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Analysis of the Secondary Heating System of Södra Cell Mönsterås

A Mapping and Data Evaluation Study for Future Energy Efficiency Studies at the Mill

Master's thesis within the Sustainable Energy Systems Programme

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

MASTER'S THESIS 2017

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Abstract

As one of the means to tackle global warming, the European Union established the 2012 Energy Efficiency Directive. As a part of fulfilling this directive, Sweden implemented the law about energy auditing for large enterprises, which aims at promoting possible energy efficiency targets. The energy audit should map the amount of energy supplied and consumed required to run the business and propose measures for the enterprise to reduce energy consumption and thereby increase their energy efficiency. The pulp and paper industry accounted for roughly 17 % of Sweden's total energy consumption during 2016, which indicates the importance of energy efficiency improvements within this industry.

A huge player within the Swedish pulp and paper industry is Södra. This project was carried out at Södra's oldest and biggest pulp mill Södra Cell Mönsterås. One way to improve its energy efficiency is by better utilizing the excess heat from the pulping process in its secondary heating system. However, Södra Cell Mönsterås main focus to produce and sell high-quality pulp has led to that the design and function of their secondary heating system has not been prioritised, resulting in lack of knowledge about their system with regards to potential energy savings, sizes of heat exchangers, consumers/producers of hot and warm water and operating data, such as temperatures and flows. This is particularly true for the digester section. Consequently the aim of this project has been to increase the knowledge of the design and function of the secondary heating system of Södra Cell Mönsterås, with special attention to the digester section and to collect and evaluate data to support future energy efficiency studies.

By studying piping and instrumentation diagrams and by collecting data through Södra Cell Mönsterås process monitoring control system (INFOPLAN), engineering estimations and measurements, the design and function of the secondary heating system of Södra Cell Mönsterås for the entire mill and for the digester section could be mapped. This was also done for the steam system and the internal and external heating networks. All the gathered data for these systems has been evaluated in terms of variations, data availability, data sources and extraction period and presented in graphs and tables. All this together increases the knowledge of the design and function of the presented systems and serves as a support for future energy efficiency studies or energy audits. Also, it serves as a basis for the carried out pinch analysis in order to identify energy targets.

From the pinch analysis it was found that, in theory, there is a potential to save 79 MW of primary energy. The pinch analysis also showed a possibility to produce 38.3 MW of hot water at 114 °C in the digester section. Since the current hot water demand is 20.9 MW, there is a theoretical possibility to achieve energy savings of 17.4 MW at various parts of the mill. However, it must be investigated further in future work how these energy savings can be achieved. To provide more accurate energy targets and to be able to come with suggestions on how to achieve these energy targets, the pinch analysis most be improved by identifying more individual streams. To further facilitate future energy efficiency projects, it is also suggested that current piping and instrumentation diagrams are continuously updated and more stationary measuring equipment for temperatures and flows are installed, especially in the digester section. Further, the possibility to introduce another water tank level should be investigated along with the possibility to replace low-pressure steam by hot water at 114 °C at some locations. Lastly, additional future work would be to investigate the practical feasibility and economical profitability of constructing an improved energy recovery heat exchanger network and introducing flue gas cooling as a measure for achieving primary energy savings.

Keywords: Secondary heating system, Energy auditing, Softwood kraft pulp mill, Energy efficiency, Pinch analysis, Data extraction, Steam savings, District heating, Digester section.

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1
Introduction

As one of the means to tackle the challenge of global warming, the policy makers of the European Union (EU) established the 2012 Energy Efficiency Directive stating that all EU countries, by the year of 2020, have to improve their energy efficiency by 20 % compared to the projections made in 2007 and reduce their greenhouse gas emissions by 20 % compare to the emission levels in 1990 [1]. In Sweden, manufacturing and energy industry accounted for 37 % of the total greenhouse gas emissions during 2016 [2]. These greenhouse gas emissions can be reduced by improving the energy efficiency in the industrial plants. As a part of fulfilling the requirements of the EU Energy Efficiency Directive and reaching the energy efficiency targets, Sweden implemented the law about energy auditing for large enterprises (EKL), which aims at promoting possible energy efficiency improvements [3]. The law require all large enterprises to perform quality-secured energy audits at least every four years. The energy audit should map the amount of supplied and consumed energy required to run the business. Further, it should propose measures for the company to apply in order to lower their costs, energy consumption and thereby increase their energy efficiency. Due to the likely long-term increase in energy prices, improved energy efficiency should, even without the law, be of great interest for the industrial companies. Improved energy efficiency would reduce their energy costs, and the risks associated with energy cost increases, which is crucial to remain competitive [4, 5].

The pulp and paper industry is an energy-intensive industry, which corresponds to 46 % of the industry's energy consumption in Sweden [6]. The potential for energy efficiency improvements is large within the pulp and paper industry [7]. In Sweden, Södra AB is a huge player within the pulp industry. Södra is an organisation that is completely owned by approximately 50 000 forest owners and is one of the world's biggest producers of chemically produced softwood pulp [8]. Södra is divided into three business areas, namely Södra Skog, Södra Wood and Södra Cell. Södra Cell mainly produces pulp and owns three pulp mills spread over southern Sweden, one at each coastline. This project was carried out at Södra Cell Mönsterås situated on the eastern coastline, which is the biggest and oldest of the three mills, but yet the most modern pulp mill in Södra. It was commissioned in 1958 and has today roughly 400 employees [8]. Its annual production capacity of pulp amounts to 750 000 tons, but the output is not only limited to pulp. They also produce electricity for internal usage and sell the excess to the sawmill of Mönsterås and to the electricity company E.ON. In addition to that, they deliver heat to the heating networks of Mönsterås municipality and to the sawmill of Mönsterås. Further, they produce and sell wood fuels, turpentine and tall oil.

The main focus of Södra Cell is to deliver high quality pulp to their customers and to increase revenues. Thus, lots of effort has been put into improving the pulping process and increasing the pulp production capacity by several retrofits and investments [8]. However, nowadays Södra Cell Mönsterås is a multi-product plant. During some periods of the year, Södra Cell Mönsterås gains higher profits from sales of electricity than sales of pulp. Consequently, it has become of greater interest for Södra Cell Mönsterås to increase their energy efficiency, since it affects the overall resource efficiency of the pulp mill, in terms of fuel usage, electricity production and heat deliveries. The opportunity to benefit from energy efficiency improvements through increased sales of valuable by-products serves as an additional argument for improving the energy efficiency in the pulp mill of Södra Cell Mönsterås.

At Södra Cell Mönsterås, the energy efficiency can be improved by better utilizing available heat from the pulping process to save steam, which can be achieved through better design and/or operation of the secondary heating system. The secondary heating system in Södra Cell Mönsterås is a system for production of hot and warm water by using excess heat from the pulping process. In the secondary heating system, used cooling water (which is thereby heated) from the process is collected in warm and hot water tanks at different temperature levels, which is distributed to heat consumers around the plant. Heat from the secondary heating system is also delivered to the internal and external heating networks. Large quantities of heat are passing through the secondary heating system, making its optimal design and operation important for the energy efficiency of the mill. The design and function of the secondary heating system at Mönsterås pulp mill has been put aside, since their main focus is to deliver high quality pulp and increase revenues. This has resulted in lack of knowledge about the secondary heating system in regards to the potential energy savings, sizes of heat exchangers and operating data, such as measurements of temperatures and flows. Therefore the secondary heating system has been treated as a black box in the process models of the pulp mill. This is particularly true for the digester section, which is one of the most energy-intensive sections of the pulp mill. Large quantities of excess heat are produced within the digester section, which is utilized in the interconnected secondary heating system. Based on this, there is reason to believe that there are possibilities to achieve energy savings through better design and/or operation of the secondary heating system of Södra Cell Mönsterås, particularly within the digester section. Because of the statutory EKL energy audit, Södra Cell Mönsterås thus has incentives to map the secondary heating system and its interconnections with the pulping process, especially in the digester section, and thereby investigate potential energy efficiency measures.

To identify and assess possible energy savings in a secondary heating system a well-established method called pinch analysis can be used. Pinch analysis is used to answer questions like how much heat that must be added to the process, how much heat that is possible to recover through internal heat exchanging, how much heat that must be removed from the process and how a heat exchanger network should be designed in order to utilize as much of the energy as possible at reasonable capital costs. Historically, several studies using pinch analysis within a pulp mill have been carried out. Lutz et al., Axelsson and Eriksson et al. have all made pinch analyses in pulp and paper mills and all found significant energy savings potentials [9, 10, 11, 12]. Persson and Berntsson estimated the energy-savings potential in the secondary heating system of Södra Cell Värö through a pinch analysis and investigated how seasonal and short-time variations in flows and temperatures influenced this potential [5]. They found that taking these variations into account decreased the energy savings potential by 6 - 12 %. These variations in the secondary heating system are also likely to affect the main process operations and, in the worst case, also affect the quality of the pulp product. Hence, there are incentives to design a secondary heating system that is flexible to these variations, making it possible to realize the energy-savings potential to a larger extent and making it easier to maintain stable operation. A new research project in cooperation between Chalmers and Södra Cell Mönsterås will develop methods to evaluate the flexibility of different heat exchanger networks, in order to guide the design in this direction. In summary, mapping and analysing the secondary heating system of Södra Cell Mönsterås can provide both valuable information about potential energy savings within the pulp mill, which can lead to improved resource efficiency and thus increased revenues, and also support the work of fulfilling the statutory EKL energy audit. Further, it can provide process descriptions, process data and models, which can serve as input to the work of developing methods within academia.

1.1 Aims and Objectives

The aim of the project is to increase the knowledge of the design and function of the secondary heating system of Södra Cell Mönsterås, with special attention to the digester section and to collect and evaluate data to support future energy efficiency studies.

The project is divided into the following objectives, which have to be accomplished in order to achieve the aim:

1. Mapping of and data collection for the secondary heating system in Södra Cell Mönsterås pulp mill with special attention to the digester section, including flowcharts and process descriptions of producers and consumers of hot water, the thermal loads of the heat exchangers and hot water tanks as well as flows and temperatures in the secondary heating system.

2. Mapping of and data collection for the internal and external heating networks, including flowcharts and process descriptions of producers and consumers of heating water.

3. Data collection for the steam system and description of the producers and consumers of steam.

4. Data evaluation and representation of all the extracted data for the steam system, the internal and external heating networks and the secondary heating system with special attention to the digester section with regards to variations, data availability, data sources and extraction period.

5. Identify energy targets using pinch analysis and provide suggestions on how to improve the analysis for future studies.

1.2 Limitations

The project was limited to only look at Södra Cell Mönsterås secondary heating system connected to the digester section in particular and to the whole mill in general. Since the project was carried out at Mönsterås pulp mill, the results of the study will not be valid for other pulp mills. Further, the measurements were carried out during the conditions described in Section 2.1. Thus, the results of the measurements and the results based on the measurements are only representative for the same conditions as those of the project.

1.3 Report Outline

The report's outline is as follows:

Chapter 2 describes the methodology of this project as well as the period and conditions for when the data was extracted and filtrated.

Chapter 3 gives a process description with focus on steam and warm and hot water production/consumption.

Chapter 4 presents a description of the energy and material balance for the pulp mill of Södra Cell Mönsterås during 2016. It also gives a mapping and a description of the steam system, the internal and external heating networks and the secondary heating system with special attention to the digester section with regards to energy demand for the studied period defined in Section 2.1.

Chapter 5 presents the evaluation and representation of all the extracted data for the steam system, the internal and external heating networks and the secondary heating system with special attention to the digester section with regards to variations, availability, source and extraction period.

Chapter 6 describes the extraction of the stream data table for the pinch analysis for energy targets and suggestions on how to improve it for future studies.

Chapter 7 concludes the project in terms of the aims and objectives and gives suggestions on how to proceed in future energy efficiency studies.

2
Methodology

This chapter describes the methodology of this project as well as the period and conditions for when the data was extracted and filtrated. Figure 2.1 presents an overview of the different steps of this project. Roughly 85 % of the total project time has been devoted to the first three steps.

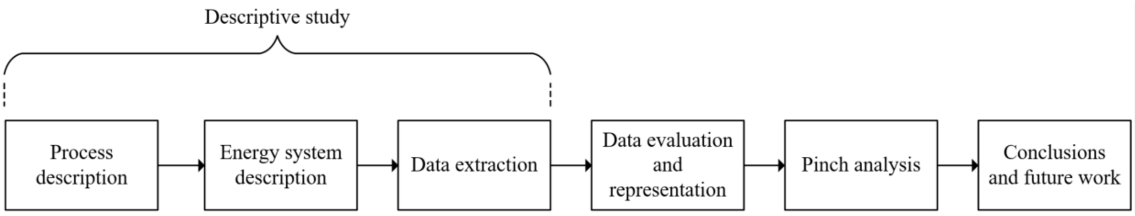

Figure 2.1: An overview of the project work procedure.

The project began with a descriptive study about the pulping process of the pulp mill of Södra Cell Mönsterås and in particular the steam and/or hot and warm water consumption/production for the different pulping processes. The information about the pulping process in general and more specifically about the steam and warm and hot water consumption/production was collected from internal documents and external literature. More mill specific information was gathered in consultation with mill process engineers. The reason for assembling this process description was to understand the processes of Södra Cell Mönsterås and in particular the role of the secondary heating system. The result of this study can be read in Chapter 3.

The descriptive study also included a description and mapping of the energy system of Södra Cell Mönsterås, resulting in flowcharts with marked sensors, and a description of the secondary heating system for the entire mill in general and for the digester section in particular. The result of this study can be read in Chapter 4. The chapter starts with a general description of the input and output energy flows of the pulp mill, with the purpose of putting the energy system description into context and providing a basic understanding and overview of the energy balances of the mill. This information was gathered from an internal energy report of Södra Cell Mönsterås for the year of 2016. The steam system of Södra Cell Mönsterås was then described with regards to producers and consumers of steam as well as the design of the feed water pre-heating system. The steam system is the heart of the energy system of Södra Cell Mönsterås and is crucial for the operation of the mill, which is why it had to be included in this project. The steam system is described in more detail in Section 4.1. Subsequently, the internal and external heating networks connected to Södra Cell Mönsterås were described with regards to design and producers of heat to these networks. This can be read about in more detail in Section 4.2. The numbers provided in Section 4.1 and 4.2 are based on average values of the data from the studied period, which is further described in Section 2.1. This data was extracted from Södra Cell Mönsterås process control monitoring system (INFOPLAN) and from engineering estimates by mill process engineers.

The next step was to map the secondary heating system of Södra Cell Mönsterås for the entire mill in general and for the digester section in particular. This work started off by mapping the secondary heating system for the entire mill with regards to warm and hot water tanks as well as producers and consumers of warm and hot water. This was done by studying the water paths from the two main tanks of warm and hot water in piping and instrumentation diagrams (P&IDs) for numerous sections. These documents were gathered from Södra Cell Mönsterås archives of P&IDs. In collaboration with mill process engineers, smaller extractions, pipes and heat exchangers were neglected. From this, a flowchart of the secondary heating system for the entire mill, with available sensors for data extraction from INFOPLAN marked on the flowchart, could be established for the biggest producers and consumers of warm and hot water. The same procedure was then applied to the digester section. The water path in the P&IDs for the digester section was followed and eventually a flowchart of the secondary heating system for the digester section, with available sensors for data extraction from INFOPLAN marked on the flowchart, could be established for all producers of hot water. The validity of this flowchart was, as far as it was possible, verified by a comparison with the reality. The flowcharts with marked sensors are, however, excluded from this report due to confidentiality reasons.

The next step was to identify which temperature and flow data that was lacking in order to be able to estimate thermal loads for the producers and consumers of warm and hot water for the secondary heating system for the entire mill and the digester section respectively. The lacking temperature and flow data in the digester section was measured. To reduce the number of required measurements, some assumptions had to be made in order to be able to determine some stream data and thermal loads. These assumptions are presented further in Section 4.4. Some of these measurements were also performed at some locations where information already was provided by INFOPLAN. This was done to create redundancy to be able to evaluate the reliability of the measurements performed. The lacking temperature and flow data for the entire mill was either estimated by senior mill process engineers or calculated through mass and energy balances. One reason for the extensive amount of lacking data and information is because of old and outdated documentation due to several retrofits throughout the years. The mapping of the secondary heating system for the entire mill and for the digester section along with a process description of producers and consumers of hot water, the thermal loads of the heat exchangers and water tanks can be read about in Section 4.3 and 4.4 respectively. To read more about the data extraction through measurements and INFOPLAN along with the definition of the studied period, the reader is referred to Section 2.1.

The next step of the project was to evaluate and represent all the data extracted for the steam system, the heating networks and the secondary heating system for the entire mill with special attention to the digester section, which can be read about in Chapter 5. The data is represented in graphs and/or tables in terms of time periods, source and time intervals as well as average values and standard deviations. The data is evaluated with regards to fluctuations and availability. Also, the chapter gives information about which data that is missing and the assumptions made when collecting the data, in order to support future energy studies that requires data extraction.

The final step of the project was to perform a pinch analysis in order to identify energy targets, which is presented in Chapter 6. To accomplish this a stream data table based on the extracted data had to be established for the entire mill. Also, a discussion about what improvements that have to be made for a future pinch analysis is included in this chapter.

2.1 Data Extraction and Conditions

It was desirable to obtain a data set for a stable as well as high production of softwood kraft pulp and for a winter case with similar conditions as for the performed measurements. The period for which this data set is valid is referred to as the studied period. The period for which measurements were carried out defines the period for data extraction from INFOPLAN. The data set obtained from measurements is spread over different periods during the 1st of of November 00:00 o'clock and the 24th of April 23:00 o'clock. The reason for this was due to unsatisfied operating conditions during some periods of the logging period or that some measurements had to be re-performed due to malfunctioning measuring equipment. The temperature measurements were carried out using a battery-run small data logger called Tiny Tag, which uses a sensor, consisting of a thermistor, to determine the temperature of the flow by mounting the sensor to the surface of the pipe. The flow measurements were carried out using a portable ultrasonic liquid flow meter called TransPort PT878, which uses ultrasonic signals to estimate the flow. Since they only had one portable flow meter at Södra Cell Mönsterås, the measurements were carried out during a few hours at the time during desirable operating conditions.

