simultaneously, the possible heat provided according to the data amounts to 30MW. This is to enough to supply the current district heating system, dependent on seasonally specific flow and temperature demands. Important to consider is the inconsistencies in supply, as looking at Figure 12 there is several times during the year where there is no black liquor supplied to the HE:D3-5. This could be counteracted by having an accumulator tank in connection to the district heating system. Also, the black liquor coolers are important as a source of HW for the mill. Thus, if they are changed to be a part of the district heating system, other

sources of HW would be needed as otherwise the mill runs the risk of lacking HW. As mentioned earlier, HW is important in the pulping process.

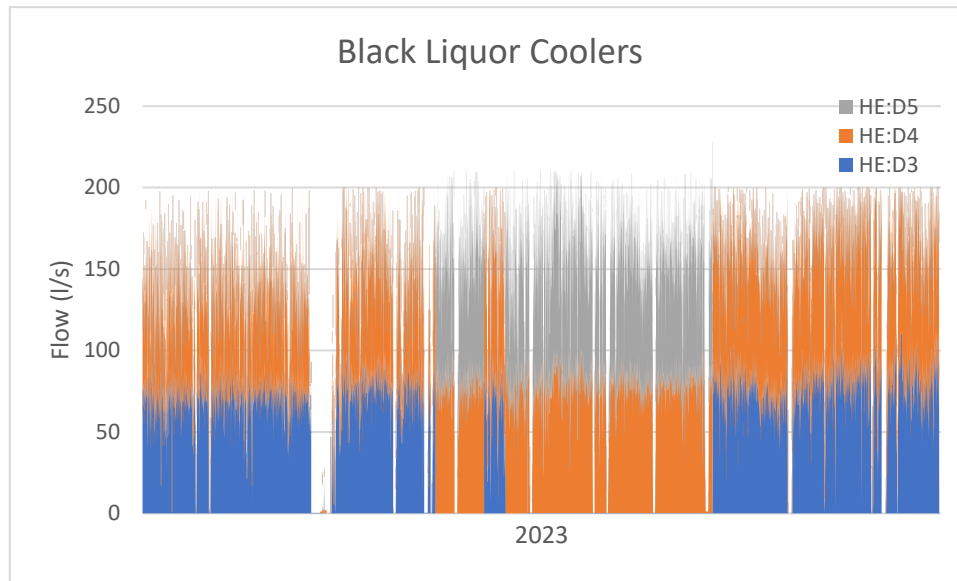


Figure 12: Operation of all three black liquor units.

Seen from the point of the secondary heating system, it would be advantageous if all HE:D3-5 would be in use simultaneously while the cooling demand from the mill remains. One of the three exchangers is around 2% smaller, but all three have the same heat transfer capacity. For calculation purpose they will be assumed to be equal in size. This means that heat transfer area is assumed to increase by 50% which, if the overall heat transfer capacity rate remains the same, corresponds to a decrease of the ΔT_{LMTD} by 1/3. Since the supplied temperatures of both cold and hot side remains and the target temperature of the black liquor remains, the only temperature subject to change is the outlet temperature of the cold medium. Solving the ΔT_{LMTD} equation for ΔT_1 , the final outlet temperature for the cold side comes to circa 117°C also corresponding to 68% less WW being required for cooling. The energy savings from less WW production required amounts to around 5.7 MW. There are feasibility concerns however, as the lower flow of black liquor increases fouling and increases the risk of blockages. These blockages stop normal production and increases maintenance costs for the heat exchangers.

As previously mentioned, the high demand from the exchangers result in difficulty in matching individual streams to the HE:D3-5 unit. Any use case will need to be able to make efficient use of the black liquor heat, as the main concern of the mill is to control the black liquor temperature. One possible direct use case could be replacing the steam in the digester calorisors. Looking at the stream heat capacity rates and considering the possible target temperatures, the calorisor becomes the limiting unit as it has a smaller heat capacity and can only use the heat from the black liquor while the circulation temperature remains within temperatures low enough. If the circulation temperature sits at the lowest temperature, the maximum possible heat recovery is 5 MW, where the circulation temperature increases from 88°C to 126°C. If the digester circulation sits at an elevated temperature, the steam savings will be smaller.

5.3.3 Utilisation of secondary heating

As was found in the mapping of the secondary heating system, there is significant excess HW which, unless something is changed in the mill, is under utilised as there are multiple possible solutions to increased HW usage. Increasing the HW outtake from the cisterns will be integral if the overflow is to be reduced, as it is known to disrupt the water treatment plant and to be a

waste of the energy of the mill which was recovered by the secondary heating system. Furthermore, the scrubber also currently produces an excess of hot scrubber water which will be showed to have immediate utilisation potential.

Heating using scrubber water.

The heat exchanger in the turbine cellar is used as backup to a steam heater used to provide hot water for the lockers. Since it is in use occasionally, and reportedly able to cover for the steam heater, it was suggested that it could potentially be used more often, if not at all time. In the flow scheme the heat exchanger is specified to be cooled from 70°C to 50°C on the hot water side, heating the glycol-water from 45 to 60 degrees. From specifications of the heat exchanger the maximum scrubber water required was found at 23.9 l/s which the scrubber is able to supply sufficient flow 80% of the time. Provided that the slightly lower scrubber water temperature can be accepted, the steam savings should amount to 1,3MW. Regarding the temperature, it falls below 65°C 14% of the time during the year, meaning that certain times during the year there will be higher steam demand. This is not the only area where scrubber HW is considered for use.

Bark drying

The mill is currently looking at installing a bark dryer and the question has been raised if HW can be used for the purpose. The heating demand from the dryer can currently not be met by any individual stream in the secondary heating or scrubber water system, meaning that any stream considered will require lifted temperature. Scrubber water is currently considered for this use in combination with S03 as heating medium. As it stands there is sufficient scrubber water to satisfy the dryer demands. To sufficiently supply the dryer temperature demand, the scrubber water requires 55% steam heating. Since the scrubber water has lower temperature than the HW system, and the excess of HW is much greater, this presents a potential HW use case. The feasibility for HW system connection depends on the specific placement of the dryer in the mill and the possibility of installing a connection to the HW cistern. Using the average HW temperature, assuming that the stream temperature is not significantly affected by the flow path, the steam heating demand amounts to 26%. Meaning that HW can therefore supply 74% of the total demand in comparison to the 45% supplied by the scrubber water. Taking into consideration the hotter HE:D3-5 HW stream at an assumed average of 90°C, using this would require only 16% of steam addition. Thereby covering 84% of the dryer heat demand. Using HW will therefore result in between 53-71% less steam used by the bark dryer in comparison to scrubber water. Once again also illustrating the value of lifted temperature in the HW system. If the average HW temperature is further increased it would result in further steam savings.