Relevant data for temperatures and flows available in INFOPLAN were extracted between the 1st of November 00:00 o'clock and the 24th of April 23:00 o'clock with one hour intervals, which is defined as ***the data extraction period***. However, the data was filtered based on a few established criteria. Firstly, data extracted during periods of hardwood kraft pulp production were eliminated, since softwood kraft pulp is produced during 75 % of the total production time and are thus more representative. Secondly, at a stable and high production of softwood kraft pulp, the recovery boiler is operating at an average of 103 - 105 % of design capacity. For this project, a stable and high production was defined as when the recovery boiler is operating at at least 98 % of design capacity. Consequently, data extracted during periods when the recovery boiler is operating at less than 98 % of design capacity were eliminated. Further, data extracted when the outside temperature was below -5 °C or higher than 8 °C at the wood handling section and at the sawmill of Mönsterås were eliminated. The reason for this temperature interval was because roughly 85 % of all data was within this interval and consequently temperatures outside this range is not corresponding to typical winter conditions. Data from periods when the fresh water temperature was below 2 °C or above 6 °C were also eliminated. These conditions were set in order to match those that was current during the measurements.

The filtration gave a data set of values from different times during the period of data extraction. The last criterion was that the final data set should stem from a coherent time period of at least 24 hours, to remove any possible variations caused by external effects, such as the heating networks, which can be a consequence of having data from different periods. A somewhat coherent period of 272 hours between the 10th of March and 27th of March were found and data from this period were used to calculate average temperatures and flows, which make up stream data tables relevant for pinch analysis. These average numbers are also used when calculating thermal loads and effects throughout the paper for the studied period. With other words, ***the studied period*** is referred to as the 272 hours between the 10th of March and the 27th of March. Table 2.1 shows the filtration process of the extracted raw data.

Table 2.1: Illustration of how the raw data from the data extraction period is filtered through the different defined criteria. One data point corresponds to one hour.

	Raw data from 1st of November to 24th of April	Criterion 1 Softwood pulp production	Criterion 2 Recovery boiler run at ≥ 98 % of design capacity	Criterion 3 $-5 \leq T \leq 8$ °C at wood yard and at sawmill	Criterion 4 2 - 6 °C intake water from Emån	Criterion 5 Coherent time period
Amount of data in data set	4 201	3 003	2 016	1 642	447	272

3
Process Description

Södra Cell Mönsterås is one of the world's biggest producers of softwood kraft pulp, with an annual production capacity of 750 000 air-dried tons (ADt) per year, whereof 75 % is softwood pulp and 25 % is hardwood. The mill of Mönsterås is a Kraft pulp mill, meaning that the lignin that binds the fibres in the wood together is degraded and dissolved using chemicals [13]. The pulping process in Mönsterås, from wood feedstock to processed and salable pulp, comprises of several mechanical and chemical steps. When the logs arrive to the pulp mill, they are stored at the wood yard. Before being used in production, the logs are sprayed with water to remove any sand, stones and other dirt. At Södra Cell Mönsterås, they produce both hardwood and softwood Kraft pulp. However, since they only have one production line, they work in campaigns. In the first step of the pulping process, bark is being separated from the logs in a debarking drum and then either transported to the power boiler for energy extraction used to support other parts of the mill, pulverized and used as fuel in the lime kilns or sold to customers as biofuel. The logs are moved to the chipping section, where sharp knives chop the logs to chips of varying size and are then stored by size in different piles on the yard. If the chips are too big or too thick the water and the chemicals in the digester section are not able to fully penetrate them. Those chips are therefore crushed or chopped again to the accepted size. The wood chips that are too small are called pin chips and are cooked in a separate and smaller digester and are hence stored in a different pile.

The subsequent steps in the process are referred to as the fibre line, which comprises of a digester, screening, washing, oxygen bleaching, bleaching and a drying section. The wood chips are transported from the piles to the digester section by conveyors. Approximately 50 % of the wood contain cellulose and hemicellulose, which constitutes the fibres in the wood. The other half comprise of lignin and other substances, such as resin substances, which will eventually end up as thin black liquor, and terpenes, which serve as a solvent for the resin substances and are flashed away early in the digester due to their low boiling point. The flashed terpenes are separately processed to create turpentine, which is a salable product. In the digester section of Södra Cell Mönsterås, the fibres are separated from the lignin in continuous digesters by adding a chemical mixture called white liquor to the wood chips. The produced pulp mixture must be cleaned from insufficiently cooked chips and impurities like sand, bark particles and plastics, which is done in the screening section right after the digester, containing several steps of filtration. After the screening section, the pulp mixture is washed in several steps to remove the digester chemicals, dissolved wood residues and the soap molecules that are likely to be formed within the digester due to the reaction between resin substances in the wood and the white liquor. The received filtrate is called thin black liquor.

The screened and washed, and thus somewhat bleached mixture of pulp leaving the washing section after the digester, is further transported to the oxygen bleaching section. Cooking the pulp too long in the digester to remove as much lignin as possible also breaks down the fibres. Interrupting the digestion when about 3 - 15 % of the lignin remains in the pulp mixture and using oxygen to delignify and bleach, increases the pulp yield. The reason for this is that oxygen is more selective and dissolves the lignin more effectively than the digester chemicals at the end of the digestion. However, the remaining lignin after the oxygen delignification section is enough to make the pulp brown-coloured. Consequently, there is a need to further bleach the pulp to a degree of brightness required by the customer. The pulp mixture is therefore supplied to the bleaching plant. At Södra Cell Mönsterås, the bleaching plant consists of several bleaching steps to reach the desired degree of brightness and at the same time not compromise the strength of the pulp too much. The bleaching plant is TCF, meaning that the pulp is totally chlorine free and is bleached using hydrogen peroxide and peracetic acid. Some extraction stages are included in the bleaching plant, to extract the metals in the wood and thus preventing those metals to harm the process. In between every bleaching stage, the pulp mixture is washed to wash out remaining lignin, bleaching chemicals, metal extractions and other unwanted substances.

The pulp mixture leaving the bleaching section enters a final screening before entering the drying section. The pulp mixture that goes into the drying section has a dry solids content of 1 %. The water content in the pulp mixture must be reduced before delivery. The pulp mixture is initially pumped onto the wire section, where water is sucked out from the pulp by the means of suction boxes located beneath the wire. The dry solids content reaches 15 - 20 %. Then the pulp enters the press section, where press rollers presses out water from the pulp, giving a dry solids content of 50 - 55 %. Then lastly, the pulp enters the fan dryer, where hot air is used to evaporate the water to achieve a dry solids content of almost 90 %. The pulp is then ready to be cut into sheets and stacked into bales, which are packaged and labelled and thus ready for delivery.

The separated thin black liquor, from the washing section, is supplied to the recovery cycle, where the cooking chemicals is regenerated and the heat content within the black liquor is retrieved. The recovery cycle comprises of an evaporation plant, a recovery boiler and a causticization section. Before the thin black liquor enters the evaporation plant, the soaps are removed in a separate soap separator. These soaps are eventually used to produce tall oil. The thin black liquor then enters the evaporation plant. The main task of the evaporators is to increase the dry solids content of the thin black liquor from 17 % to approximately 60 - 70 % to ensure good performance for the recovery boiler. The product leaving the evaporation plant is called thick black liquor and is supplied to the recovery boiler in the subsequent step, where it is combusted. The energy content within the black liquor produces heat, which is used to generate high pressure steam. The steam is supplied to three back-pressure turbines and one condensing turbine, where the steam is expanded to generate electricity and extracted at different pressure levels to be used as process steam in different parts of the pulping process. At the bottom of the recovery boiler, a byproduct of the combustion falls out in molten form. The melt is mixed with wash water from the lime kilns to create green liquor. The green liquor flows to the slaker, where it is mixed with calcium oxide, also known as lime. The mixture is moved to the causticizing reactors and then through a filter, where the lime mud, mainly comprising of calcium carbonate, also known as limestone, is removed. The filtered liquor is white liquor and is recycled back into the digester to complete the recovery cycle. The lime mud is supplied back to the lime kilns, where it is washed, heated and burned to once again form lime. Figure 3.1 shows a process overview of the pulping process at Mönsterås pulp mill. For more indepth description of the pulping process, the reader is referred to either Theliander et al.'s book or Södra Cells Pulp Faction [14, 15].

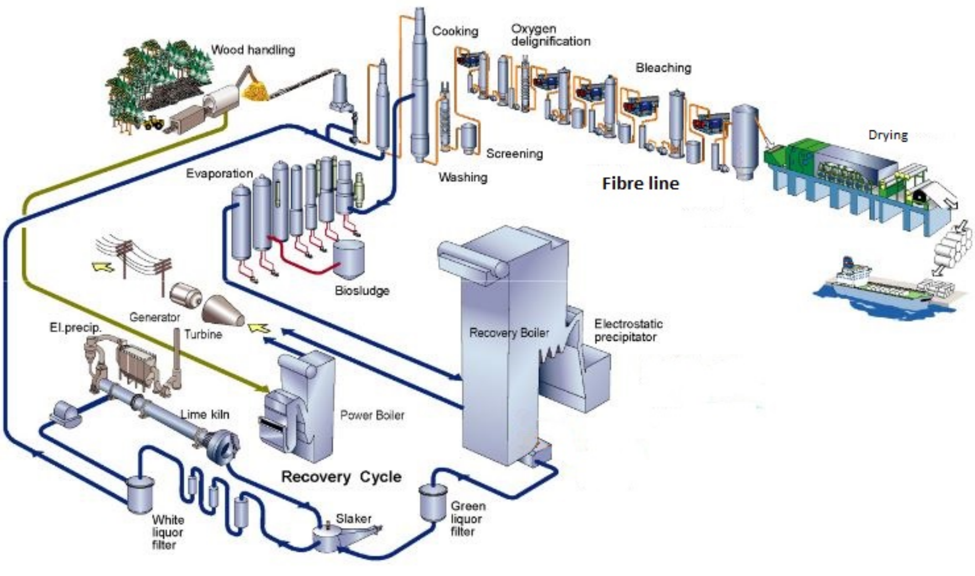

Figure 3.1: A process overview of Södra Cell Mönsterås kraft pulp mill [13].

The rest of the chapter give, for each process step of the fibre line and the recovery cycle respectively, a deeper description of the processes with regards to steam consumption/production and hot and warm water consumption/production.

3.1 The Fibre Line

The fibre line refers to the fibres way through the process, from being a part of the wood to being extracted from the wood, bleached, dried and packaged and ready for delivery. In the following subsections, the different processes that make up the fibre line of Södra Cell Mönsterås, including the wood handling section, are described with regards to steam consumption/production and hot and warm water consumption/production.

3.1.1 The Wood Handling Section

Wood is transported to Södra Cell Mönsterås by trucks from the logging site usually situated in vicinity to the pulp mill and then stored at the wood yard where they are kept as a buffer. From the wood yard, the logs are transported by forklifts to the wood handling section. Here, the logs are washed, debarked and chipped into chips. During periods when the logs are frozen, they enter a thawing device prior to entering the debarking drum. In the thawing device low-pressure steam and/or cold water is added in order to thaw the logs, making the debarking easier.

The separated bark is used as fuel in the power boiler to provide the internal pulping process with process steam and electricity and/or in the lime kilns to recover lime from limestone. The bark could also be sold as biofuel to other facilities. In general, 10 - 15 % of the steam consumption in Södra Cell Mönsterås is covered by burning of bark, sawdust from the wood chipping section and process rejects in the power boiler. The rest of the process steam is obtained from combustion of black liquor in the recovery boiler, which is further discussed in section 3.2.2.

Immediately after the debarking drum, the logs passes by a number of equidistantly spaced rollers, where stones and bigger objects can fall through. Also, gravel and sand is washed off the logs, to reduce wear on the chipping blades. Subsequently, the logs are transported to the chipping section, where they are cut into chips, to enable the cooking liquid to easier penetrate the wood. The cooking procedure is hugely affected by the size of the chips. Too big chips will not let the cooking chemicals to sufficiently penetrate the wood, leading to a higher amount of reject that needs to be recooked. This decreases the production capacity and essentially the energy efficiency of the digester section. Hence, it is important that the chips fulfills the criterion of chip size. The quality of the chips is manually checked and then screened in a standard screener. The different kinds of chips are then stored in separate chip piles, where it is later transported to the digester section by a conveyor.

No steam or warm/hot water is used at the wood handling section. However, through the debarking of the logs, wood fuel is produced in the form of bark, and the chipping procedure is crucial for the overall efficiency of the digester section. Heat in the form of low-pressure steam, together with cold water, is used to thaw and wash the logs when it is needed. Since this usage of steam is small in relation to the usage at other parts of the mill, this section is negligible.

3.1.2 The Digester Section

The wood consists mainly of lignin, cellulose and hemicellulose, where the last two are the fibres extracted to give the pulp. The aim of the digestion section is to remove as much lignin as possible without damaging the fibres. At Södra Cell Mönsterås, this is achieved in two identical continuous digesters, digester 4 and 5, and in one smaller continuous digester, digester 6, for the pin chips. The larger chips are transported to digester 4 and 5 and are at first supplied to a silo, which works as a buffer. Also, here the degassing process begins by supplying low-pressure steam at 3 bar with a temperature of 160 °C. The larger chips are then degassed in the degassing vessels, which use excess steam from the digesters. The chips reaches a temperature of 120 °C in the degassing vessels, which vaporizes the water content within the chips and removes the volatiles and air. That way a suction due to a under-pressure within the chips can make the cooking chemicals fully penetrate the chips, ensuring higher digestion performance.

The larger chips enter the high pressure feeders after the degassing vessels, where the cooking chemicals, the white liquor, is added. The white liquor is a mixture of sodium sulphide and sodium hydroxide. The mixture of white liquor and chips is then transported to the phase digesters, where the chips at first are supplied to the top of the impregnation vessels. Excess liquor is supplied back to the high pressure feeders as shown in Figure 3.2. The impregnation begins by adding white liquor with a temperature below 100 °C into the vessels, which initialize a process of condensation of steam within the chips. This causes the chips to be filled by the added white liquor through a suction. The obtained mixture of water and liquor-filled chips, referred to as cooking liquor, is then fed to the top of the digesters 4 and 5, which are equipped with separators. These separate the excess of white liquor and resupply it to the bottom of the impregnation vessels. The pin chips are directly fed into digester 6 without any degassing process nor any impregnation process, since they are already sufficiently small, which ensures the white liquor to fully penetrate the chips.

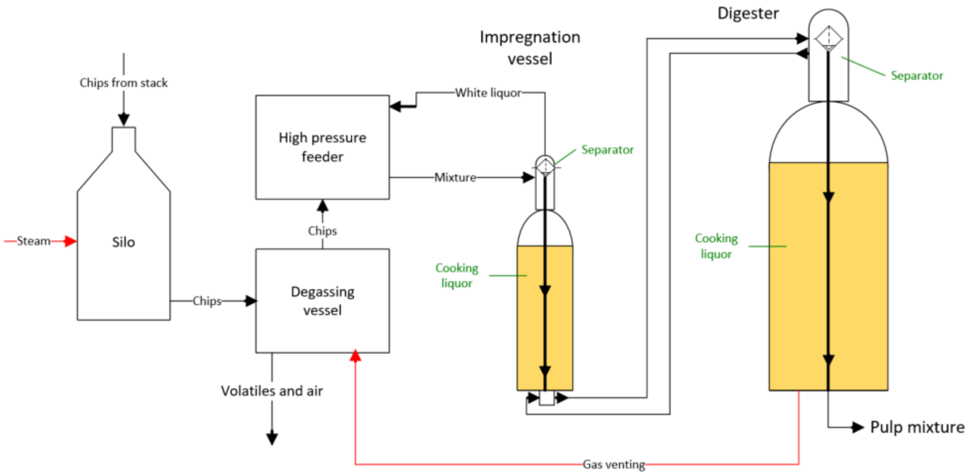

Figure 3.2: The degassing and impregnation process in a continuous digester.

In the digesters the optimal cooking temperature is around 170 °C and higher temperatures will give undesired reactions and weaker fibres. Consequently, the temperature increases rapidly to roughly 170 °C in the digesters, by supplying intermediate pressure steam at 11 bar with a temperature of 200 °C to the top of the digesters. The spent liquor in the digesters contains lignin carbohydrates and used cooking chemicals, mainly substances as sodium carbonate and sodium sulphate, and is called black liquor. The black liquor is extracted a distance down in the digesters through screeners. The black liquor expands in an expansion vessel to approximately

100 °C, which causes some of the black liquor to flash. The flash steam enters a treatment section before it is used for heating of the external heating network connected to the sawmill of Mönsterås, for hot water production in the digester section and for turpentine production. The black liquor condensate is supplied to the washing and screening sections to create thin black liquor, which is subsequently supplied to the evaporation section and essentially the recovery cycle for energy extraction and white liquor recovery. A distance further down in the digesters, cooking liquor is extracted and mixed with white liquor, which is pre-heated using low-pressure steam of 3 bars at 160 °C. This mixture is heated with steam in a heat exchanger using intermediate pressure steam at 11 bar with a temperature of 200 °C and then resupplied back to the top of the digester and mixed with the cooking liquor from the impregnation vessels. This process is shown in Figure 3.3.

Washing liquor is supplied in the bottom of the digesters, which works as a first washing step by displacing the original cooking liquor. The washing liquor is flowing counter-current to the pulp mixture direction towards the first screener, where the black liquor is extracted. Since the washing liquor have a temperature around 100 °C, the digestion will start to cease. In the bottom of the digesters there is a scrape, which forces the pulp mixture to enter the blow line and thus the digestion is complete.

As discussed, lots of low and intermediate pressure steam of 3 and 11 bars respectively is consumed within the digester section. Also, a lot of warm water and some cold water is used to cool flash steams and process streams, which produces hot water, supplied to the hot water tank. The amount of steam and warm and hot water consumed/produced within the digester section is given in Table 4.4 and Table 4.6 respectively.

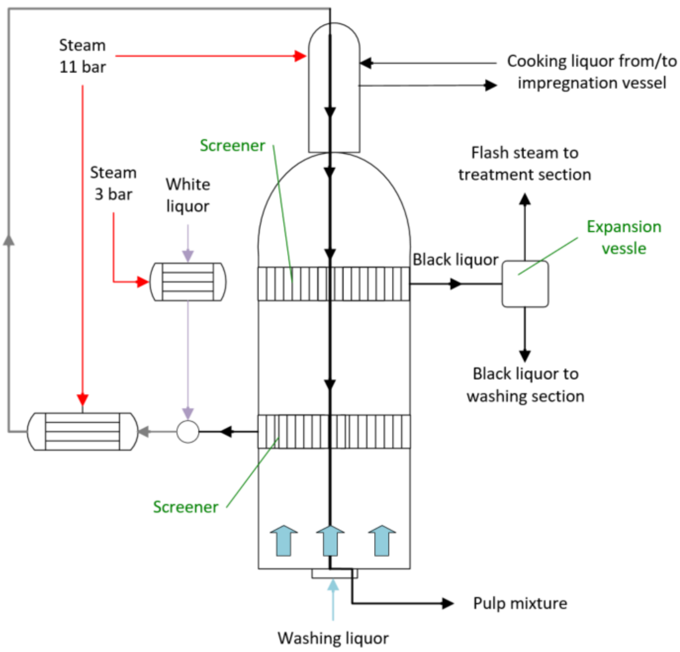

Figure 3.3: The digestion process in the digesters 4 and 5.

3.1.3 The Screening, Washing and Bleaching Sections

The pulp mixture leaving the digester section enters a screening and washing section. In the screening section undigested wood, shives and impurities are removed from the pulp. This is referred to as reject and some is supplied back to the digester and some is used as additional fuel in the power boiler and/or in the lime kilns. The accept, i.e. the accepted pulp mixture, is transported to the washing section, where remaining cooking chemicals and dissolved lignin is washed away. The final filtrate is called thin black liquor and is supplied to the evaporation section. The washing and screening section does not consume or produce any hot and warm water or steam.

The screened and washed pulp mixture continues to the oxygen bleaching section. Here intermediate pressure steam of 11 bars at 200 °C is consumed in an oxygen and steam mixer before entering the oxygen reactor. Some hot water is mixed with oxygen liquor after a press before being supplied to a high consistency oxygen tank. No warm water is consumed or produced within the oxygen bleaching section. The subsequent bleaching stages, referred to as the bleaching section, consumes hot and warm water, mainly in the filters to wash off the bleaching chemicals, but also in the cylinders draining backwater from the pulp. The produced backwater is in turn used as heat source in the external heating network and to heat the feed water, further described in section 4.2 and 4.1 respectively. Further, intermediate pressure steam of 17 bars at 217 °C is used to heat the pulp mixture before entering the PO- and OP-reactors. Also, low-pressure steam of 3 bars at 160 °C is used to heat the backwater leaving the processes. The preparation of the chemicals used in the bleaching sections also consumes low-pressure steam of 3 bars at 160 °C as well as hot and warm water to dilue and dissolve the chemicals. The amount of steam and warm and hot water consumed within the oxygen bleaching, bleaching and the chemical preparation section is given in Table 4.4 and Table 4.6 respectively.

3.1.4 The Drying Section

In the wire section the pulp is placed on to a wire cloth passing over several cylinders heated with low-pressure steam of 4 bars at 162 °C. Vacuum pumps located beneath the wire is sucking water out from the pulp. The collected backwater is used in the final screening section, just before the drying section and after the bleaching section. The pulp is then lifted up from the wire cloth and formed into a blanket and supplied to the press section. In the press section the pulp blanket is passed in between big rollers, in which the water is squeezed out of the pulp. More backwater is produced and supplied to the final screening section. The final drying occurs in the fan dryer, where the water is evaporated by blowing hot air in vertical direction across the pulp blanket. The hot air is heated in a heat exchanger using a lot of low-pressure steam of 4 bars at 162 °C. The final dry solids content usually reaches almost 90 % after the fan dryer. The hot air from the fan dryer, with a temperature of 56 °C, is released out in the atmosphere. No warm and hot water, except the backwater used in the final screening section, is produced or consumed within the drying section. The total amount of steam consumed within the drying section is given in Table 4.4.

3.2 The Recovery Cycle

The recovery cycle refers to the cycle where white liquor is regenerated from the separated black liquor from the fibre process. The separated black liquor is evaporated and combusted in the recovery boiler in order to generate steam, and the byproduct of the combustion is treated in a causticization section to regenerate white liquor. This section presents the different processes that make up the recovery cycle of Södra Cell Mönsterås with regards to steam consumption/production and hot and warm water consumption/production.

3.2.1 The Evaporation Sections

In order to evaporate the water from the thin black liquor supplied from the digester section, a lot of heat is needed. The heat is supplied as intermediate and low-pressure steam of 11 bars at 200 °C and 3 bars at 160 °C respectively. To decrease the energy consumption in the evaporation section the evaporation process takes place in series of connected evaporators. The method is called multiple-effect evaporation. The evaporation sections at Södra Cell Mönsterås consists of three sets of evaporation trains. In each of the effects the temperature of the thin black liquor is increased to boiling temperature. The steam generated from boiling is used as a heat source for the next effect and the last effect in the series is connected to a condenser. The first effect operates at a temperature that is high enough to generate steam with a heat content that can evaporate the water in the following effect. The boiling point is affected by both the decreased pressure and by the concentration of black liquor in the mixture. In the effects 1B/2A/2B the pressure is lower than the ambient, giving a boiling temperature between 65 - 120 °C. The effects 1A/B/C are supplied with super-heated steam at 3 bar, which is seen in Figure 3.4.

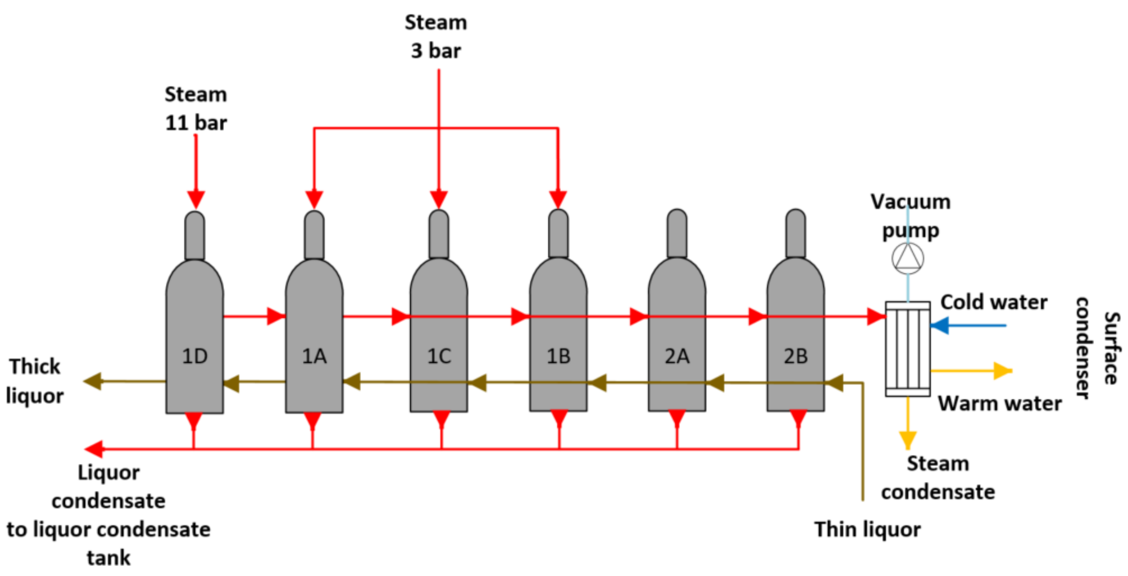

Figure 3.4: An example of a multiple-effect evaporation train.

The thin black liquor enters the effect 2B, i.e. to the last effect with the lowest temperature and pressure operation. The water within the liquor evaporates gradually through the effects and the liquor leaves the effect operating at the highest pressure as thick black liquor and is supplied to the recovery boiler. Increased efficiency is obtained by pre-heating the liquor with a lower temperature, by heat exchanging with the condensate leaving the effects.

As described the evaporation sections of Södra Cell Mönsterås requires a lot of intermediate and low pressure steam. Warm water is produced when condensing the steam using cold water in the surface condenser. Also, a lot of hot liquor condensate is produced, which is supplied to a liquor condensate tank. From there, the condensate is used to cool liquor, producing hotter water, which is then mixed with hot water from the hot water tank before being supplied to the bleaching sections. The amount of steam and warm and hot water consumed/produced within the evaporation sections is given in Table 4.4 and Table 4.6 respectively.

3.2.2 The Power and Causticization Section

At Södra Cell Mönsterås, high-pressure steam of 60 bars at 475 °C is generated by combustion of thick black liquor in the recovery boiler and by combustion of biofuels (bark, sawdust and screening rejects) in the power boiler. Intermediate pressure steam was also produced in a separate strong gas boiler, which was shutdown and instead integrated in the recovery boiler in the beginning of January 2017. The steam is supplied to three back-pressure turbines and one condensing turbine to generate electrical energy as well as extracting steam at different pressure levels for use in different processes in the mill. Intermediate pressure steam of 26 bars at 380 °C is used for soot removal in the recovery boiler. In addition to that, steam of 11 bars at 200 °C as well as low-pressure steam of 3 bars at 160 °C is used to heat 60 % of the primary and secondary combustion air to 160 °C, which corresponds to 60 % of the total added air in the recovery boiler. The intermediate pressure steam at 11 bars is also used to adjust the end temperature of the thick liquor and to split the melt falling out from the boiler. Flue gases at a temperature of 197 °C is produced in the recovery boiler and released out to the atmosphere. This is also true for the power boiler, which produces and releases flue gases at a temperature of 142 °C out to the atmosphere. The total electricity supply and use during 2016 can be seen in Table 4.1.

A feed water system is needed in order to be able to produce steam. The feed water to the boilers comprise of condensate and dilution water. The condensate stem from steam condensate from the turbines and is very pure, why as much steam condensate as possible is recycled back to the feed water tanks. The steam that has been directly injected into the process does not produce any condensate that can be recycled back to the feed water tank. Therefore it has to be replaced by dilution water, which is raw water that has been mechanically treated, chemically treated, desalinated and heated in different steps. It is important that the feed water is free from salts that otherwise can form coatings in the boiler or in other parts of the steam system. It is also important that the dilution water is free from volatile oxygen, since it otherwise can cause corrosion on boiler tubes and/or heat exchangers. Low-pressure steam of 3 bars at 160 °C is consumed by the feed water tanks in order to heat the feed water. Also, the feed water is being heat exchanged with hot water. The feed water system is further described in Section 4.1.

At the bottom of the recovery boiler, a melt falls out as a byproduct in to dissolving tanks, where it is mixed with wash water from the lime kilns to create green liquor. Since the melt is very hot, a great amount of wash water is evaporated. The generated steam is then heat exchanged with warm water in a mist condenser, which produces hot water. This hot water is used to heat the feed water and the internal heating network before being supplied back either to the mist condenser or the warm water tank. The green liquor is transported to the causticization section, where it is mixed with calcium oxide, also known as lime. Insoluble calcium carbonate, also known as limestone, is created and is separated in the slaker. The remaining liquor then contains the same active compounds as the provided liquor in the digester; the white liquor. Hence, the produced white liquor is pumped back to the digester section and the circle is complete, which is illustrated in Figure 3.5. The separated limestone is washed before inserted into the lime kilns. The lime kilns uses bark dust as fuel, but also screening rejects, tall oil, tall oil pitch, methanol and fuel oil when needed. Also the lime kilns consumes a small amount of intermediate pressure steam of 11 bars at 200 °C. At high temperatures (900 °C), calcination occurs and lime is created out of the limestone. The lime kilns produces hot flue gases at 250 °C, which is released to the atmosphere. The causticization section, including the lime kilns, has a low demand of intermediate pressure steam at 11 bars and no demand of warm and hot water. The amount of steam and warm and hot water produced and consumed within the power and causticization section can be seen in Table 4.3, 4.4 and 4.6 respectively.

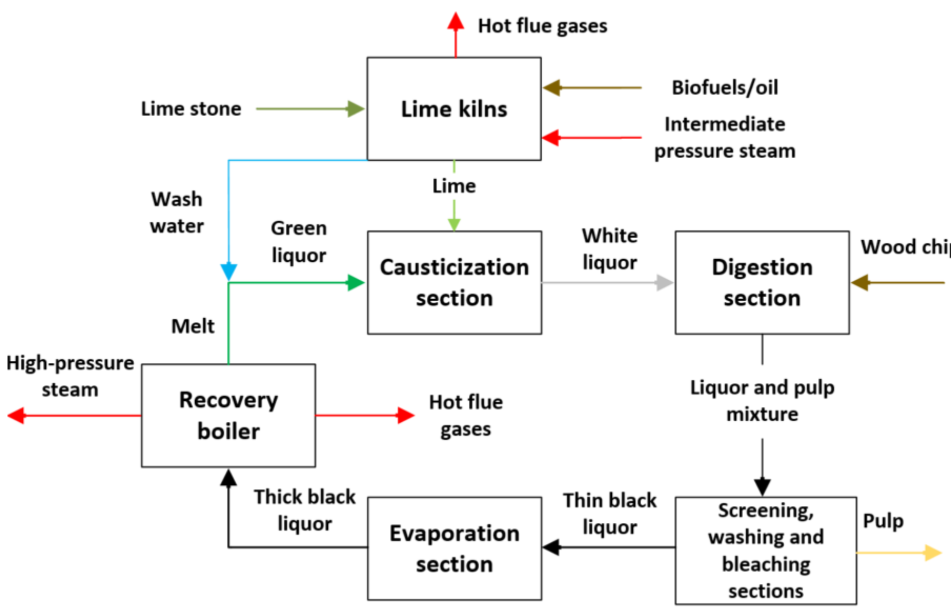

Figure 3.5: The recovery cycle of Södra Cell Mönsterås.

4
The Energy System of Södra Cell Mönsterås

Södra Cell Mönsterås demands a great deal of energy and raw materials in order to produce pulp. However, lots of energy and substances are generated and/or recovered within the pulp mill. In fact, the pulp mill of Södra Cell Mönsterås is self-sufficient in supply of energy from the incoming wood raw material and even converts and recovers an excess of electrical and thermal energy. Figure 4.1 shows the in- and outflows of energy for the mill during the year of 2016 [16].

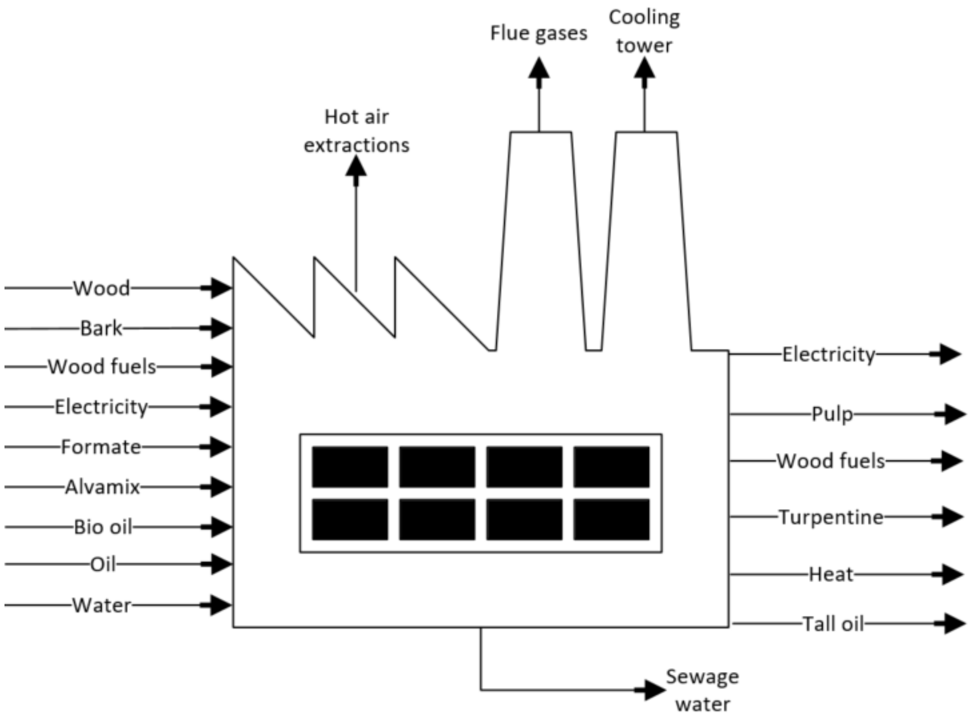

Figure 4.1: The in- and outflows of energy for Södra Cell Mönsterås during 2016.

721 792 ADt pulp was produced at Södra Cell Mönsterås during 2016. Roughly 50 % of the wood raw material ends up as pulp. The other half will first end up as turpentine and thin black liquor, which in turn falls out as tall oil and thick black liquor. The latter is combusted in the recovery boiler to generate electricity and the turpentine and the tall oil are sold to customers. The bark, which is debarked from the logs, is initially dried before facing three different fates, namely (1) used as biofuel in the power boiler, (2) used as pulverized biofuel in the lime kilns or (3) sold

as biofuel. When there is a deficit of bark, bark and sawdust from Södra's sawmills are imported and used as fuel in the power boiler and lime kilns. If there is a total deficit of wood fuel, a substitute fuel has to be used. Historically oil (EO1 and EO3) as well as small quantities of gas have been used for this purpose. However, Södra Cell Mönsterås pursuit to be free from usage of fossil fuels has lead to an increase use of bio-oil, such as tall oil, tall oil pitch and methanol, instead of oil and gas, which has in turn led to a decrease of the fossil fuel use.

The combustion of the thick black liquor in the recovery boiler and the bark in the power boiler generate high pressure steam. The high pressure steam is expanded in the turbines to generate electrical energy. The majority of this electricity is used within the internal pulping process, but sometimes the production is higher than the consumption. This excess is sold to the sawmill of Mönsterås and to E.ON. Sometimes the opposite is true and then they have to buy electricity from E.ON. Primary heat, i.e. steam, at different pressures are also extracted from the turbines. This thermal energy is used at different parts of the pulp mill. However, the excess heat from the pulping process is recovered in the secondary heating system and in various process streams, which in turn act as a heat source to different parts of the pulp mill. Around 24,5 billions of litres of fresh water (34 m^3/ADt) were taken into the mill during 2016. Water is an essential part of the secondary heating system. 80 - 90 % of the heat delivered to the internal and external heating networks is provided by the secondary heating system. Primary heat is used for the last 10 - 20 %. The consumers of heat from the external heating network are the Mönsterås sawmill and the municipality of Mönsterås. The internal heating network is used to heat up office spaces and workshops. It is also used to heat up a separate network of glycol, which is used for heating of the ventilation air and the combustion air to the boilers. Table 4.1 shows the electricity supply and usage and the heat deliveries during the year of 2016.

Table 4.1: The electricity supply and usage as well as heat deliveries at Södra Cell Mönsterås during 2016.

Electricity	GWh/year	kWh/ADt		**Heat**	GWh/year	kWh/ADt
Imported from E.ON	9	13		Used internally	115.9	161
Produced within the mill	740	1 025		To the sawmill	101.7	141
TOTAL SUPPLY	**749**	**1 038**		To the municipality	66.7	92
Sold to E.ON	180.3	250		**TOTAL DELIVERIES**	**284.3**	**394**
Sold to the sawmill	22.4	31				
Used internally	546.3	757				
TOTAL USE	**749**	**1 038**				

Alvamix and formate, which are residual products from other industries, are imported to generate sodium compounds, which are used in the causticization and digester section. The total energy efficiency of the mill of Mönsterås during the year of 2016 is estimated to just below 45 %. Just over 55 % of the energy is lost through hot flue gases, hot sewage water, cooling tower and hot air extractions from tanks and from the drying section. Table 4.2 gives the energy balance in numbers.