Increased pulp temperature

There is a significant amount of steam added to the pulp in order to regulate the temperature it holds. As different parts of the pulping process hold different temperature demands. Most of the pulp target temperatures are currently outside the possible scope of HW heating potential. There are areas where the pulp holds temperatures below HW average, thus here there could be steam saving potential by heating the pulp, at least partially, using HW. This could be done indirectly, by heating backwater and other streams set for addition to the pulp. Further analysis of the pulp additive flows would be required. Should these additive streams show to result significant cooling of the pulp heating the cold additive streams with HW could be considered in order to avoid lowered pulp temperature. Adding HW to the pulp stream, increasing its water content, would increase the pressing and evaporation demand which can negate any gain done by steam removal in this stage. Also, it can impact the chemical balance by increasing the water content. Thus, indirect heating is to be preferred here. While the mixers using steam are intimately linked with chemical addition to the pulp if the heat demand is only considered there

could be steam savings available. As for their demand, The oxygen bleaching and bleaching stages heat demand can as it stands now not be provided by HW. Due to the systems demanding temperatures above HW average. The heating demand in the pulp could maximally replace between 3.6, if only the bleach heating is considered, to upwards of 5.4 MW of steam heating. Dependent on whether or not the chemical mixers steam use can be reduced without concern for the chemical mixing impact.

5.3.4 Lifting the HW temperature

As has been showed, more processes can utilise HW if the temperature of the HW is increased. While using steam to this end may seem counterintuitive, however to meet specific demands by using steam to lift HW temperatures. The overall steam usage can be decreased as energy for heating is obtained from the HW system as well. Lifting the HW temperature to 105°C, in order to avoid unobtainable demands at stream temperature difference below $\Delta T_{\min}$, enables further HW usage potential. The choice of 105°C is currently based on the considered unit HE:B7 at peak load where the target temperature of the washing water is 95°C. For understanding the amount of steam required to heat the HW in order to meet the process demand showed below, the total demand from candidate streams needs to be known.

Condensate, WCC and washing water heating

HE:WCC, HE:C2-3 and HE:B7 all use steam for heating of WCC, condensate and washing water. From the temperature difference demand from the exchangers, it is clear that lifted temperature HW could possibly be used instead of steam. Replacing the HE:WCC steam with high temperature HW means that circa 2.5MW of heat needs to be provided by the new stream. As the current design relies on a steam condenser, a new unit needs to be installed which will have to be balanced against any steam saving profit found. The balancing act in replacing steam with high temperature HW for HE:C2 and HE:C3 is similar to the previous case. HE:C2 saves 0.7 MW and HE:C3 1.2 MW, resulting the two condensate heating units can save 2 MW of steam. Possibly simplifying the heating process if the units can be united into one single unit. In order to not violate the $\Delta T_{\min}$, set at 10K, the return temperature of the high temperature will need to be at 80,1°C for the WCC heater, 88,8°C and 89,4 respectively for the two condensate heaters. Returning these temperatures to the HW cistern would not constitute a problem. Unless a single condensate heater unit is considered. Washing water is both heated and cooled in F:B2 as previously mentioned. Looking at the current demands of the mill, the change from steam to high temperature HW as heating medium for HE:B7 would result in savings of 0,4MW. Possibly increased to upwards of 1,2 MW if the mill desires to further increase the washing water temperature. Either way, the outlet temperature would be 90°C with regards to $\Delta T_{\min}$ which once again can be returned to the HW system without concerns. In total these stream amount to a high temperature HW demand of 95.9 kg/s, which is less than the current HW has available in excess. Meaning that these processes can be partially heated by HW, and that the availability of steam is the limit.

White liquor heating

Similar to HE:B7, should the temperature of HW be lifted there will be increased possible savings of primary heat. For example, HE:D7 would facilitate savings of 3MW primary heat. Resulting in outlet temperature of at minimum 74.9 which while there are precedents to let this stream be deposited in the WW-system, the HW system is suggested as the better option.

Shown in Table 10 is the individual candidates for high temperature HW with their respective demand. Heating is assumed to be conducted by use of S03, as it is the lowest pressure and temperature steam available thereby being the preferred option. The demand of the high temperature HW comes to 8315 kW meaning that the saved steam comes to 0.3 MW. If the

already slightly lifted temperature from HE:D3-5 is used, the steam demand drops to 5.8MW resulting in 2.8 MW saved instead.

Process	Demand [kW]	T _{out} [°C]	$\dot{m}$ [kg/s]
HE:WCC	2547	80.1	24.3
HE:C2	741	88.8	10.9
HE:C3	1212	89.4	18.4
HE:B7	1200 (400)	90	19.0
HE:D7	2946	74.9	23.3
Total	8647	-	95.9
HW at average	8315	-	-
HW from HE:D3-5	5817	-	-

Table 10: High temperature HW demand from suggested units.

5.4 Extendsim

In order for the secondary heating system to become a part of the simulation, it first needed to be mapped out. In the current model there are some flows of HW and WW showcased, but there are other HW and WW streams and consumers not showcased. Most notably, the HW and WW cisterns were not. All three cisterns have now been modelled up and added, with missing parts of the secondary heating system also added when possible. While not simulation ready yet, the structure is now there for future simulation purposes.

6. Discussion

HE:D3-5 is an important part of the secondary heating system providing large quantities of HW at higher than average temperatures, while of course performing its primary role as black liquor coolers. The coolers can be kept in mind should future district heating demands increase, as the units could be utilised to provide 30 MW of water at temperatures sufficient for district heating. These exchangers are at current operational conditions over dimensioned for the role they perform. To that degree that if the maximum heat transfer rate reported is reached, almost all the black liquor flowing through today could be cooled in a single unit. While ideally for the secondary heating system, all three should be used simultaneously this is not believed to be feasible. Lower black liquor flow would cause fouling and blockages which disrupts normal operations. The advantage of the current system is that it allows for great availability of black liquor cooling, with one unit always on stand-by. Future research could possibly show if mill operations could be improved with different black liquor coolers or if there is a possible change to current running conditions that would allow all three exchangers to be used simultaneously without causing an increase in blockages. Overall, the proposed changes to HE:D3-5 are generally not feasible at the moment. However, one current option is to directly utilise the higher temperature HW of the HE:D3-5 in the applications with target temperatures above the capabilities of the average temperature of HW. If the HW from the three units is further heated with steam to 105°C, it can be utilised in processes that currently consume steam. Resulting in eventual savings of 2.8 MW of steam. Which is considerably higher than if HW at average temperature is used.