Table 4.2: The energy balance of Södra Cell Mönsterås for the year of 2016 [16].

IN	GWh/year	kWh/ADt		**OUT**	GWh/year	kWh/ADt
Wood	7 942	11 000		Pulp	3 448	4 777
Bark	662	917		Wood fuels	19	26
Wood fuels	1	2		Electricity	203	281
Electricity	9	13		Turpentine	7	10
Formate	1	2		Heat	168	233
Alvamix	23	32		Tall oil	89	123
Bio oil	92	127		Losses	4 868	6 753
Oil	72	100				
TOTAL IN	**8 802**	**12 203**		**TOTAL OUT**	**8 802**	**12 203**

4.1 The Steam System

Around 85 - 90 % of all the generated steam at Södra Cell Mönsterås is generated in the recovery boiler. Almost 98 % of the fuel combusted in the recovery boiler is thick black liquor. The rest comprises of oil, bio sludge and strong gases. At Södra Cell Mönsterås, they also have a power boiler for steam generation. Roughly 10 - 15 % of the total steam generation in the mill is from the power boiler, where 95 % of the fuel is solid biofuels (bark, sawdust and screening rejects) and the rest is oil. Table 4.3 shows the average production by the boilers of high-pressure steam of 60 bars at 475 °C during the studied period, defined in more detail in Section 2.1. Note that the combustion of strong gases is explicitly presented, even though the combustion is integrated in the recovery boiler since the beginning of 2017 and it only manages to produce intermediate pressure steam at 11 bars and 200 °C.

Table 4.3: The average high-pressure steam production and the average contribution of intermediate pressure steam of 11 bars from combustion of strong gases in MW during the studied period.

Recovery boiler	Power boiler	Combustion of strong gas
559	48	2.5

The steam is run through three back-pressure turbines and one condensing turbine. The back-pressure turbines have extractions at different pressure levels in order to supply different sections at the mill requiring steam of different quality. Table 4.4 shows the average consumption of the different steam qualities around the mill of Södra Cell Mönsterås during the studied period. The total production and consumption of steam during the same period was 607 MW and 328.5 MW respectively. The discrepancy is due measurement errors, losses and that lots of the energy content within the steam (160 MW) is used to generate electricity in the condensing turbine.

Table 4.4: Average process steam consumption in MW at different pressure and temperature levels by section during the studied period.

	ÅM26	ÅM17	ÅM11	ÅL5	ÅL3	ÅL 1.5
	26 bars	16.5 bars	11 bars	4 bars	3 bars	3 bars
Section	380 °C	217 °C	200 °C	162 °C	160 °C	145 °C
Recovery boiler	13.42		7.06		8.90	
Digestion			32.13		49.49	
Oxygen bleaching			4.23			
Bleaching		11.91			1.40	
Drying				53.64		
Evaporation			17.50		100.92	
Feed water heating					20.00	
Lime kilns			0.29			
Chemical preparation					1.40	
Heating networks					3.05	0.81
TOTAL	**13.42**	**11.91**	**61.21**	**53.64**	**185.16**	**0.81**

The desalinated dilution water used as feed water to generate steam is heated in several steps according to Figure 4.2. Dilution water at 29 °C, which has been desalinated and chemically treated in separate plants, is firstly heat exchanged in heat exchangers VVX 18A and 18B with hot water to obtain a temperature of 75 °C. The warm water originates from the first evaporation section surface condenser and are heat exchanged with BQ1 backwater and BPO backwater and diluted with hot water from the hot water tank and from the second evaporation section tuning condensers before being heat exchanged with the feed water. The BQ1 backwater comes from a heat exchanging in the external heating network of the sawmill and has a temperature of 70 °C after being heat exchanged in VVX BQ1 MAVA. The BQ1 backwater is then supplied to the sewage. The BPO backwater stem from a BPO backwater tank and is recirculated back to this tank after being heat exchanged with water in VVX BPO MAVA. After being heat exchanged with hot water in VVX 18A and 18B, the feed water is split into two different streams and supplied to two different heat exchangers, VVX 11A and VVX 11B, where they are heat exchanged with hot water from the mist condenser to reach a temperature of 86 °C and 84 °C respectively. Then the feed water streams are supplied to one feed water tank each. The heat exchanged hot water is supplied either to the warm water tank, to the cooling towers or back to the mist condenser. The feed water tanks themselves consumes 20 MW of low-pressure steam of 3 bars at 160 °C to heat the feed water to 125 °C, which is the supply temperature to the boilers. Also, 22.5 MW of hot water is consumed in order to heat the desalinated water, as can be seen in Table 4.6. Note that all numbers are based on average values of the data extracted from the studied period defined in Section 2.1.

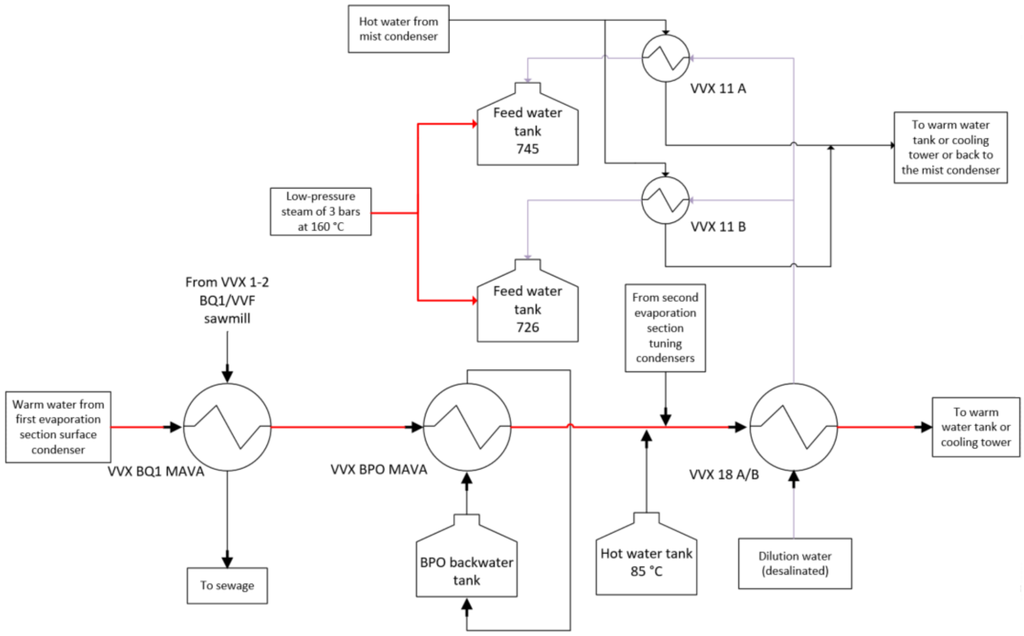

Figure 4.2: The desalinated feed water heating system of Mönsterås mill with marked sensors for the BPO-backwater.

4.2 The Internal and External Heating Networks

Södra Cell Mönsterås have three different heating networks, namely the external heating network connected to the municipality of Mönsterås, the internal heating network and the external heating network connected to the sawmill of Mönsterås. 80 - 90 % of the heat delivered to the heating networks is provided by the secondary heating system either directly or indirectly via various types of backwater. The rest is provided by primary heat. Table 4.1 shows the heat deliveries during the year of 2016 and in Table 4.4 the total consumption of steam by the heating networks can be found. Below, the three different heating networks are further described and all numbers used in the text are based on average values of the data from the studied period, described in more detail in Section 2.1.

The external heating water returning from the municipality of Mönsterås has a temperature of almost 42 °C. It is then first heated by being heat exchanged with hot backwater from the first Q-stage in the bleaching section to reach a temperature of 82 °C. Then it is further heat exchanged in a PO-condenser using PO-gas, which has been used in an earlier step to heat the external heating water for the sawmill of Mönsterås. The external heating water after the PO-condenser reaches a temperature of 82.5 °C and the PO-gas is blown out in the atmosphere. In a final step, 0.81 MW of low-pressure steam of 3 bars at 145 °C is used in order to achieve the desired supply temperature of 86 °C. Figure 4.3 shows the external heating network connected to the municipality of Mönsterås and Table 4.5 shows the average thermal loads of the heat exchangers involved in the heating network of the municipality of Mönsterås during the studied period.

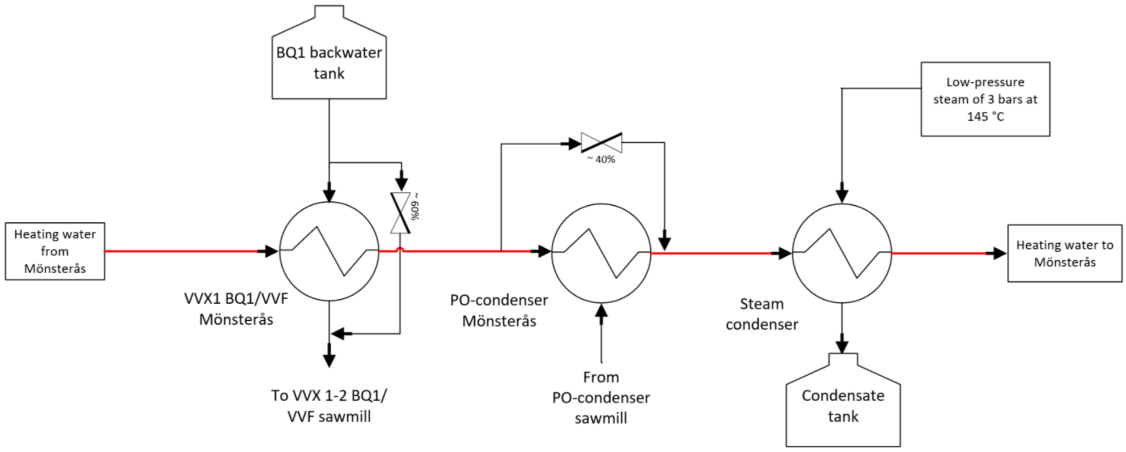

Figure 4.3: The external heating network connected to the municipality of Mönsterås.

The internal heating network delivers heat by heat exchanging the hot heating water with a glycol circuit. The glycol circuit is then connected to different services, such as ventilation coils to heat the air used in the facilities, but the hot heating water does also supply heat to the radiators, delivers heat to the tap water system and preheats the combustion air. The return temperature of the internal heating water is 51 °C. Then it is heated in a heat exchanger (VVX 2:1) with warm water coming from a subsequent heat exchanging (VVX 2:2) with hot water according to Figure 4.4. The heating water leaving VVX 2:2 has a temperature of 73 °C, which is the desired supply temperature. If needed, the heating water can further be heat exchanged with low-pressure steam of 3 bars at 160 °C and then, in a subsequent step, heat exchanged with water that has been heated separately in a hot water boiler. Table 4.5 shows the average thermal loads of the heat exchangers involved in the internal heating network during the studied period.

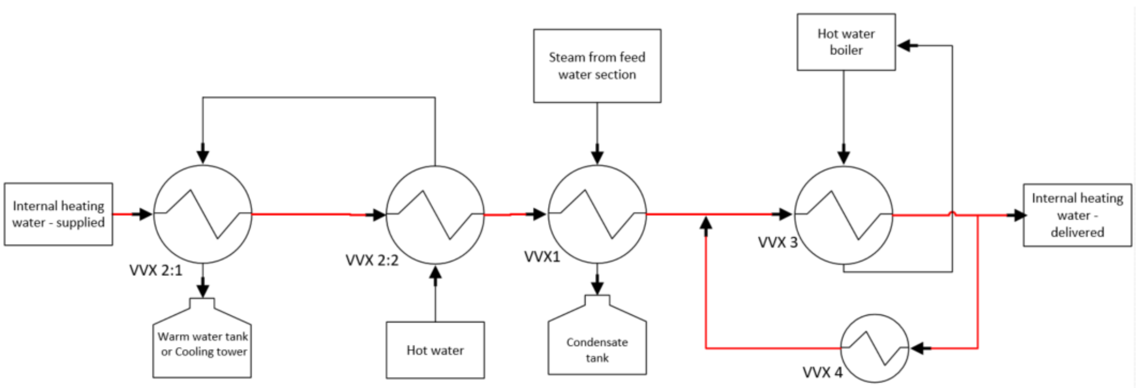

Figure 4.4: The internal heating network.

The heating water returning from the sawmill of Mönsterås has a temperature of 85.4 °C. More than two thirds of this water is run through a separate heating system called Bark and glycol circuit, where heat is extracted in order to heat up the facilities in the wood handling section as shown in Figure 4.5. The inlet heating water temperature to the first of the two heat exchangers, VVX 1-2 BQ1/VVF, is 59 °C. Backwater, coming from the first heat exchanger in the external heating network connected to the municipality of Mönsterås, is used as heat source in these heat exchangers. The backwater is then supplied to feed water heater VVX BQ1 MAVA. The heating water reaches a temperature of 80 °C and then enters a third heat exchanger, VVX LO/VVF, where hot white oxygen liquor with a cooling demand is used as heat source. The heating water then reaches a temperature of 86 °C and passes along to the next heat exchanger, a PO-condenser, which uses hot and moist PO-gas from the bleaching section. The PO-gas continues to the heat exchanger in the external heating network connected to the municipality of Mönsterås and the heating water, with a temperature of 90 °C, continues to the sawmill condenser, which uses flash steam supplied from the digesters when black liquor is extracted. After this heat exchanger, the temperature of the heating water is 104 °C. Lastly, the heating water is heat exchanged with 3.05 MW of low-pressure steam of 3 bars at 160 °C to reach the supply temperature of 105 °C. Table 4.5 shows the average thermal loads of the heat exchangers involved in the heating network of the sawmill of Mönsterås during the studied period. The detailed flowcharts of the heating networks connected to the pulp mill of Mönsterås with marked senors used for data extraction is excluded from the report due to confidentiality reasons.

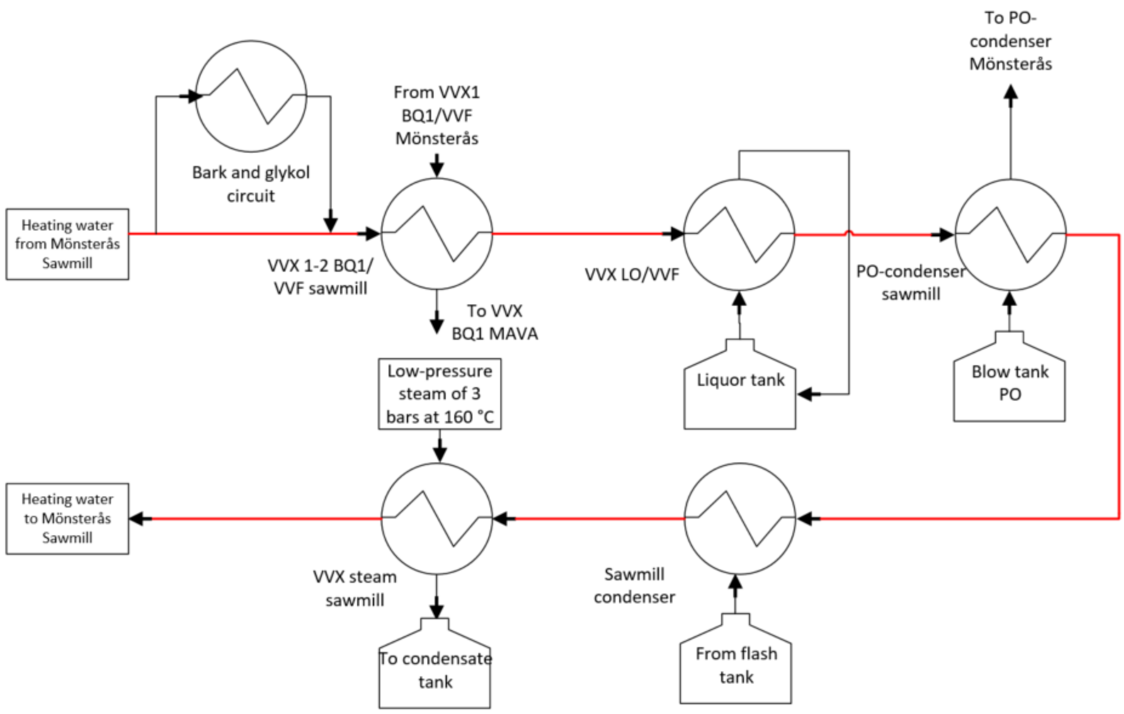

Figure 4.5: The external heating network connected to the sawmill of Mönsterås.

Table 4.5: The average thermal loads of the heat exchangers in the different heating networks during the studied period.

Heat exchanger	T_{in}	T_{out}	$\dot{V}$	Q
	°C	°C	l/s	MW
VVX1 BQ1/VVF Mönsterås	42	82	59	10
PO-condenser Mönsterås	82	82.5	59	0.1
Steam condenser	82.5	86	59	0.9
Total Mönsterås	42	86	59	11
VVX 2:1	51	61	30	1.3
VVX 2:2	61	73	30	1.5
VVX 1	73	73	30	-
VVX 3	73	73	30	-
Total Internal	51	73	30	2.8
VVX 1-2 BQ1/VVF sawmill	59	80	140	12.3
VVX LO/VVF	80	86	140	3.5
PO-condenser sawmill	86	90	140	2.3
Sawmill condenser	90	104	140	8
VVX steam sawmill	104	105	140	0.7
Total Sawmill	59	105	140	27

4.3 The Secondary Heating System - Entire Mill

The need of water as a cold and/or hot utility is not continuous and therefore the water is stored in different tanks at different temperature levels. Those tanks make up the heart of the secondary heating system for the entire pulp mill of Södra Cell Mönsterås. Three major tanks can be found at Södra Cell Mönsterås, namely one with cold water at a temperature of 12 °C, one with warm water at a temperature of 55 °C and one with hot water at a temperature of 85 °C. Table 4.6 shows the average production and consumption of warm and hot water by section around the mill during the studied period defined in Section 2.1.

Table 4.6: Average warm and hot water production and consumption in MW by section during the studied period.

Warm Water Producers		**Warm Water Consumers**		**Hot Water Producers**		**Hot Water Consumers**	
Section	MW	Section	MW	Section	MW	Section	MW
1st evap. surf. condensers	33.64	Backwater coolers	16.84	Digester warm water	38.05	Desalinated water	25.55
Liquor cooler MCO2	4.23	Chem. treated water	4.30	Digester cold water	14.19	Chem. treated water	4.98
2nd evap. surf. condensers	72.90	Glycol circuit	1.18	Backwater coolers	16.84	Internal heating network	2.70
TOTAL	**110.77**	Chem. preparation	6.76	Mist condenser	11.69	O_2 bleaching and bleaching	111.93
		Bleaching	0.73	Liquor cooler 1 & 2	12.61	Chemical preparation	2.82
		Digester	38.05	Liq. cond. evap. 1 & 2	87.60	**TOTAL**	**151.20**
		Mech. treated water	18.20	**TOTAL**	**180.98**		
		TOTAL	**86.06**				

Södra Cell Mönsterås extracts raw water from the river Emån, with an average of 753 l/s at 4 °C during the studied period. This raw water is firstly filtrated in order to remove larger objects. Then, in a second step, it is further treated to remove smaller particles and are then considered to be mechanically treated. Some of this mechanically treated water is then heat exchanged with warm water from the second evaporation plant's surface condensers in VVX 1 + 2 and then used for producing chemically treated water. The cooled water stemming from the second evaporation plant is supplied to the mechanically treating section and subsequently to a large tank with cold water at a temperature of 12 °C. The biggest consumers of cold water is the first evaporation section, the liquor cooler in the oxygen bleaching section, the mist condenser in the recovery boiler, the digester section, for level retaining in the cooling tower pool and in the chemical treatment section for water.

The biggest producers of warm water are the first and second evaporation sections' surface condensers along with the liquor cooler in the oxygen bleaching section. The second evaporation section's surface condensers, however, uses cold water from the cooling tower water pool. During the studied period, 110.77 MW of warm water was produced by these sections, corresponding to an average production of 613 l/s warm water at 55 °C. The produced warm water is then consumed in a complex matter. Two backwater coolers, VVX BQ1/BPO MAVA, are consuming warm water to produce hot water later used for heating of the desalinated feed water. The warm water is heat exchanged with backwater, which has been heat exchanged earlier with heating water in the external heating networks. Some warm water is also consumed to heat up chemically treated water in VVX 10B and the glycol circuit in VVX 61 and VVX 5. A very small amount of warm water is consumed in the tuning condensers of the second evaporation section, to produce hot water. This is however excluded in this project, since it was very small compared to other consumers/producers. The two biggest consumers of warm water is however the digester section and heating of mechanically treated water in VVX 1 + 2 before being chemically treated. The total use of warm water during the studied period was 86.06 MW, corresponding to a demand of cold water of 477.5 l/s being heated from 12 to 55 °C.

The majority of the hot water is gained from evaporation of the water within the thin liquor in the evaporation sections, but also by using warm and cold water as cold utility for the process streams in the digester section. The hot liquor condensate is supplied to a liquor condensate tank, and subsequently used to cool liquor, in the liquor coolers 1 and 2, to create even hotter water. Hot water is also produced when using warm water to cool backwater from the bleaching section, in VVX BQ1/BPO MAVA, and when using cold water along with warm water to heat exchange with the steam produced by the melt from the recovery boiler in the mist condenser. In total, 180.98 MW of hot water was produced during the studied period.

The majority of the hot water is consumed within the bleaching and oxygen bleaching section to dilute and wash the pulp from residual lignin and bleaching chemicals. This hot water is around 90 °C, since water at 85 °C from the hot water tank is mixed with hotter liquor condensate at almost 95 °C from the liquor condensate tank. The backwater produced in the bleaching sections is even hotter, around 100 °C and is used as heat source for feed water heating and for the different heating networks, described in Section 4.1 and 4.2 respectively. A substantial amount of hot water is also used to heat the desalinated feed water in VVX 18A and 18B and VVX 11A and 11B as well as heating chemically treated water in VVX 7 for preheating the combustion air in the recovery boiler. Further, some hot water is also used to heat the heating water in the internal heating network in heat exchangers VVX 2:2 and subsequently VVX 2:1. Hot water is also consumed when preparing chemicals. In total, 151.2 MW of hot water was consumed during the studied period, corresponding to a demand of cold water of 494 l/s being heated from 12 to 85 °C. The discrepancy in energy between the produced and consumed warm and hot water can to a large extent be explained by measurement errors, assumptions made, losses in the pipes, excluded mixings and losses through the cooling towers. Figure 4.6 shows a coarse flowchart of the secondary heating system of the entire mill with the biggest producers and consumers of warm and hot water, meanwhile the more detailed flowchart is excluded from this report due to confidentiality reasons.

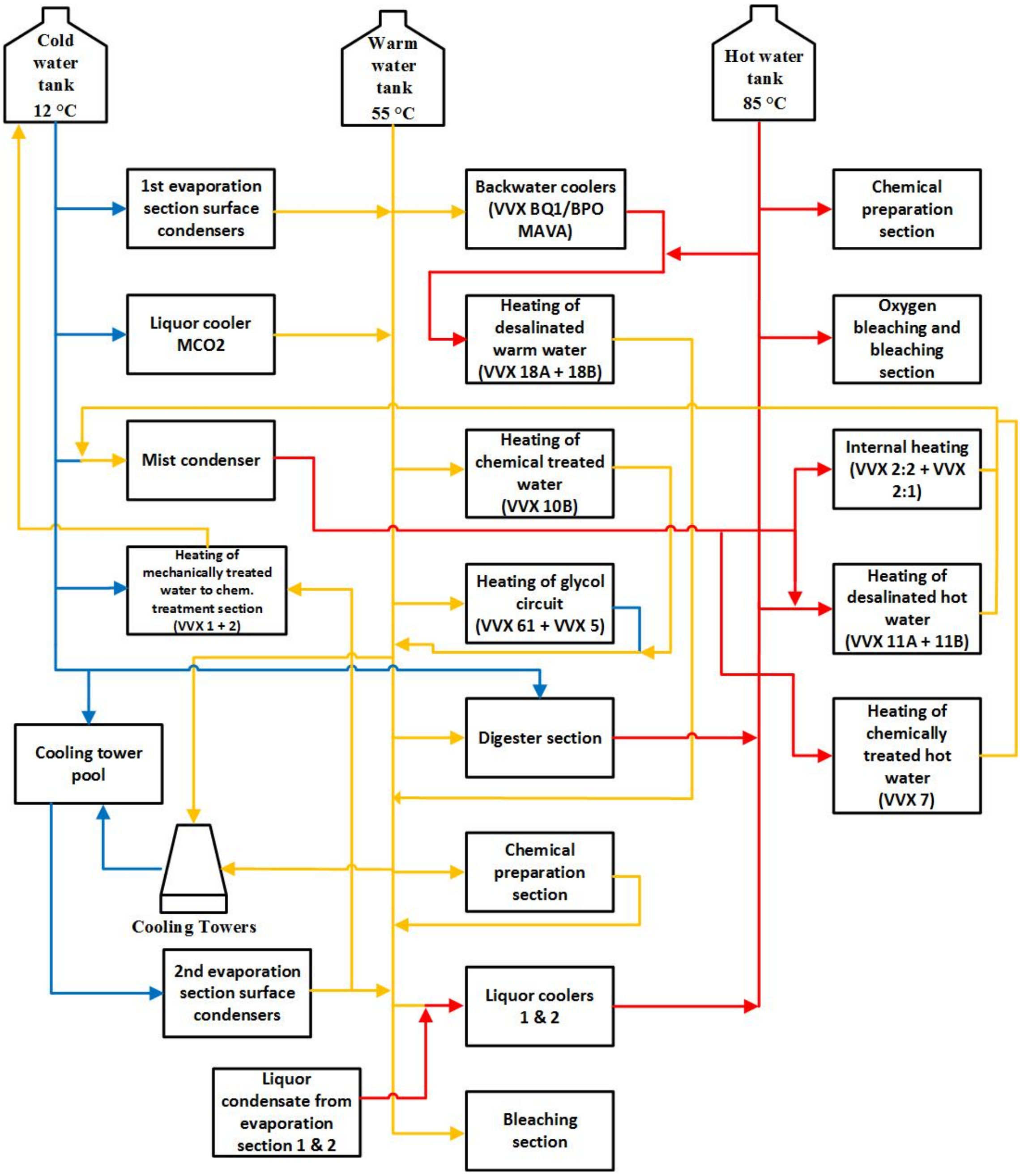

Figure 4.6: A schematic overview of the secondary heating system for the entire mill. The blue lines correspond to cold water, orange lines correspond to warm water and red lines correspond to hot water.

4.4 The Secondary Heating System - Digester Section

In the digester section much heat is recovered by cooling white liquor, BSO-backwater and by flashing and condensing turpentine, which is produced within the digester section. The heat exchanging network integrated with the secondary heating system is built up by 13 heat exchangers, which are consuming cold water at 12 °C supplied from the cold water tank and warm water at 55 °C supplied from the warm water tank. The supplied water is used as cold utility for the process steams, which produces hot water. The hot water is supplied to the hot water tank and from the tank to the different users of hot water around the plant, as shown in Table 4.6. Table 4.7 provides stream data and thermal loads for the warm and hot water producers in the digester section based on calculations and average values from the studied period.

Warm and hot water producers

Below the warm and hot water producers are presented with regards to their main function and what assumption that were made in order to be able to calculate their thermal load. If no other information is given regarding heat exchangers with streams which have liquids with unknown properties such as enthalpy of condensation, heat capacities and densities, the thermal load has been calculated from the water side of the heat exchanger. All heat exchanging processes have been assumed to be adiabatic. Calculations for the water have been preformed by assuming constant heat capacity of 4.18 kJ/kgK and constant density of 998 kg/m^3. If the data was extracted from INFOPLAN or measured and how redundancy is used is presented in Section 5.4.

Heat exchanger for uncondensed turpentine

The main function of this heat exchanger is to condense degassed turpentine from the turpentine condenser K6 and from the primary turpentine condenser, into turpentine condensate. The remaining degassed turpentine is extracted and supplied to a turpentine scrubber, where it is treated, the turpentine condensate is delivered to the turpentine indicator. The cold water is supplied from the cold water tank and the produced warm water is mixed with warm water from the warm water tank, which is used as cold utility in the primary and cooler turpentine condenser. No assumptions had to be made in order to calculate the thermal load of this heat exchanger.

BSO-cooler 1 & BSO-cooler 2

The main function of the BSO-coolers is to utilize excess heat from the BSO-backwater. The backwater is extracted from the backwater tank supplied from the diffuser connected to digester 4, but also from the screening section. The cooled backwater is mixed with white liquor, which have been cooled in Fimp cooler K4 in an earlier step. The mix is then supplied to the degassing vessel. Cold water from the cold water tank is supplied to the first BSO-cooler, which is heated to warm water. The warm water is supplied to the second BSO-cooler producing hot water, which essentially is supplied to the hot water tank.

The volumetric flow of water from the first BSO-cooler was possible to determine by extracting the information from INFOPLAN, but the second BSO-cooler did not have any flow measuring device for the water side and was hard to measure due to practical reasons. In order to be able and determine the thermal load in the second BSO-cooler, the two heat exchangers was assumed to be completely connected in series, i.e. the volumetric flow of the first BSO-cooler is equal to the volumetric flow of the second BSO-cooler. This is not the case in reality since there is a small extraction for the water flow between the two BSO-coolers, meaning that some water is able to by-pass the second BSO-cooler. However, with this assumption the extraction is considered to be a closed valve.

Turpentine condenser K6

The main function of the turpentine condenser K6 is to condense turpentine from the degassed turpentine stemming from the degassing vessel of digester 6. The condensed turpentine is supplied to the turpentine production section and the remaining degassed turpentine is supplied to the heat exchanger for uncondensed turpentine. The heat sink used for this heat exchanger was warm water provided from the warm water tank. The produced warmer water is mixed with several streams and hence heated by those before being supplied to the hot water tank.

In order to be able to calculate the thermal load of this heat exchanger, the warm water flow had to be determined. The warm water flow to both the flash steam condenser and to the turpentine condenser K6 was known. To determine the flow of water to the turpentine condenser K6 and to the flash steam condenser separately, it was assumed that the delivery of water is proportional to the pipe diameter, i.e. the total flow to both these heat exchangers was 58.4 l/s and the pipe diameter of the pipe leading to the turpentine condenser K6 is 80 mm in diameter and the corresponding pipe to the flash steam condenser is 250 mm in diameter, which gives an assumed flow of $58.4 \cdot 80/250 = 18.7$ l/s to the turpentine condenser K6.

Primary turpentine condenser

The main function of the primary turpentine condenser is to cool the degassing steaming condensate from the flash steam condenser, from the flash steam condenser used to heat the heating water for the sawmill and from the degassing vessels from digester 4 and 5. This multiphase steaming condensate is somewhat condensed and separated into different streams, namely turpentine condensate and degassed turpentine. The turpentine condensate is mixed with the turpentine condensate produced in the flash steam condenser and the cooler turpentine condenser and then supplied to the turpentine indicator. The degassed turpentine is mixed with degassed turpentine from digester 6 and supplied to the heat exchanger for uncondensed turpentine. The primary turpentine condenser is supplied with warm water from the heat exchanger for uncondensed turpentine and producing hot water, which is mixed with hot water from the flash steam condenser before being supplied to the hot water tank. No assumptions had to be made in order to calculate the thermal load of this heat exchanger.

Cooler turpentine condenser

The main function of this heat exchanger is to cool the turpentine condensate produced in the flash steam condenser and in the flash steam condenser used to heat the heating water for the sawmill. The cooled turpentine condensate is mixed with turpentine from a turpentine scrubber and then provided to the turpentine production section. The cooler turpentine condenser is supplied with warm water from the heat exchanger for uncondensed turpentine. The produced warmer water is mixed with warm water from the warm water tank and this mix is subsequently supplied to the deduction white liquor heat exchanger 2. No assumptions had to be made in order to calculate the thermal load of this heat exchanger.

Deduction white liquor heat exchanger 2

The main function of this heat exchanger is to cool the white liquor from the secondary flash tank, which is supplied with white liquor from both the digesters and their impregnation vessels. The cooled white liquor is subsequently transported to a white liquor tank located in the evaporation section. The heat exchanger is consuming warm water, provided from the cooler turpentine condenser and the warm water tank. The produced hot water is mixed with several other hot water streams before being supplied to the hot water tank.

By knowing the total volumetric flow of hot water to the hot water tank in the main pipe and by knowing all volumetric flows for each heat exchanger connected to this main pipe, except for this heat exchanger, the volumetric flow of water through this heat exchanger could be calculated.

Liquor cooler

The main function of the liquor cooler is to cool BSO-backwater from and to a pressure diffuser. The backwater is extracted from the cooking liquor by increasing the pressure in a pressure diffuser. This process works as a part of the washing process. The warm water is supplied to the liquor cooler from the warm water tank and the produced warmer water is mixed with the warm water produced in the turpentine condenser K6 before being mixed with the hot water produced in the deduction white liquor heat exchanger 2. No assumptions had to be made in order to calculate the thermal load of this heat exchanger.

Fimp coolers K4 & K5

The main function of the fimp coolers is to cool the cooking liquor from the primary flash tanks. The cooking liquor from the primary flash tank is cooled in the heat exchangers and then mixed with a white liquor stream and a backwater stream, which is supplied back to the degassing vessels. During the study, results from measurements did indicate that the fimp cooler K4 did not operate as it should. Measurements did indicate of steam flashing within the heat exchanger, resulting in bad heat transfer from the hot liquor to the water. The supplied warm water stem from the warm water tank. Very hot water is produced and eventually supplied to the hot water tank.

Since fimp cooler K4 was malfunctioning, the two coolers are assumed to be equally large and consume the same amount of water. They are connected in a parallel configuration and the volumetric flow of water before the water was split was measured and assumed to be equally distributed between the two fimp coolers when working under normal conditions and they are also assumed to be working with the same temperatures, resulting in equally large thermal loads.

Flash steam condenser

The main function of the flash steam condenser is to condense white liquor steam. The white liquor steam is condensed and separated into two different streams, namely turpentine condensate and degassed steaming condensate. The turpentine condensate is subsequently supplied to the turpentine cooler and the degassed steaming condensate is supplied to the primary turpentine condenser. The produced hot water is mixed with hot water from the primary turpentine condenser and further with hot water produced in the deducation white liquor heat exchanger 2 before being supplied to the hot water tank.

In order to calculate the thermal load of this heat exchanger, the warm water flow had to be determined. The warm water flow to both the flash steam condenser and to the turpentine condenser K6 was known. To determine the volumetric flow of water to the turpentine condenser K6 and to the flash steam condenser separately, it was assumed that the delivery of water is proportional to the pipe diameter, just as for the turpentine condenser K6.

Live steam condenser

The main function of the live steam condenser is to cool live steam condensate. The live steam condensate is supplied as a mixture of a streams mainly from the steam used in the heating networks and from the digester 6. The warm water comes from the warm water tank. The measurement of the volumetric flow of water indicated that the flow into this heat exchanger never exceeded 2 l/s, meaning that the hot production by this condenser is negligible compared to others presented.

Deduction white liquor heat exchanger 1

This heat exchanger has the same main function as the deduction white liquor heat exchanger 2. These are connected in a parallel manner with respect to the white liquor. The warm water used as heat sink is supplied from the warm water tank. The produced hot water is mixed with hot water from the two fimp coolers before being mixed with several other streams and supplied to the hot water tank.

In order to calculate the thermal load of this heat exchanger the volumetric water flow had to be determined. In order to do this the liquor flow was calculated for the deduction white liquor heat exchanger 2 giving a white liquor flow of 225.7 l/s, assuming the same properties for white liquor as for water. The total white liquor flow out from both the heat exchangers deducion white liquor heat exchanger 1 and deduction white liquor heat exchanger 2 was possible to extract from INFOPLAN and by assuming that there was no flow of white liquor in very small extractions in comparison to the total flow, which made it possible to determine the thermal load of this heat exchanger. The total volumetric flow of liquor was 371.7 l/s, which gave the white liquor flow in the deduction white liqour heat exchanger 1 to 146 l/s. Knowing the volumetric flow of white liquor, the volumetric flow of water and the thermal load could be calculated, assuming the same properties for white liquor as for water.

Table 4.7: Stream data and thermal loads for the warm and hot water producers in the digester section based on calculations and average values from the studied period.