In the pinch analysis energy pockets of circa 12 MW were found, while 42 MW in total was shown to be available for possible energy recovery by internal heat exchanging in the mill. Parts of the energy recovery pockets are indicated to be in the low temperature region, linked in large parts to the ventilation condenser. But certain amounts of energy is recoverable in 60-70°C and 80-90°C region specifically. The WC heating could be done by better matching with hot streams in the mill. Instead of using steam from the start, but seeing as it currently produces HW the usefulness of the work conducted by the ventilation condenser is questionable. For the current

possible steam savings, the ventilation condenser currently used for HW production can, without any concern for lack of HW, be removed. Since its main use is to ventilate the excess steam, which is set to be reduced, and the need for steam ventilation will be reduced to near zero it thereby causes the unit to become redundant. Saving a total of 5.5 MW without any new heat recovery unit needing to be installed. This represents the only process in the pulping section that can feasibly be shown to immediately reduce steam usage in the mill. There are however processes that with some tweaking and reconstruction efforts could reduce steam usage further.

Any specific stream analysis of the cisterns was not performed. However as can be observed, there are several significantly warmer streams entering the WW-cisterns, see for example HE:OB1 and HE:OB2. While these aid with regulation of temperature to circa 40-45°C, as the overwhelming majority of WW streams are used for cooling purpose it is possible that the savings of WW would be greater if the streams significantly hotter than the average WW-temperature were redirected. While directing these warmer streams to the HW cistern could be done, this would impact the heating potential of HW. Which as has also been noted is a very important role of the HW, with increased HW usage dependent on higher temperature HW possibly found in this report. In actuality, the HW temperature might already have been increased to circa 90°C on average, meaning that there has already been an increase. Meaning the heating potential of the HW system has been increased. Using steam for lifting the HW temperature increases HW usage by 95.9 kg/s making a solid dent in the current excess available. An intermediate level, around 60°C, cistern could be set up, reducing unnecessary heating and cooling of WW and HW respectively. Currently there are few if any processes that would benefit from this change and seeing as there is reportedly a lack of available space, a new cistern would not be beneficial. Finding specific use of these intermediate streams to either heat them so that they can reasonably be sent to the HW cistern. Or cooled enough to not heat the WW-cistern unnecessarily. The HW cistern suffers from the same problem, for example the significantly cooler stream from the oxidised white liquor cooling section enters the cistern. This stream is small, especially in comparison to the HE:D3-5 streams meaning that its impact on temperature should be kept at a minimum. This could indicate that the too hot streams entering the WW-cistern should possibly be redirected to the HW-cistern instead. Disconnection of connections to the WW-cistern increases the required WC addition to the WW-cistern to cover for the lost flow. This results in reducing the average temperature of WW, which could mean less WW is needed for each cooling process. Resulting in a possible overall decrease in WW-use, which would help in rectifying the current lack of WW experienced by the mill.

The scrubber system shows possible direct implementation of scrubber HW usage by always using a currently available heat exchanger. Amounting total steam savings possible of upwards of 1.3 MW. The experience at the mill is that the steam exchanger otherwise can sufficiently be replaced by scrubber HW. Further use of scrubber HW, mutually exclusive of the other alternative, for the bark dryer indicates that it can on average cover the flow demand from the dryer. However, due to the relatively low temperature of the scrubber HW, this would require steam heating. Using the normal HW system instead would reduce steam requirements further, and seeing as the flow available from the current HW-system is much greater this is a more reasonable option. The most optimal alternative would be to use the specific hotter HW stream from HE:D3-5, seeing as the flow demand can be covered by these streams and the higher temperature means lower steam heating requirements.

6.1 Conclusion

In conclusion, there is 5.5 MW of steam recoverable in the current pulping process removing unnecessary steam consumers. With a further 1.3 MW saved from increased scrubber HW usage. The 5.5 MW saved from the pulping process is less than the graphically indicated heat pockets found in the pinch analysis, which indicates further savings are possible. The pinch analysis does indicate the possibility of better stream matching with total heat recovery internally of 42 MW. With heat pockets indicating 12 MW of available energy recovery internally by stream matching in the current system. After analysing the system, it was discovered that the black liquor coolers could play a role in finding savings. As their heat could be possible by either direct utilisation or with its higher temperature HW. Heating the HE:D3-5 HW for use in cases where the HW temperature is currently too cold would save a further 2.8MW in comparison to 0.3 MW should average temperature HW be steam heated. Showing that more dedicated stream analysis and better matching of hot and cold streams can to a certain extent provide decent energy savings. With that knowledge, further changes to the cistern system can be understood as beneficial. As it could assist in achieving colder WW, which is mostly used for cooling, and higher average temperature HW, which is primarily used for heating. Resulting in increased possible HW usage. With the most reasonable option for the bark dryer being to use steam heated HW, providing 74% of the heating demand. Increased usage of HW directly facilitates less overflow which directly reduces cooling demand in the waste water treatment section and reduces the requirement for new water addition. While further savings are possible by more specific hot HW stream usage, the impact on the remaining HW system would need to be considered. Finding solutions to increase the average HW temperature by optimising the HW and WW cistern connections would lead more possible HW heating applications. As it stands, the current HW system is too cold for most cases of steam heating to be replaceable, as these cases require too high temperatures. If HW use is to be increased, it likely requires an average temperature increase.

6.2 Future studies

Since only part of the system was mapped out, there are going to be HW and WW usage not properly analysed in this report, as it is outside the scope. While these streams can potentially be mentioned in the chapter concerning the HW and WW cisterns, further analysis of these streams would be of interest for the mill. Also, it is possible that these non-analysed systems contain possible replacement of current heating and cooling mediums with HW and WW. For future projects in the mill, should target temperatures, dependent on if it is a heating or cooling process, of any system amount to 75-95°C, HW should be considered for the purpose. If the target temperature instead is 40-45°C the WW system should be considered. This then demands that the average HW and WW temperature remains at current levels, something that cannot be guaranteed. Setting up a simulation of the HW and WW cisterns with optimisation of stream connections could possibly further increase in energy savings.

IEA mentions industrial heat pumps as a tool in reducing emissions from the pulp and paper industry, it could be possible to install at the mill to lift the HW temperature for use in higher temperature applications. IEA acknowledge the potential for implementation of increased mill process heat usage by lifting the temperature of recovered heat using high temperature heat pumps [2]. Being able to make use of streams at 80°C as heat sources for other streams to reach higher temperatures at +100°C. Even having the capacity of producing steam for internal use, increasing possible waste heat utilisation [20]. From the system analysed, if enough steam at the same or similar temperature as S03 3, 155°C, can be produced from the HW system to cover the pulp line demand. This would further reduce demand from the current S03 system. The demand that can possibly be met by current high temperature heat pump technology and the accompanying energy cost of running it will have to be carefully analysed. Illustrating the

potential usage is if the pulp heating demand to be provided by HW used as a sink for generating steam for pulping process usage. This would open up for pulping process steam to be generated separately from the steam used in turbines.