Heat exchanger	Streams	Hot/Cold	T_{in}	T_{out}	$\dot{V}$	Q
			°C	°C	l/s	MW
Heat exchanger for uncondensed turpentine	Degassed turpentine	Hot	104	61	-	7.0
	Water	Cold	18	62	37.9	
BSO-cooler 1	Backwater	Hot	90	86	-	1.3
	Water	Cold	20	82	4.6	
BSO-cooler 2	Backwater	Hot	90	83	-	0.1
	Water	Cold	84	89	4.6	
Turpentine condenser K6	Degassed turpentine	Hot	99	82	-	1.6
	Turpentine condensate	Hot	-	67	-	
	Water	Cold	50	70	18.7	
Primary turpentine condenser	Steaming condensate	Hot	112	-	-	5.1
	Degassed turpentine	Hot	-	106	-	
	Turpentine condensate	Hot	-	95	-	
	Water	Cold	54	97	28.7	
Cooler turpentine condensate	Turpentine condensate	Hot	102	82	-	0.6
	Water	Cold	55	73	7.8	
Deduction white liquor heat exchanger 2	White liquor	Hot	113	104	225.7	8.5
	Water	Cold	66	90	84.5	
Liquor cooler	Backwater	Hot	95	67	-	1.6
	Water	Cold	48	72	16	
Fimp coolers K4 & K5	Cooking liquor	Hot	133	114	-	2.0 each
	Water	Cold	56	104	20	
Flash steam condenser	White liquor steam	Hot	111	-	-	6.1
	Degassed steaming condensate	Hot	-	94	-	
	Turpentine condensate	Hot	-	97	-	
	Water	Cold	55	92	39.7	
Live steam condenser	Live steam condensate	Hot	101	95	-	0.03
	Water	Cold	86	92	1.3	
Deduction white liquor heat exchanger 1	White liquor	Hot	114	107	146	2.4
	Water	Cold	55	86	18.8	

A simplified flowchart of the secondary heating system in the digester section is presented in Figure 4.7 and the more detailed flowchart is excluded from this report due to confidentiality reasons. Small extractions of water from the pipes and smaller supplies of water in between the heat exchangers are not considered in neither of the flowcharts, since these are negligible compared to the main flows. Two heat exchangers have been excluded, since one of them is shutdown and one of them is very small.

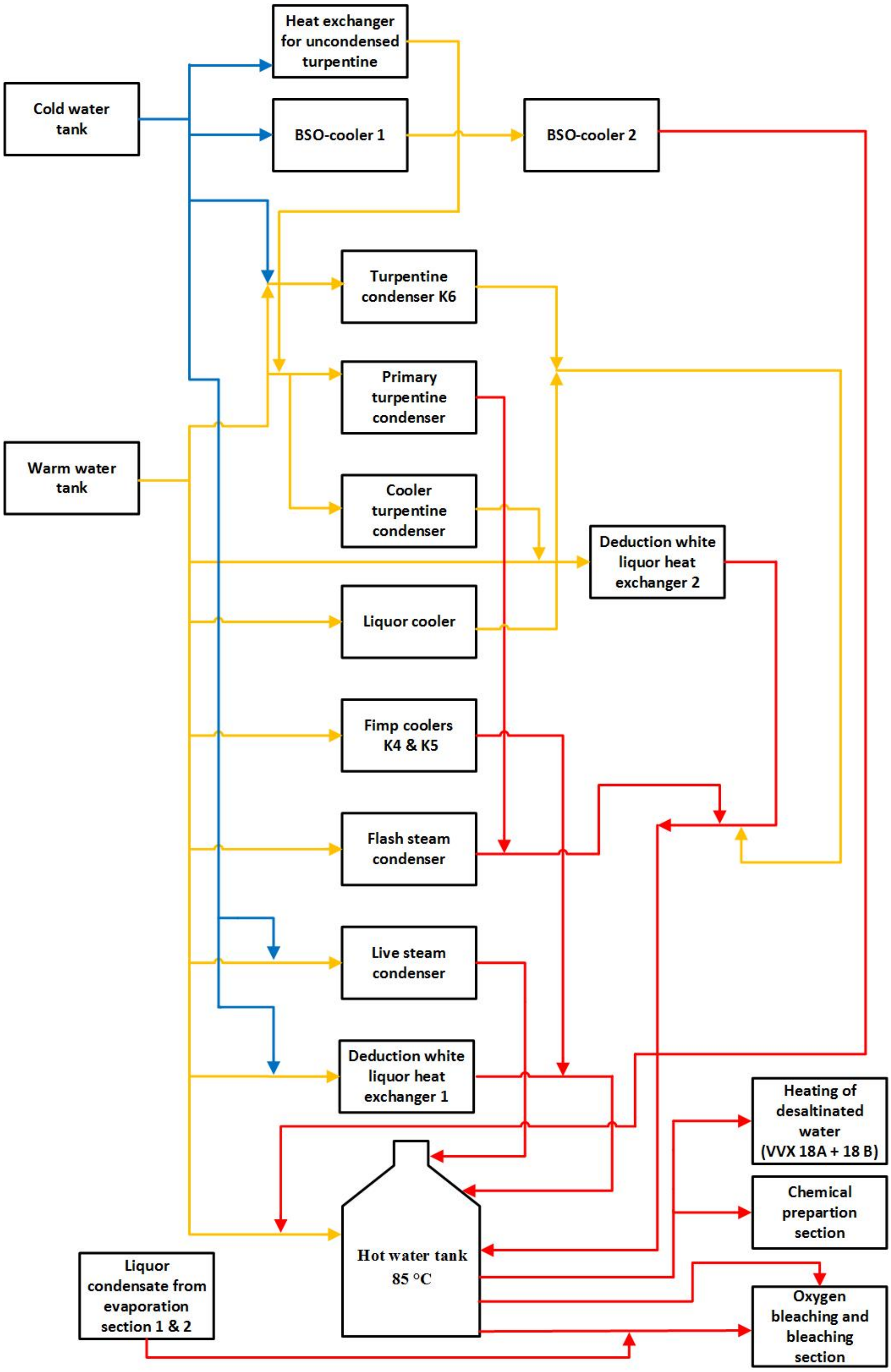

Figure 4.7: A schematic overview of the secondary heating system for the digester section. The blue lines correspond to cold water, orange lines correspond to warm water and red lines correspond to hot water.

5
Data Evaluation

In this chapter the extracted data that is used to describe the different systems in Chapter 4 is described with regards to how it was extracted, what time interval that was used for data extraction and during which period it was extracted. Also, the data is evaluated with regards to variations and availability.

5.1 Steam Data

The steam system is described with regards to steam production and consumption by Tables 4.3 and 4.4 respectively. The data used to create these tables are based on average values of the data from the studied period, which, as described in Section 2.1, corresponds to 272 hours between the 10th of March and the 27th of March 2017. All steam data was, however, extracted from INFOPLAN for every hour of the data extraction period. The variations in total production and consumption of high-pressure steam during this period is shown in Figure 5.1.

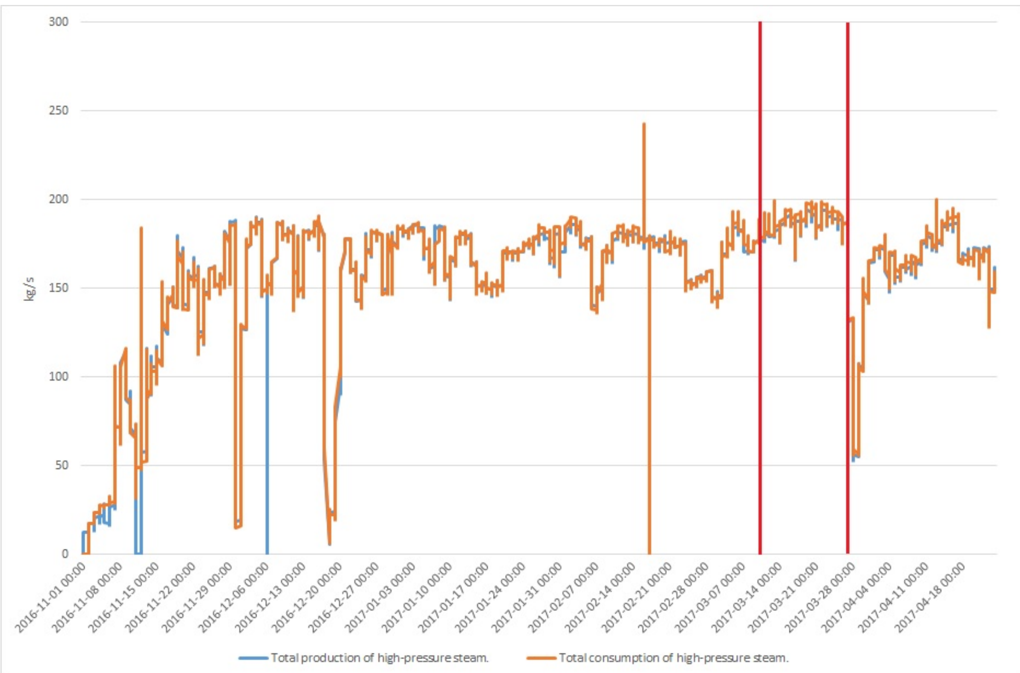

Figure 5.1: The variations of the total production and consumption of high-pressure steam during the data extraction period. The space between the red lines correspond to the studied period.

From Figure 5.1 it can be seen that the consumption overlaps the production almost all the time, which indicate that the extracted data is reasonable. There are some spikes during the period, which are indications of temporarily shutdowns due to problems in the process or change of wood campaign. However, when the process is operating as it should, the production and consumption of high-pressure steam is relatively stable, varying between 150 and 200 kg/s. However, during the studied period, the demand of high-pressure steam is even more stable with an average of 186.4 kg/s and a standard deviation of 4.6 kg/s, meaning that all data within one standard deviation has a deviation of maximum 2.5 % from the average value. Hence, the average value for the demand of high-pressure steam used in this project is a representative value for the whole studied period. In Figure 5.2, the variations in consumption of the different steam qualities around the mill are illustrated during the data extraction period.

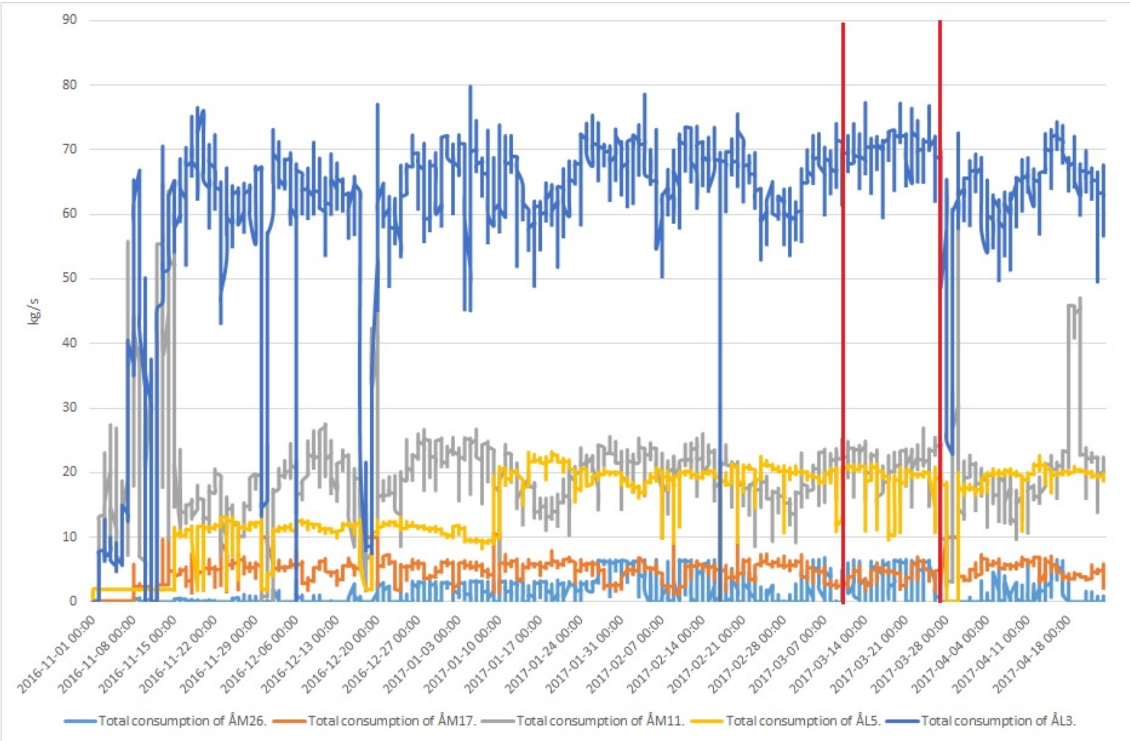

Figure 5.2: The variations of the consumption of different steam qualities in the mill during the data extraction period. The space between the red lines correspond to the studied period.

The variations in consumption of the different steam qualities follow the same trend as the variation of total production and consumption of the high-pressure steam during the data extraction period. The demand of each steam quality is relatively stable around a certain value when the process is operating as it should be. During the studied period, the consumption of the different steam qualities are more stable than during the data extraction period. In Table 5.1, the average values of the aggregated steam consumption of each steam quality used in Table 4.4 and the standard deviations of this data from the studied period is presented. Note that one steam quality, ÅL1.5, is excluded both from Figure 5.2 and Table 5.1, since it was not possible to extract data for this steam quality. Instead, an average value that could be used as a substitute in Table 4.4 during the studied period was estimated by mill process engineers.

Table 5.1: The average values and standard deviations for the aggregated consumption of the different steam qualities in kg/s during the studied period.

	ÅM26	ÅM17	ÅM11	ÅL5	ÅL3
$\bar{m}$	4.2	4.2	21.7	19.3	70.5
σ	2.1	1.1	2.1	2.4	2.2

Judging by Table 5.1, the variations in demand of the low-pressure steam qualities and the intermediate pressure steam of 11 bars are rather stable. Using average values for these steam qualities in calculations during the studied period consequently provides reasonable estimations. However, the demand of the intermediate pressure steam of higher pressures than 11 bars are varying some more during the studied period than the other steam qualities and using their average values for calculations might not provide representative estimations of the actual consumption. One should remember that the flow measures can differ up to 30 % of the actual value.

Almost all relevant steam data necessary for energy audits and energy efficiency studies are available at INFOPLAN, except those presented in Table 5.2. To be able to determine the enthalpy of the steam, the temperature and the pressure of the steam have to be known. In this project, the lacking data was estimated by mill process engineers for winter conditions and hence used in calculations.

Table 5.2: Steam data not available for extraction at INFOPLAN, but in this project estimated by mill process engineers for winter conditions.

Stream	**Source**	**Period**	**Interval**	$\bar{x}_s$	σ_s
Intermediate pressure steam ÅM26 temperature [°C]	Engineering Estimate	Winter conditions	-	380	-
Intermediate pressure steam ÅM26 pressure [MPa]	Engineering Estimate	Winter conditions	-	2.6	-
Low-pressure steam ÅL1.5 temperature [°C]	Engineering Estimate	Winter conditions	-	145	-
Low-pressure steam ÅL1.5 pressure [MPa]	Engineering Estimate	Winter conditions	-	3	-
ÅL1.5 consumed in the heating networks [kg/s]	Engineering Estimate	Winter conditions	-	0.3	-

5.2 Heating Network Data

In this section the data extracted for the different heating networks are evaluated. For all the heating networks, almost all data could be extracted from INFOPLAN. All the extracted data was extracted for each hour during the data extraction period. Figure 5.3 shows the variation in production of heat to the municipality of Mönsterås during the data extraction period and Figure 5.4 illustrates the duration curve of the heat production as well as the heat sources used for providing heat to the municipality for the same period. From Figure 5.3 it can be seen that the heating production varies a lot through out the data extraction period and the spikes occurring during the end of 2016 is corresponding to the spikes seen in Figure 5.1 and are due to temporarily production stops. During the studied period, the average heating water production was 11 MW with a standard deviation of 1.8 MW compared to an average value of 11.8 MW and a standard deviation of 3.2 MW during the data extraction period, when excluding the production stops. With other words, the heating demand varies less during the studied period than during the data extraction period.

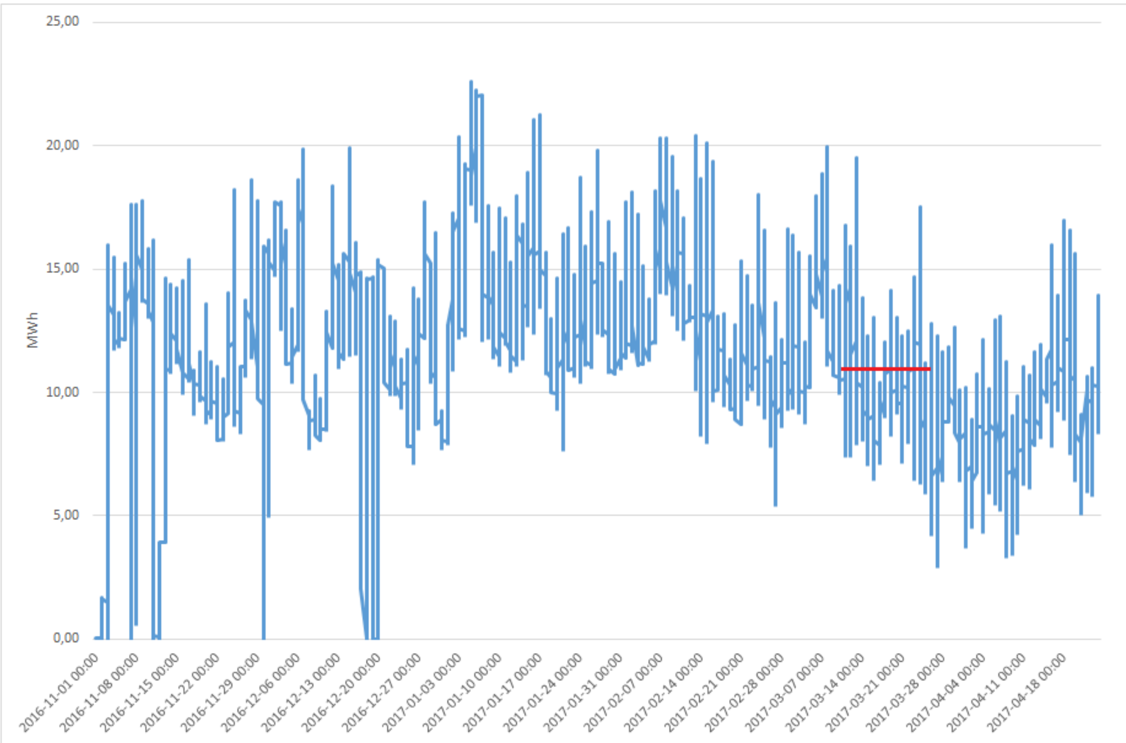

Figure 5.3: The variation of the production of heat to the municipality of Mönsterås during the data extraction period. The red line represents the average production of heating water during the studied period.

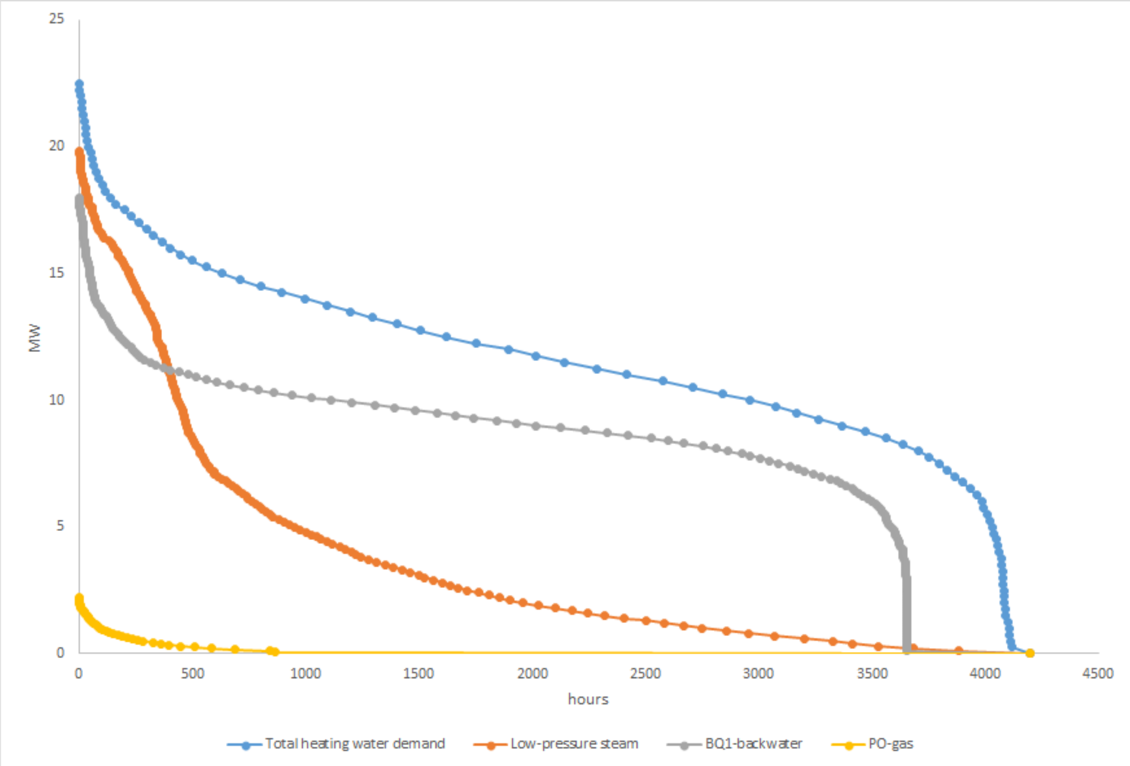

Figure 5.4: The duration curve for the external heating of the municipality of Mönsterås and its heating utilities during the data extraction period.

Looking at Figure 5.4, BQ1-backwater is the base load and low-pressure steam is used for quite many hours as the BQ1-backwater alone can not supply the total heating demand during these hours. During a few hundreds of hours where the demand is peaking, lots of low-pressure steam is used for heating, which might be hard to replace with another heating source using secondary heating. However, some low-pressure steam is used as base load and this could be replaced by hot water or by increasing the temperature of the backwater. During a few hundred hours, the heating effect of the PO-gas is between 1 - 2 MW.

The corresponding figures for the internal heating network are Figure 5.5, which shows the variation in production of heat to the internal heating network during the data extraction period and Figure 5.6, which illustrates the duration curve of the heat production as well as the heat sources used for providing heat to the internal heating network during the same period. During the studied period, the average heating water production was 2.8 MW with a standard deviation of 0.4 MW compared to an average value of 3.2 MW and a standard deviation of 1.1 MW during the data extraction period. Also for the internal heating network, the heating demand varies less during the studied period than during the data extraction period.

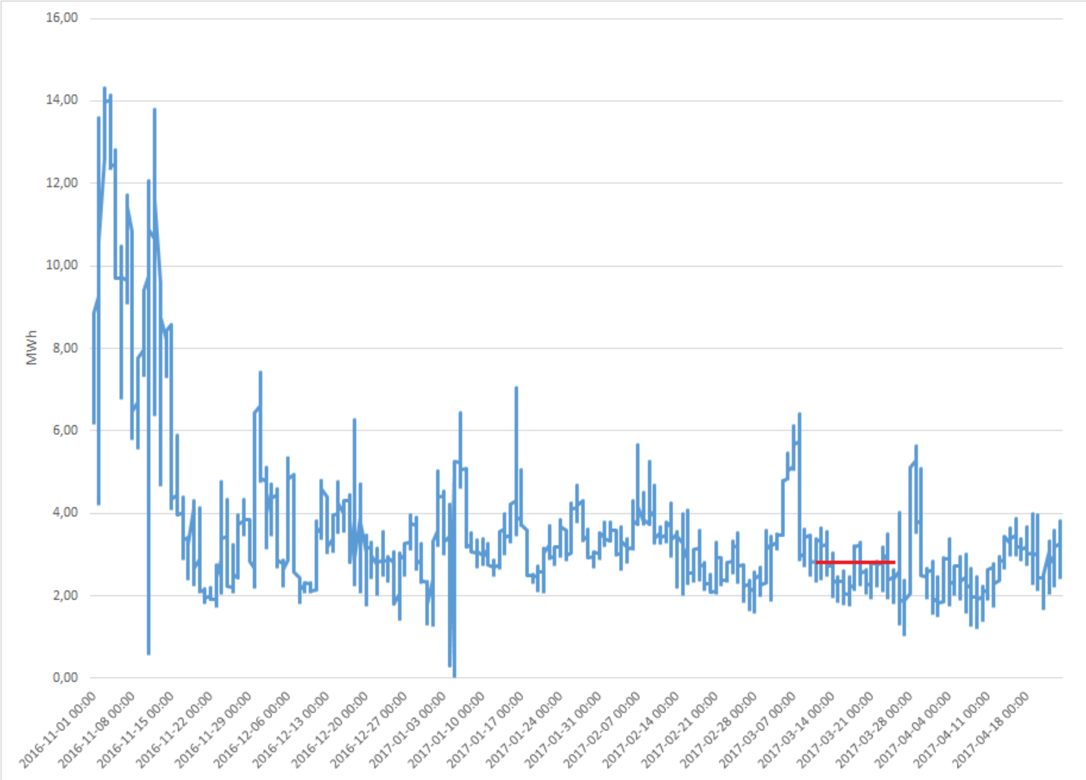

Figure 5.5: The variation of the production of heat for internal use. The red line represents the average production of heating water during the studied period.

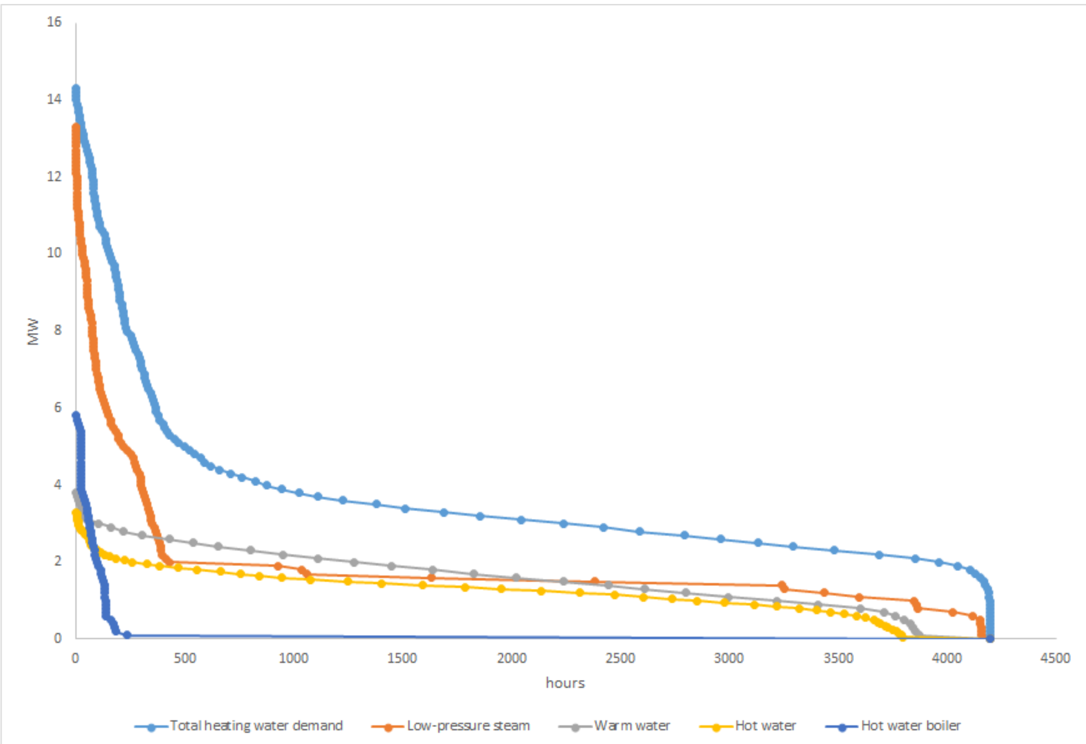

Figure 5.6: The duration curve for the internal heating network and its heating utilities during the data extraction period.

From Figure 5.6, it can be seen that the hot water boiler is used only a few hours during hours when the demand is high. Otherwise it is shutdown. Warm and hot water are used equally much as base load of roughly 2.5 - 3 MW, which is also true for the low-pressure steam. Low-pressure steam is also used during hours of high heating water demand.

The corresponding figures for the sawmill of Mönsterås are Figure 5.7, which shows the variation in production of heat to the sawmill of Mönsterås during the data extraction period and Figure 5.8, which illustrates the duration curve of the heat production as well as the heat sources used for providing heat to the sawmill of Mönsterås during the same period. During the studied period, the average heating water production was 27 MW with a standard deviation of 2.3 MW compared to an average value of 25.6 MW and a standard deviation of 5.6 MW during the data extraction period, when excluding the production stops. With other words, the heating demand varies less during the studied period than during the data extraction period.

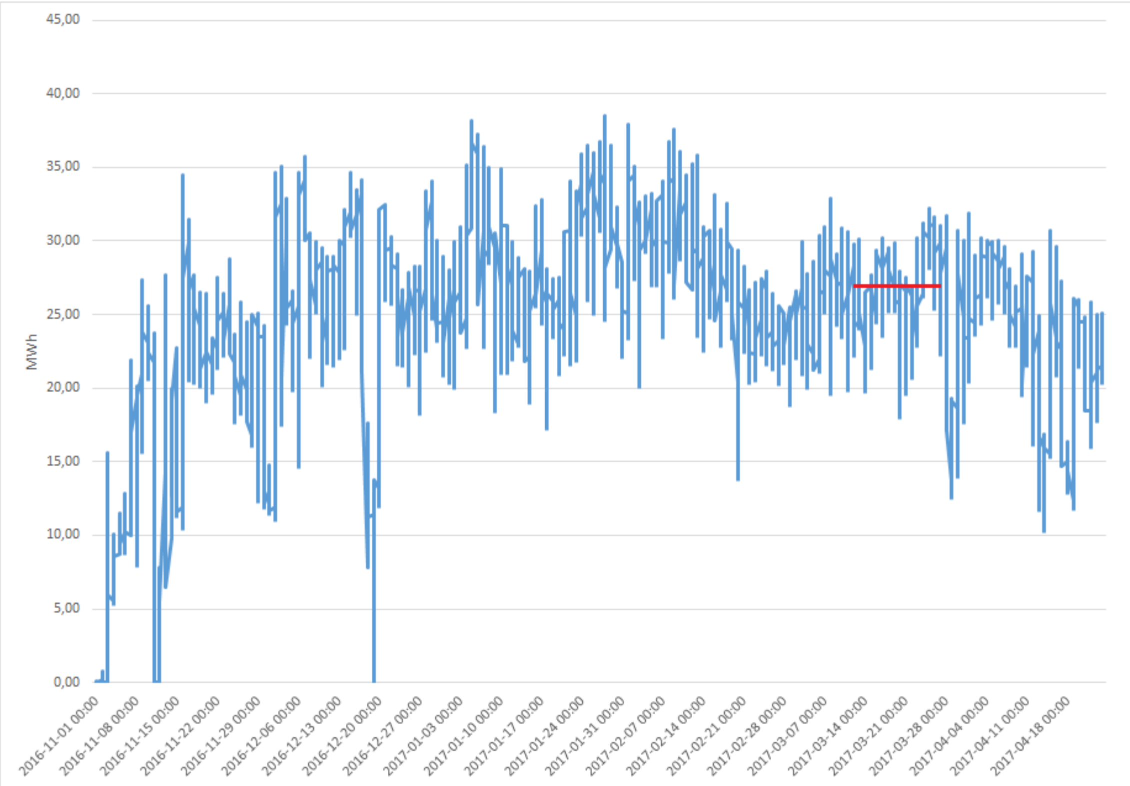

Figure 5.7: The variation of the production of heat to the sawmill of Mönsterås. The red line represents the average production of heating water during the studied period.

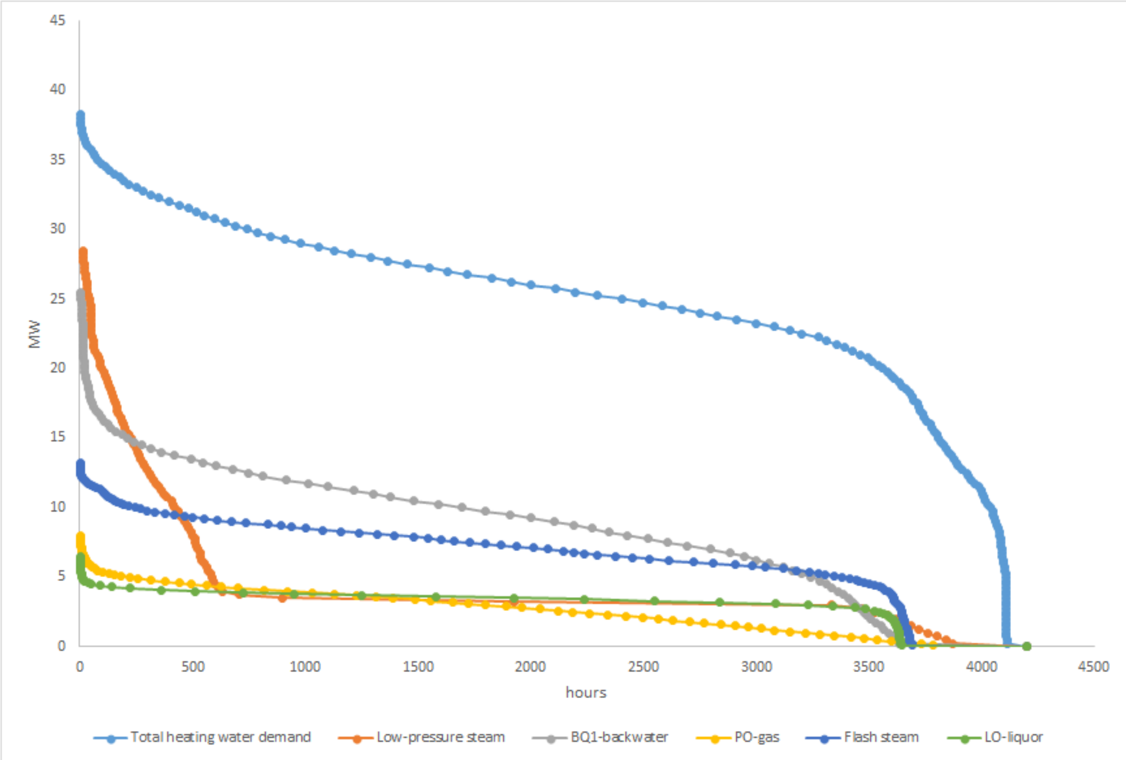

Figure 5.8: The duration curve for the external heating of the sawmill of Mönsterås and its heating utilities during the data extraction period.

Looking at Figure 5.8, the BQ1-water and the flash steam are the most important heat utilities for the heating network connected to the sawmill of Mönsterås. The LO-liquor and the PO-gas are contributing with almost a constant heat load of 5 MW during the whole period and are thus also important contributors. 3 MW of low-pressure steam at 3 bars and 160 °C is also used during the majority of the time. At some time, however, lots of low-pressure steam is used when the demand of heating water to the sawmill is high.

Almost all relevant data for the heating networks necessary for energy audits and energy efficiency studies are available at INFOPLAN, except stream data for the PO-gas. However, all thermal loads of the heat exchangers can be calculated from the heating water side. With other words, the PO-gas heat load was determined from the water side of the heat exchangers.

5.3 Secondary Heating System - Entire Mill Data

Most of the data for the secondary heating system of the entire mill was extracted from INFOPLAN for every hour during the data extraction period. At locations with no data, the information was either collected by engineering estimates in collaboration with the mill process engineers or calculated through mass and/or energy balances. Table 5.3 presents how the stream data, i.e. temperatures as well as volumetric flow, of the most relevant streams in the secondary heating system for the entire mill were extracted along with their average values and standard deviations for the data of the studied period. The heat exchangers in Table 5.3 can be found in Figure 4.6 in Chapter 4.

Table 5.3: Stream data for the most relevant streams in the secondary heating system of the entire mill along with average values and standard deviations for the data of the studied period.