Further research into more efficient black liquor heat exchangers could also be of interest of the mill, possibly for the pulp industry as a whole. As shown, there is significant potential savings in the black liquor cooling system when it is analysed without concern for the black liquor flow. Finding more efficient solutions for cooling black liquor would not only improve operational integrity by avoiding blockage induced production disturbances, but also mean a direct lower water usage for the mill. More optimised use of the warmer HW resulting from the liquor cooling could be useful for processes requiring heating to temperatures above current HW average.

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Appendix

Process	S14 (MW)	S11 (MW)	S03 (MW)
T [°C]	207	193	155
Digesters	-	13.4	6.6
Washing and bleaching	6.3	2.4	5.6
WCC	-	-	2.5
Condensate	-	-	2.0
White liquor Heating	-	6.2	2.9
HW production	-	-	5.5
Total [MW]	6.3	22.0	25.1

Table 11: Steam consumers analysed in the report.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:D1	WW	24.2	41.8	80.8	-
	White Liquor	146.8	87.9	81.0	-
HE:D2	WC	23	20	45	HE spec.
	White Liquor	40	90	75	-
HE:D3	WW	66.8	40.7	92.9	-
	Black liquor	73.9	135.6	85.1	-
HE:D4	WW	77.8	41.9	88.0	-
	Black liquor	72.9	136.7	86.1	-
HE:D5	WW	76.9	39.8	93.9	-
	Black Liquor	74.8	136.8	84.4	-
Turpentine water trap	WW	0.3	41.4	-	-
	Turpentine	-	-	-	-
Prim. Turpentine Condenser	WC	1.5	11.6	82.3	-
	Turpentine	-	100.7	80.7	-
Sec. Turpentine Condenser	WC	1.5	11.6	41.5	Assumed
	Turpentine	-	80.7	58.4	-

Table 12: Digester secondary heating streams.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:W1	WW	21.3	40.9	73.7	-
	Black Liquor	45.7	87.5	70.8	-
Reject tank 1	WW	0.2	41.5	-	-
Reject tank 2	WW/WC	6.1	-	-	WC/WW

Table 13: Washing stage secondary heating streams.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:OB1	HW	12.4	84.7	79.1	-
	White liquor	39.8	73.8	78.0	-
HE:OB2	HW	17.5	85.1	76.8	-
	White liquor	48.8	74.0	78.6	-
HE:OB3	HW	56.0	13.0	42.6	-
	White liquor	56.4	63.2	40.4	-
WP:OB1 – dilution	HW	0.6	84.4	-	-
	washing water	-	-	-	-
WP:OB1	HW	0.8	84.4	-	-
	washing water	-	-	-	-
WP:OB2	HW	0.6	84.4	-	-
	washing water	-	-	-	-
WP:OB2-dilution	HW	0.8	84.4	-	-
	washing water	-	-	-	-
White Liquor Reactor	WW	3.5	41.5	60.6	-
	(Oxidised) White Liquor	-	-	100.7	-
HE:OB4	WW	0.3	41.5	66.3	-
	Oxidised White Liquor	0.9	100.7	80.7	-
HW: Oxygen vaporiser	HW	0.5	84.4	62.3	-
	Oxygen	-	-	-	-
MgO/MgSO4	WW	0.4	41.9	-	-
	MgO/MgSO4	-	-	-	-

Table 14: Oxygen bleaching secondary heating system.

Process	Fluid	Flow [l/s]	T _{in} [°C]	T _{out} [°C]	Notes
HE:B1	HW	34.1	85.4	87.3	-
	S03	-	155.3	155.3	Spec.
HE:B2	WW	14.9	41.5	37.2	-
	ClO ₂	3.9	21.8	35.6	-
HE:B3	WW	19.2	40.7	49.3	-
	washing water	84.0	72.1	68.8	-
HE:B4	WC	4.6	11.6	-	-
	washing water	Finns	Saknas	Finns	-
HE:B5	WC	16.7	11.6	32.9	-
	Evac. Gas	-	100	90	Spec.
F:B1	HW	33.8	88.0	-	-
	Pulp	-	-	-	-
WP:B1	HW	29.6	85.0	-	-
	Pulp	-	-	-	-
Bleaching stem	WW	8.2	41.5	-	-
	Spare acids	-	-	-	-
WP:B2	HW	33.6	85.6	-	-
	Pulp/washing water	-	-	-	-

Table 15: Bleaching section secondary heating streams.

Inlet flows	Average flow [l/s]	Temperature In[°C]
Prim.Turpentine condenser	1.5	82.3
HE:D3	66.8	92.9
HE:D4	77.8	88.0
HE:D5	76.9	94.0
White Liquor Oxidation	3.8	60.1
HE:D1	24.2	80.8
HE:W1	21.3	73.7
Ventilation condenser	19.3	79.8
Average Inlet	370,7	-
Outlet flows	Average flow [l/s]	Temperature Out[°C]
WP:B2	33.6	84.4
O2-production	0.5	84.4
Evaporation system	20.9	84.4
WW-cistern	35.5	84.4
Space heating	0.1	84.4
CLO2 reactor	0.29	84.4
F:B1	33.8	84.4
WP:B1	29.6	84.4
HE:OB1	12.4	84.4
HE :OB2	17.5	84.4
WP:OB2	0.58	84.4
WP:OB2-dilution	0.78	84.4
HW-Stems	Average flow [l/s]	Temperature Out[°C]
Stem 1	33.8	84.4
Stem 2	71.9	84.4
Stem 3	33.6	84.4
Stem 4	29.9	84.4
Average Outlet	238.5	84.4

Table 16: HW cistern flows.

Inlet flows 1	Average flow [l/s]	Temperature In [°C]
WC to WW-Cistern	110.5	11.7
HW to WW-Cistern	35.5	84.4
HE:B4	4.6	
HE:OB1	12.4	79.1
HE:OB2	17.5	76.8
HE:C1	20.5	53.3
HE:B5	16.7	32.9
Inlet flows 2	Flow [l/s]	Temperature In [°C]
Sec. Turpentine condenser	0.14	41.5
HE:D2	23	45
Average Inlet (Both Cist.)	174.7	-
Outlet flows 1	Average flow [l/s]	Temperature Out[°C]
HE:B2	14.9	41.5
MgSO4	0.4	41.5
Stem. Bleaching 1	8.2	41.5
Ox. White Liq. /HE:OB4	3.2	41.5
Stem. Bleaching 3	19.2	41.5
HE:W1	21.3	41.5
Reject Tank 2	6.1	41.5
HE:D3-4	144.6	41.5
HE:B3	19.2	41.5
Outlet flows 2	Average flow [l/s]	Temperature Out[°C]
Reject Tank 1	0.2	41.4
HE:D5	76.8	41.4
HE:D1	21.7	41.4
Turpentine Water Trap	0.3	41.4
Average Outlet (Both Cist.)	213.4	-

Table 17: WW cistern flows

Inlet flows	Average flow [l/s]	Temperature In [°C]	Notes
Chipping factory heating	64.0	29	Spec.
WC	21.8	11.6	-
Scrubber recirculation	118.8	-	-
Heating system	32.2	38	Spec.
Total Scrubber Inlet	155.7	35	Measured
Outler flows	Average flow [l/s]	Temperature Out [°C]	Notes
Chipping factory heating	64.0	67	-
Caustisation	43.9	67	-
Recirculated to WC	37.8	67	-
Heating system	32.2	67	-

Table 18: Scrubber water.

Name	Hot/Cold	Start T (°C)	Target T (°C)	Demand (kW)	Medium
HE:D1	Hot	87.9	81	3916	WW
HE:OB3	Hot	63.2	40.4	6927	WW
HE:B3	Hot	72.1	68.8	684	WW
HE:W1	Hot	87.5	70.8	2898	WW
HE:D3-5	Hot	136.7	86	30048	WW
Prim. Turpentine condenser	Hot	119.7	83.5	548	WC
HE:OB4	Hot	100.7	80.7	31	WW
White Liquor Reactor	Hot	110.7	100.7	277	WW
HE:B5	Hot	100	90	1488	WC
HE:D2	Hot	90	75	2400	WC
Sec. Turpentine condenser	Hot	83.5	58.4	187	WC
HE:OB1	Cold	73.8	78.0	282	HW
HE:OB2	Cold	74.0	78.6	590	HW
HE:B1	Cold	85.4	87.3	264	S03
HE:B2	Cold	21.8	35.6	265	WW
Ventilation condenser	Cold	11.6	79.8	5504	S03
HE:C1	Cold	32.9	49.9	2587	HW
HE:WCC	Cold	70.1	78.4	2547	S03
HE:C2	Cold	78.8	80.7	741	S03
HE:C3	Cold	79.4	83.8	1212	S03
HE:D6	Cold	109.2	153.1	6157	S11
HE:D7	Cold	64.9	93.4	2946	S03
HE:B7	Cold	80	85	408	S03
S14:Mixer 1	Cold	83.0	89.7	1292	S14
S14:Mixer 2	Cold	85.7	103.9	5045	S14
Mixer (S11)	Cold	85.1	89.2	509	S11
S11: Oxygen Bleaching 1	Cold	93.3	98.6	477	S11
S11: Oxygen Bleaching 2	Cold	94.2	97.9	1386	S11
S03: Bleaching	Cold	78.0	82.7	3626	S03
S11: Digester	Cold	144	159	2766	S11
S11:Digester - Calorisator	Cold	88	171	10672	S11
S03:Digester	Cold	85	144	1942	S03
S03:Digester	Cold	85	135	4613	S03

Table 19: Hot and cold streams for pinch analysis, including the medium used for heating/cooling.

Process	Demand [kW]	T _{out} [°C]	$\dot{m}$ [kg/s]
HE:WCC	2547	80.1	24.3
HE:C2	741	88.8	10.9
HE:C3	1212	89.4	18.4
HE:B7	1200 (400)	90	19.0
HE:D7	2946	74.9	23.3
Total	8647	-	95.9
HW at average	8315	-	-
HW from HE:D3-5	5817	-	-

Table 20: High temperature HW demand from suggested units.

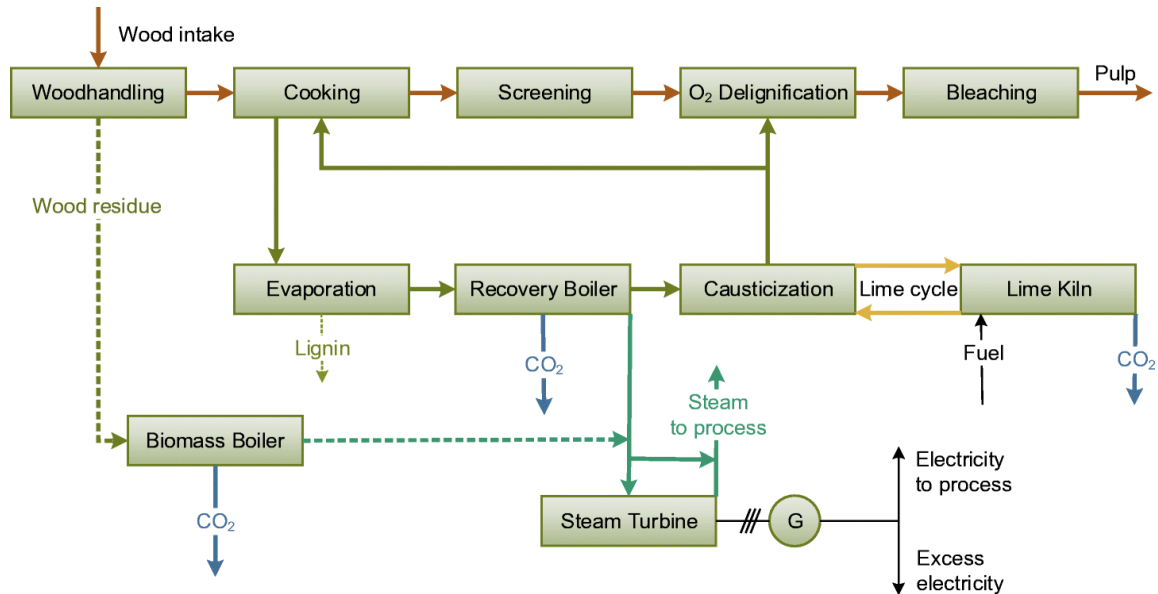


Figure 13: Kraft pulp mill overview with pulping, recovery cycles and electricity generation [3]. After the bleaching stage the pulp is ready to be dried. Note that washing stage and district heating is not shown in the figure, but is very much present in the mill analysed.

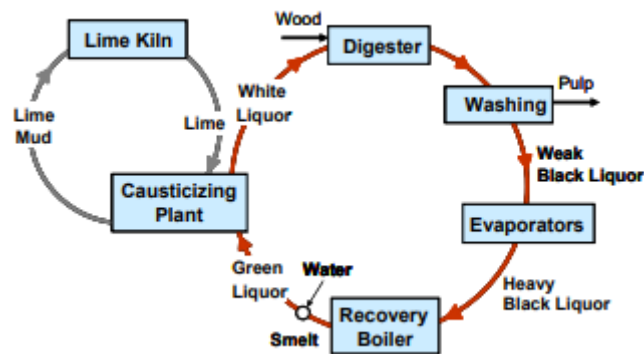


Figure 14: The Kraft recovery cycle [7] Note the presence of the washing stage after the digester.

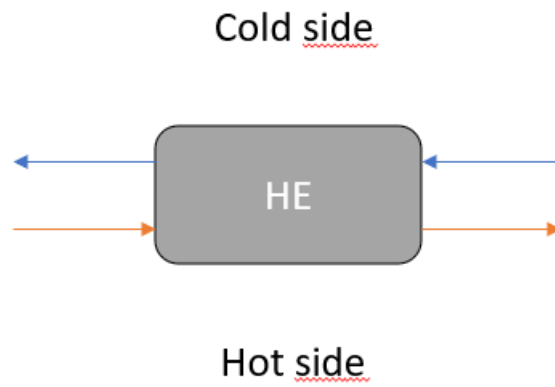


Figure 15: Illustration of a counter flow heat exchanger.

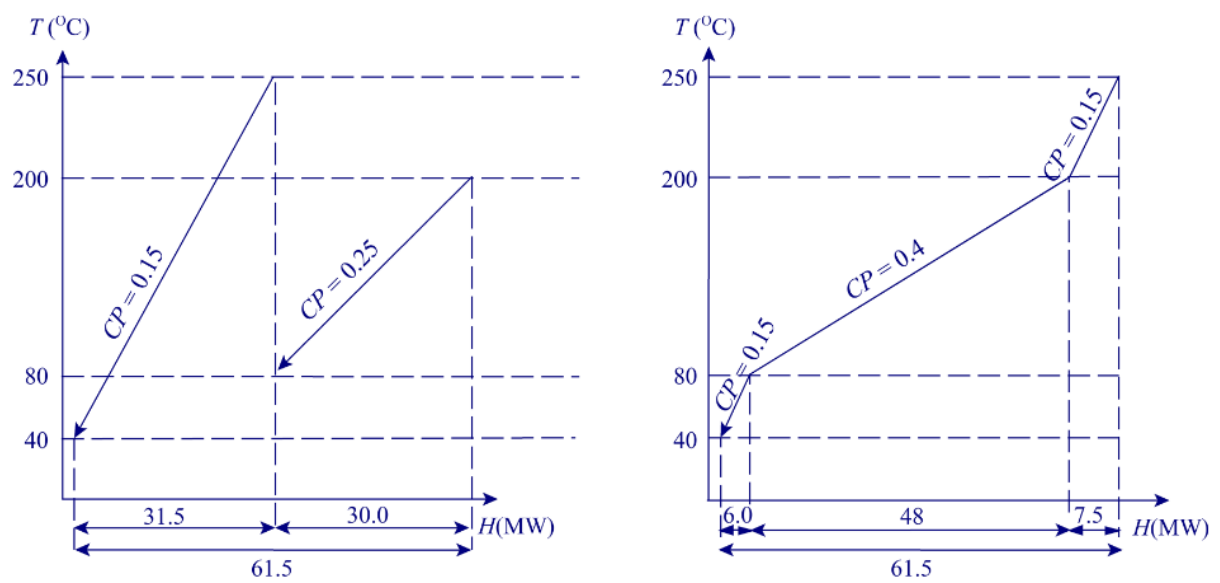


Figure 16: Individual streams and the composite curve formed from them [19].

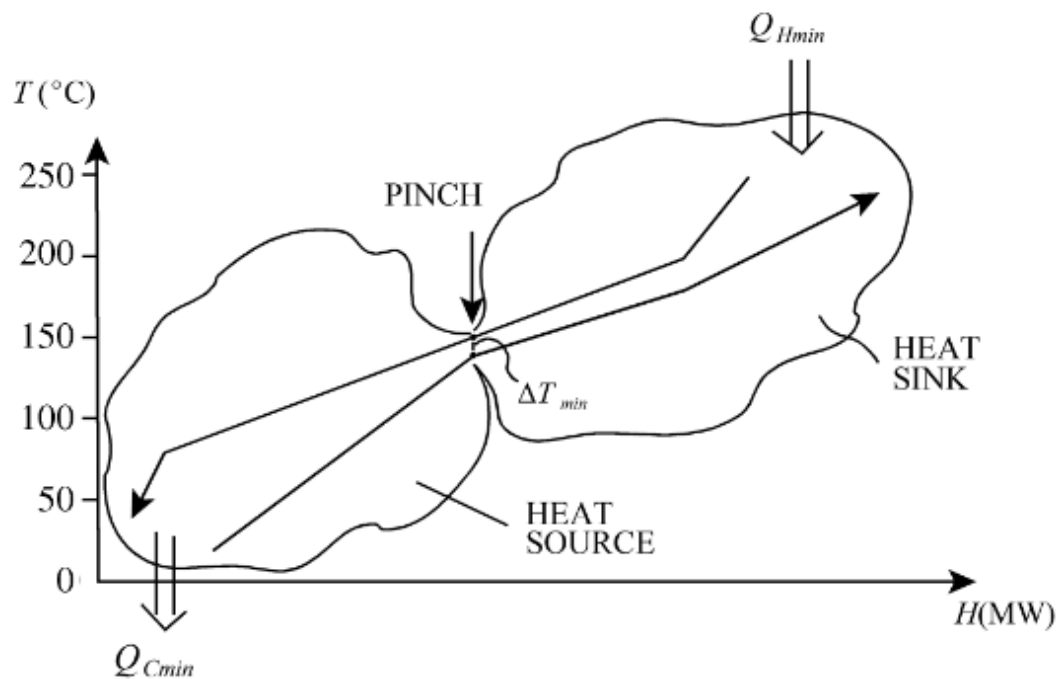


Figure 17: Composite curves and the pinch point separating the sink and source [19].

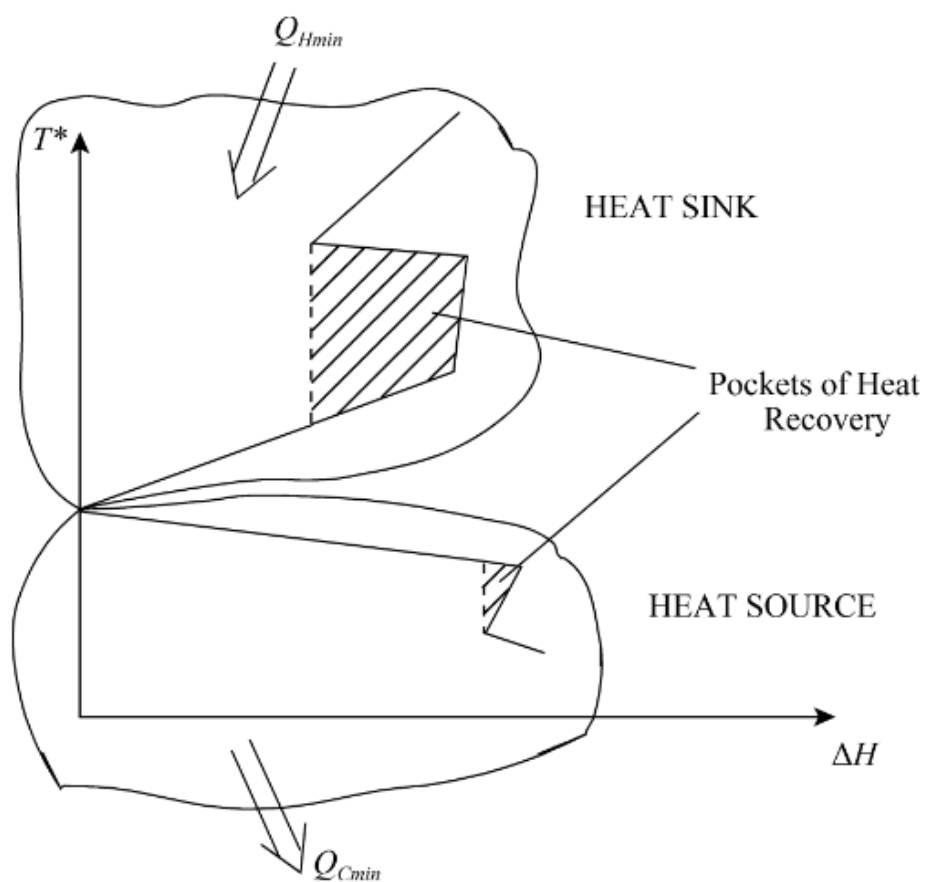


Figure 18: The grand composite curve, with energy recovery possible shown [19].

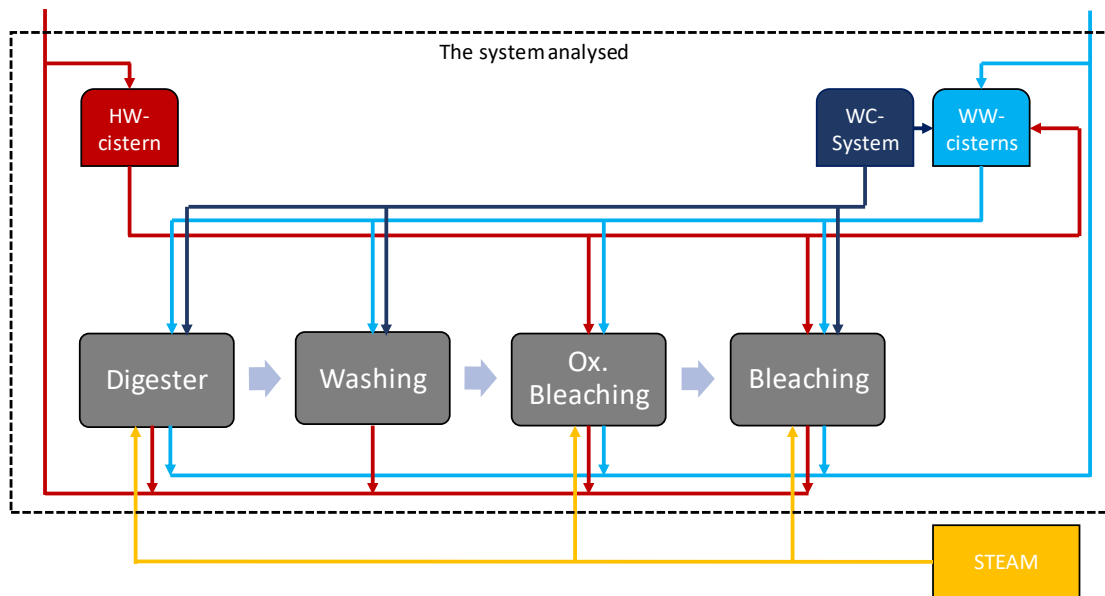


Figure 19: The water streams in the system analysed

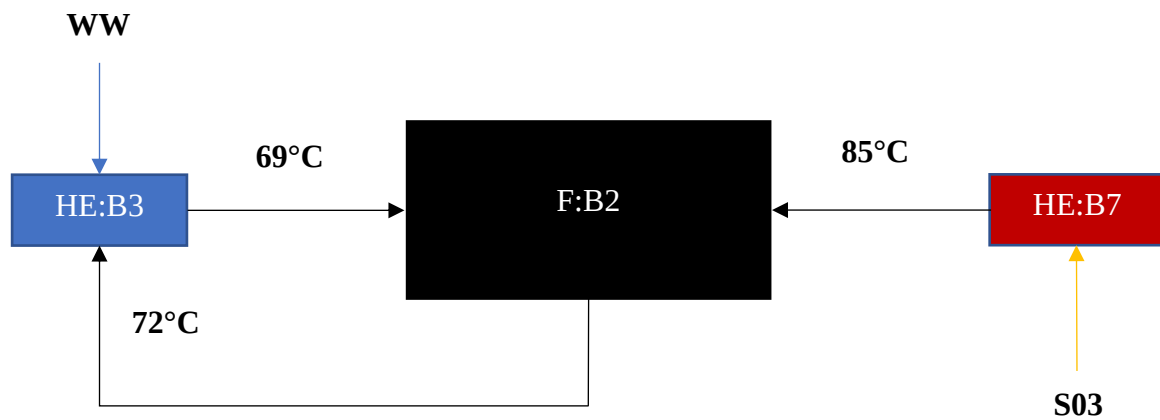


Figure 20: Illustration of the bleaching filter washing water streams. The washing water in HE:B7 is heated using steam while the washing water stream in HE:B3 is cooled with WW.

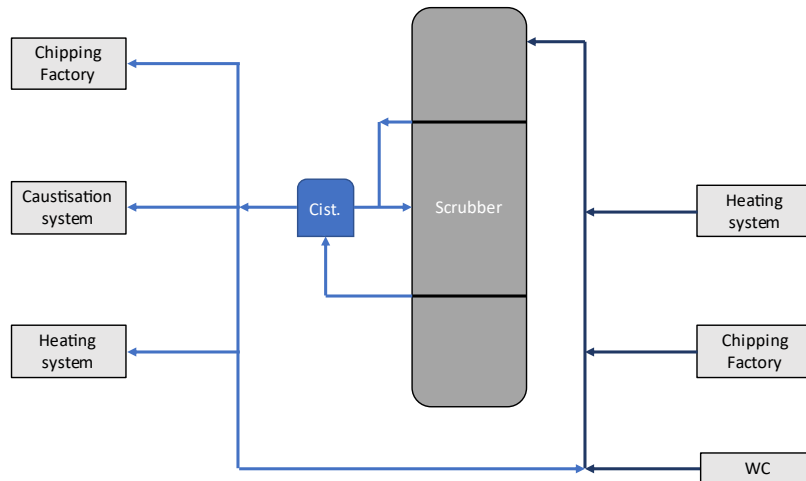


Figure 21: The Scrubber water system

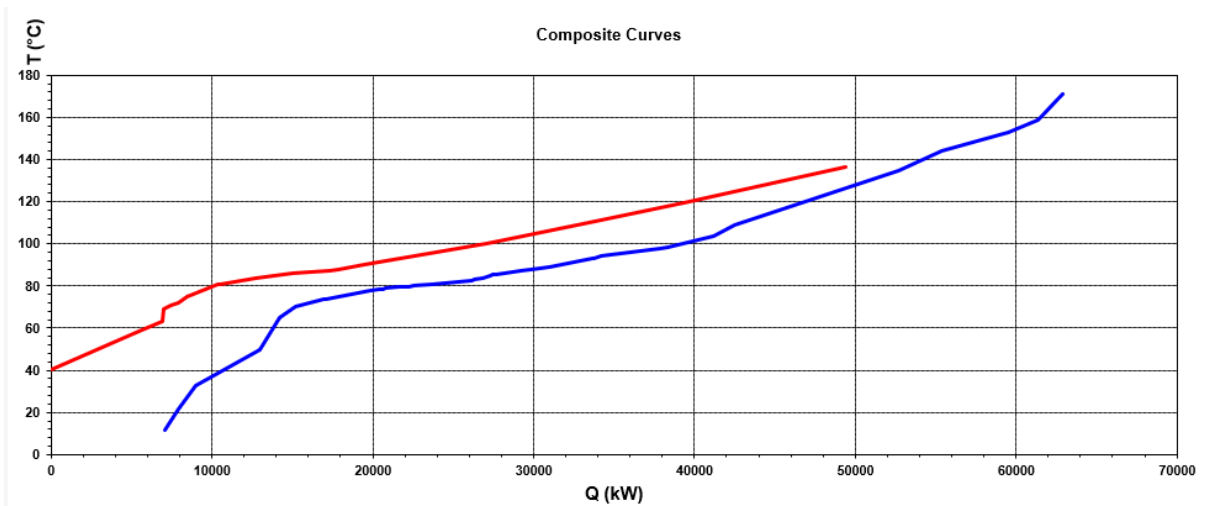


Figure 22: The composite curves.

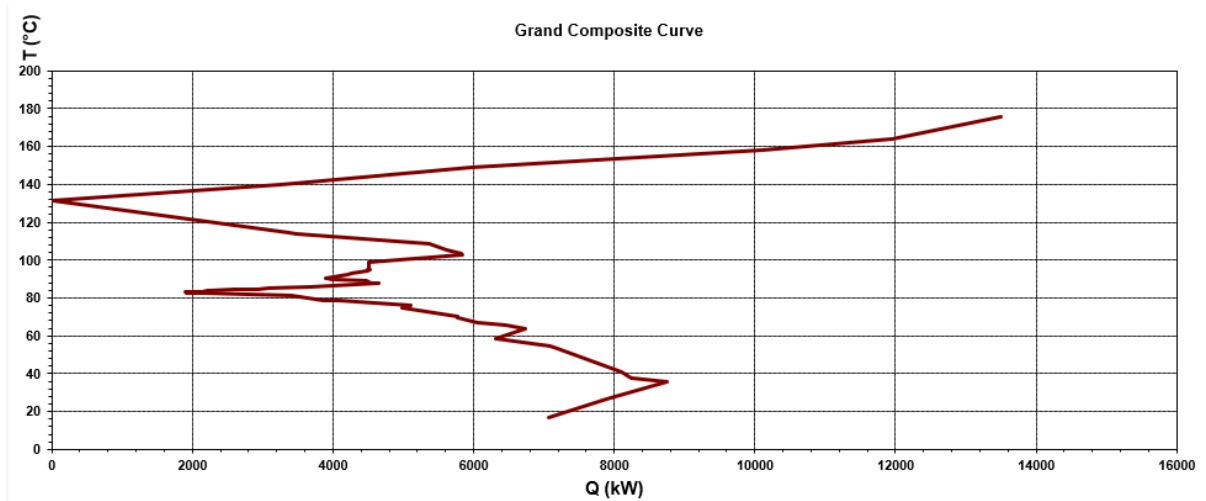


Figure 23: The grand composite curve.

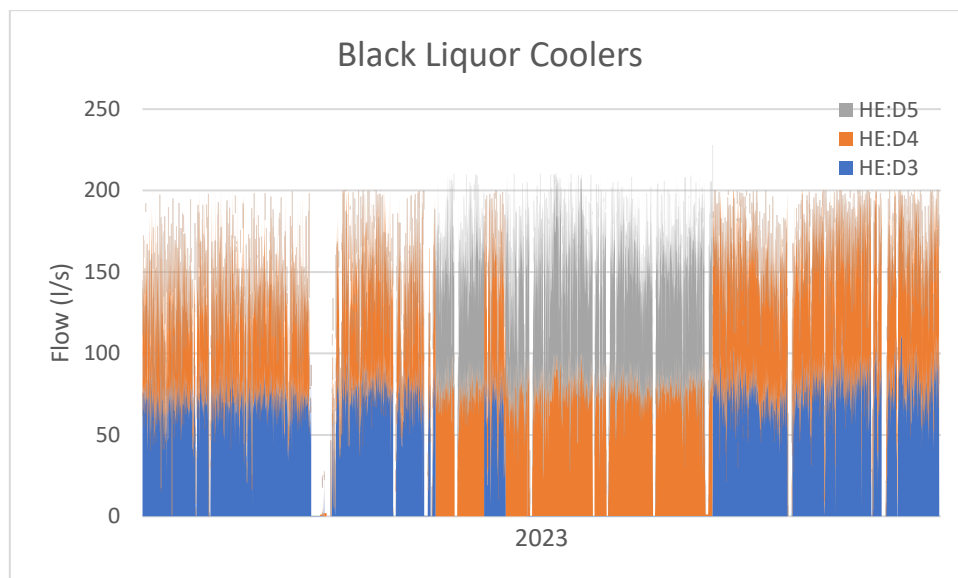


Figure 24: Operation of all three black liquor units.