Heat exchanger	**Stream**	T_{in}	$\bar{T}$	σ	T_{out}	$\bar{T}$	σ	$\dot{V}$	$\bar{\dot{V}}$	σ
Heat exchanger	Warm water	INFOPLAN	53.2	1.62	INFOPLAN	35.5	1.1	INFOPLAN	236.5	12
1 + 2	Cold water	INFOPLAN	4.3	1.1	INFOPLAN	19.4	0.5	INFOPLAN	279.5	1.5
1st Evaporation section	Cold water	Engineering Estimate	-	-	INFOPLAN	59	0.6	INFOPLAN	174.2	5.5
Surface condenser	Steam	Engineering Estimate	65	-	Engineering Estimate	65	-	Engineering Estimate	14.2	-
VVX	Backwater	INFOPLAN	71.7	1.6	INFOPLAN	103	0	INFOPLAN	313.2	11
BQ1 MAVA	Warm water	INFOPLAN	59.2	0.8	INFOPLAN	70.2	1.5	Calculated	87.2	-
VVX	Backwater	INFOPLAN	93	1.6	INFOPLAN	86.5	1.3	INFOPLAN	188.9	30.1
BPO MAVA	Hot water	INFOPLAN	70.2	1.5	INFOPLAN	81.2	1.6	Calculated	87.2	-
VVX	Desalinated water	INFOPLAN	30.9	1	INFOPLAN	82.2	2.2	Calculated	116	-
18A + 18B	Hot water	INFOPLAN	83.3	1.7	INFOPLAN	53.6	6.5	INFOPLAN	93.6	8.9
Liquor cooler	Oxygen liquor	INFOPLAN	94	0.6	INFOPLAN	84.4	0.9	INFOPLAN	114.9	10.2
MCO2	Cold water	INFOPLAN	16.8	1.1	Calculated	42.8	-	Engineering Estimate	33	-
Mist condenser	Warm water	INFOPLAN	54.6	1.1	INFOPLAN	82.7	1.4	INFOPLAN	79.8	0
	Steam	Engineering Estimate	90	-	Engineering Estimate	50	-	-	-	-
VVX 7	Hot water	INFOPLAN	87.6	0.6	INFOPLAN	56.9	0.6	INFOPLAN	38.7	0.9
	Chemically treated water	INFOPLAN	51.9	0.7	INFOPLAN	83.1	0.6	Calculated	38.1	-
	Warm water	INFOPLAN	54.5	1.1	INFOPLAN	81.7	2	INFOPLAN	2.6	0.3
2nd Evaporation section	Liquor steam	-	-	-	-	-	-	-	-	-
tuning condenser	Various gases	INFOPLAN	80.4	5.1	-	-	-	INFOPLAN	0.1	0
	Condensate	-	-	-	-	-	-	-	-	-
VVX 61	Warm water	INFOPLAN	54.6	1.1	INFOPLAN	15.7	0.8	INFOPLAN	3.7	3
	Glycol	-	-	-	-	-	-	-	-	-
VVX 5	Warm water	INFOPLAN	54.8	1	INFOPLAN	23.4	1.1	INFOPLAN	1.4	0.3
	Glycol	INFOPLAN	23.1	1	INFOPLAN	25	1.4	Calculated	25.7	-
VVX 10B	Warm water	INFOPLAN	54.6	1.1	INFOPLAN	26.1	3.3	Calculated	47.5	-
	Chemically treated water	INFOPLAN	8.3	0.9	INFOPLAN	19.7	1	INFOPLAN	63.4	9.6
Liquor cooler	Thin liquor	INFOPLAN	106.7	1.5	INFOPLAN	95.6	0.6	Calculated	371.1	-
1 & 2	Hot liquor condensate	INFOPLAN	83.4	1.4	INFOPLAN	95.3	1.6	INFOPLAN	221.7	6.9
VVX 2:1	Warm water	INFOPLAN	67.1	0.7	INFOPLAN	54.9	2.2	INFOPLAN	24	3.5
	Heating water	INFOPLAN	51.4	2.2	INFOPLAN	60.8	1.2	INFOPLAN	29.5	1.2
VVX 2:2	Hot water	INFOPLAN	82.9	1.8	INFOPLAN	67.6	0.6	INFOPLAN	24	3.5
	Heating water	INFOPLAN	60.8	1.2	INFOPLAN	73.2	0.1	INFOPLAN	29.5	1.2
VVX 11A	Hot water	Calculated	86.4	-	INFOPLAN	83.4	1.8	INFOPLAN	22	0.5
	Desalinated water	INFOPLAN	82.2	2.2	INFOPLAN	85.7	1	INFOPLAN	18.5	3.4
VVX 11B	Hot water	Calculated	86.4	-	INFOPLAN	82.8	2.1	INFOPLAN	25.5	0.7
	Desalinated water	INFOPLAN	82.5	2.1	INFOPLAN	84.1	1.4	Calculated	50.2	-
2nd Evaporation section	Cold water	INFOPLAN	15.6	4.9	INFOPLAN	55	1.8	INFOPLAN	239.3	32.7
Surface condenser	Cold water	INFOPLAN	15.6	4.9	INFOPLAN	55.7	1.9	INFOPLAN	204.4	17.3
	Steam	Engineering Estimate	65	-	Engineering Estimate	65	-	Engineering Estimate	30.9	-

Table 5.3 does also indicate that some stream data have a rather high standard deviation. Relying entirely on those average values in calculations might not give a fully accurate and representative estimation. In the same table, there are some standard deviations indicating that there are not any fluctuations whatsoever for that particular stream data, which is unlikely. This is an indication of a malfunctioning measuring device. In general, however, the extracted stream data are not varying more than 10 - 12 % from their average values within one standard deviation.

In Table 5.4 individual and independent streams of final consumers and producers of warm and hot water are presented. The supply temperature of these streams are assumed to be equal to the temperature of the tank they originate from, except for hot water going to the oxygen bleaching and bleaching section, which has been calculated, since it is essentially mixed with the liquor condensate from evaporation section 1 and 2, which has been heated in an earlier step in the liquor coolers 1 and 2. The streams volumetric flows could mainly be extracted from INFOPLAN. The standard deviation is high for both the hot water delivered to the VVX 18A and 18B and to the chemical preparation section. These volumetric flows are not reasonable to describe with average values, since it will ultimately affect the entire heat and cooling demand for the mill.

Table 5.4: Stream data for individual and independent streams of final consumers and producers of warm and hot water with average values and standard deviations for the data of the studied period extracted from INFOPLAN.

Producer/Consumer	**Stream**	T_{in}	$\bar{T}$	σ	$\dot{V}$	$\bar{\dot{V}}$	σ
Producer Liquor condensate from evaporation section 1 & 2	Hot water	Engineering Estimate	85	-	Engineering Estimate	257.5	-
Consumer Liquor condensate to oxygen bleaching and bleaching section	Hot water	INFOPLAN	95.3	1.6	INFOPLAN	221.7	6.9
Consumer Oxygen bleaching and bleaching section from hot water tank	Hot water	Engineering Estimate	85	-	Calculated	88.8	7.2
Consumer Mixed hot water and liquor condensate to bleaching sections	Hot water	Calculated	90	-	INFOPLAN	310.5	7.2
Consumer VVX 18A & 18B	Hot water	Engineering Estimate	85	-	INFOPLAN	34.1	17.9
Consumer Bleaching section	Warm water	Engineering Estimate	55	-	INFOPLAN	3.4	1
Consumer Chemical preparation section	Hot water	Engineering Estimate	85	-	INFOPLAN	8.3	6.6

During the mapping studies and construction of flowcharts, some streams have been excluded, due to that it has been hard to find information about those streams. This includes streams for turbine blade cooling, pump coolers, switch gear coolers, backwater from the drying machines, sewage streams and cooling tower streams. For instance, the turbine cooling equipment is for many cases directly connected to the cooling towers, which also not have been investigated into depth, but the interconnections between the cooling towers and the rest of the secondary heating system is nevertheless represented in the constructed flowcharts.

5.4 Secondary Heating System - Digester Section Data

In the digester section, only a few stream data could be extracted from INFOPLAN. Therefore lots of measurements had to be carried out in order to gather all necessary stream data to be able to calculate thermal loads of the heat exchangers. Table 5.5, 5.6 and 5.7 give information of how the inlet temperature, outlet temperature and volumetric flow respectively, for all in- and outlet streams of all the heat exchangers in the digester section were extracted with regards to source, time period and time interval. Average values and standard deviations for the data extracted from INFOPLAN are based on the studied period, which is 272 hours between the 10th and 27th of March, described in more detail in Section 2.1, meanwhile average values and standard deviation for the measured data are based on the measured period.

Table 5.5: The source, time period and time interval for which the stream data for the inlet temperature were extracted along with its average values and standard deviations in [°C].

Heat exchanger	Stream	T_{in}	Time period	Time interval	$\bar{T}$	σ
Heat exchanger for uncondensed turpentine	Degassed turpentine	Measured	10:50 09/12/16 - 14:50 11/01/17	10 min	97.7	1.3
	Cold water	Measured	13:20 15/03/17 - 20:40 17/04/17	10 min	16.5	0.7
BSO-cooler 1	Backwater	Measured	18:20 26/04/17 - 15:20 27/04/17	10 min	84.6	1.3
	Cold water	Measured	09:20 15/03/17 - 05:00 18/04/17	10 min	18.9	0.71
BSO-cooler 2	Backwater	Measured	07:58 09/11/16 - 09:08 11/01/17	10 min	84.6	5.9
	Hot water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	84.3	2.2
Turpentine condenser K6	Degassed turpentine	Measured	11:05 09/11/16 - 15:05 11/01/17	10 min	92.8	1.0
	Turpentine condensate	-	-	-	-	-
	Degassed turpentine	-	-	-	-	-
	Warm water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	49.6	10.7
Primary turpentine condenser	Steaming condensate	Measured	10:20 09/12/16 - 14:40 11/01/17	10 min	105.8	1.1
	Degassed turpentine	-	-	-	-	-
	Turpentine condensate	-	-	-	-	-
	Warm water	Measured	10:20 09/12/16 - 14:40 11/01/17	10 min	50.8	1.0
Cooler turpentine condensate	Turpentine condensate	Measured	11:20 09/11/16 - 15:20 11/01/17	10 min	96.2	4.1
	Warm water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	55.3	1.2
Deduction white liquor heat exchanger 2	White liquor	Measured	01:00 26/11/16 - 15:30 11/01/17	10 min	106.3	1.4
	Warm water	Measured	12:00 14/03/16 - 14:00 18/04/17	10 min	62.3	1.5
Liquor cooler	Backwater	Measured	18:25 26/04/17 - 15:15 27/04/17	10 min	89.7	1.7
	Warm water	Measured	12:40 14/03/17 - 11:50 27/03/17	10 min	45.4	3.1
Fimp cooler K4	Cooking liquor	Measured	07:00 09/11/16 - 03:50 04/01/17	10 min	124.7	7.0
	Warm water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	55.9	1.2
Fimp cooler K5	Cooking liquor	Measured	01:00 26/11/16 - 10:10 25/04/17	10 min	126.0	0.0
	Warm water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	55.9	1.2
Flash steam condenser	White liquor steam	Measured	11:40 09/12/16 - 12:10 16/01/17	10 min	104.5	1.4
	Degassed steaming condensate	-	-	-	-	-
	Turpentine condensate	-	-	-	-	-
	Warm water	Measured	11:00 09/12/16 - 15:10 11/01/17	10 min	51.9	1.8
Live steam condenser	Live steam condensate	Measured	12:50 18/04/17 - 10:40 25/04/17	10 min	94.9	2.2
	Hot water	Measured	12:00 14/03/17 - 15:40 02/04/17	10 min	80.8	5.1
Deduction white liquor heat exchanger 1	White liquor	Measured	01:10 26/11/16 - 09:30 11/01/17	10 min	107.1	1.3
	Warm water	Measured	12:00 14/03/17 - 13:40 18/04/17	10 min	51.9	1.5

Notes: Average values and standard deviations for the data extracted from INFOPLAN are based on the studied period, which is 272 hours between the 10th and 27th of March, meanwhile average values and standard deviation for the measured data are based on the measured period.

From Table 5.5, it can be seen that only 5/26 inlet stream temperatures can be extracted from INFOPLAN. The other 21 have to be measured. The measurements were carried out at different time periods due to practical reasons, but all the measurements produced rather low volatile data. It should, however, be noted that extracted/measured data from shorter periods is likely to be less volatile than extracted/measured data from longer periods. Based on this, one can not conclude that the former data vary less in general than the latter. The inlet temperature of the cooking liquor to Fimp cooler K5 could not be properly measured, since the sensor melted all the time, explaining the standard deviation of 0. The data for the inlet temperature of the warm water entering the turpentine condenser K6 had the biggest variations, with a variation of almost 22 % from the average value within one standard deviation. Consequently the average value for this stream is not representative for the studied period. The other values are not deviating more than 10 % from its average value within one standard deviation and thus, when used in calculations of thermal loads, produces representative estimations of the actual thermal loads of the heat exchangers.

Table 5.6: The source, time period and time interval for which the stream data for the outlet temperature were extracted along with its average values and standard deviations in [°C].

Heat exchanger	Stream	T_{out}	Time period	Time interval	$\bar{T}$	σ
Heat exchanger for uncondensed turpentine	Degassed turpentine	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	60.7	17.4
	Warm water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	61.9	5.1
BSO-cooler 1	Backwater	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	86.4	0.9
	Hot water	Measured	12:00 14/03/17 - 14:50 18/04/17	10 min	77.5	7.5
BSO-cooler 2	Backwater	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	83.2	0.5
	Hot water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	88.9	0.4
Turpentine condenser K6	Degassed turpentine	-	-	-	-	-
	Turpentine condensate	Measured	18:35 26/04/17 - 15:05 27/04/17	10 min	63.2	2.8
	Degassed turpentine	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	81.8	7.5
	Warm water	Measured	07:30 15/11/16 - 18:50 15/01/17	10 min	65.6	8.3
Primary turpentine condenser	Steaming condensate	-	-	-	-	-
	Degassed turpentine	Measured	17:40 18/04/17 - 09:40 25/04/17	10 min	99.8	1.0
	Turpentine condensate	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	94.9	1.6
	Hot water	Measured	16:37 14/03/17 - 13:47 18/04/17	10 min	91.1	2.8
Cooler turpentine condensate	Turpentine condensate	Measured	07:10 09/11/16 - 15:20 11/01/17	10 min	76.9	5.8
	Hot water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	73.1	1.7
Deduction white liquor heat exchanger 2	White liquor	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	104.1	1.5
	Hot water	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	90.2	1.7
Liquor cooler	Backwater	Measured	18:30 26/04/17 - 15:10 27/04/17	10 min	63.2	1.7
	Warm water	Measured	12:00 14/03/17 - 11:10 27/03/17	10 min	67.3	3.32
Fimp cooler K4	Cooking liquor	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	120.8	1.5
	Hot water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	66.3	2.7
Fimp cooler K5	Cooking liquor	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	114.0	3.0
	Hot water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	104.2	4.0
Flash steam condenser	White liquor steam	-	-	-	-	-
	Degassed steaming condensate	Measured	17:30 18/04/17 - 09:40 25/04/17	10 min	87.9	7.5
	Turpentine condensate	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	97.1	0.5
	Hot water	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	91.9	1.9
Live steam condenser	Live steam condensate	Measured	17:50 18/04/17 - 10:50 25/04/17	10 min	89.3	4.9
	Hot water	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	92.3	2.2
Deduction white liquor heat exchanger 1	White liquor	INFOPLAN (& measured)	00:00 01/11/16 - 23:00 24/04/17	60 min	106.7	1.5
	Hot water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	86.1	1.7

Notes: Average values and standard deviations for the data extracted from INFOPLAN are based on the studied period, which is 272 hours between the 10th and 27th of March, meanwhile average values and standard deviation for the measured data are based on the measured period.

Most of the outlet temperatures of the streams were available in INFOPLAN. Some measurements were still required and some of those were even carried out at locations where data was available in INFOPLAN. The reason for this was to create redundancy to be able to evaluate the accuracy of the measurements. To evaluate this, the average values of the measurements were compared with the average values of the data extracted from INFOPLAN at the locations with redundancy. It was found that the measurements underestimate the temperature by an average of 6.4 % with a standard deviation of 0.7 %. To account for this underestimation, 6.4 % was added to all the measured temperatures used in calculations in Table 4.7.

All extracted data for the outlet temperatures has a relatively low spread, except the outlet temperature of the degassed turpentine from the heat exchanger for uncondensed turpentine, whose spread is ±29 % within one standard deviation. All other data has a spread less than ±13 % within one standard deviation, meaning that their average values produces representative estimations when used in calculations.

Table 5.7: The source, time period and time interval for which the stream data for the volumetric flow were extracted along with its average values and standard deviations in [l/s].

Heat exchanger	**Stream**	$\dot{V}$	**Time period**	**Time interval**	$\bar{\dot{V}}$	σ
Heat exchanger for uncondensed turpentine	Degassed turpentine	-	-	-	-	-
	Water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	37.9	2.0
BSO-cooler 1	Backwater	-	-	-	-	-
	Water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	4.6	2.0
BSO-cooler 2	Backwater	-	-	-	-	-
	Water	Measured	08:00 26/04/17 - 12:00 26/04/17	60 min	6.1	0.2
Turpentine condenser K6	Degassed turpentine	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	0.050	0.052
	Turpentine condensate	-	-	-	-	-
	Degassed turpentine	-	-	-	-	-
	Water	Calculated	-	-	18.7	-
Primary turpentine condenser	Steaming condensate	-	-	-	-	-
	Degassed turpentine	-	-	-	-	-
	Turpentine condensate	-	-	-	-	-
	Water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	28.7	4.8
Cooler turpentine condensate	Turpentine condensate	-	-	-	-	-
	Water	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	7.8	0.5
Deduction white liquor heat exchanger 2	White liquor	Calculated	-	-	225.7	-
	Water	Calculated	-	-	84.5	-
Liquor cooler	Backwater	-	-	-	-	-
	Water	Measured	13:00 25/04/17 - 17:00 25/04/17	60 min	16.0	0.2
Fimp cooler K4	Cooking liquor	INFOPLAN	00:00 01/11/16 - 23:00 24/04/17	60 min	18.8	1.8
	Water	Measured K4 + K5	08:00 25/04/17 - 12:00 25/04/17	60 min	20.0	0.3
Fimp cooler K5	Cooking liquor	-	-	-	-	-
	Water	Measured K4 + K5	08:00 25/04/17 - 12:00 25/04/17	60 min	20.0	0.3
Flash steam condenser	White liquor steam	-	-	-	-	-
	Degassed steaming condensate	-	-	-	-	-
	Turpentine condensate	-	-	-	-	-
	Water	Calculated	-	-	39.7	-
Live steam condenser	Live steam condensate	-	-	-	-	-
	Water	Measured	13:00 26/04/17 - 17:00 26/04/17	60 min	1.3	0.1
Deduction white liquor heat exchanger 1	White liquor	-	-	-	-	-
	Water	Calculated	-	-	18.8	-

Notes: Average values and standard deviations for the data extracted from INFOPLAN are based on the studied period, which is 272 hours between the 10th and 27th of March, meanwhile average values and standard deviation for the measured data are based on the measured period.

For energy efficiency studies in general, and for pinch analyses in particular, start and target temperatures for the streams along with the thermal loads for the heat exchangers are the important parameter to collect information about. At Södra Cell Mönsterås there are no explicit information about the thermal loads of the heat exchangers. Therefore the thermal loads have to be calculated using temperature differences, densities, heat capacities and volumetric flows at either side of the heat exchanger. Unfortunately, not that many volumetric flows could be found in INFOPLAN. Consequently many had to be measured or calculated. Mass and energy balances were established in order to reduce the number of measurements required, since the number of available flow meters and the time were restricted. The volumetric flows that were calculated were calculated using average values with certain standard deviations. This produces average values of calculated volumetric flows with increased standard deviation, increasing the spread of the estimations. Also, some assumptions were made to be able to perform these calculations, presented in Section 4.4. However, the extracted volumetric flow data has decently low spread and can be used in calculations for thermal loads to produce representative estimations, except for the water running through the BSO-cooler 1, which has a spread of ±43.5 % within one standard deviation. Also, the extracted volumetric flow for the degassed turpentine going in to the turpentine condenser is highly inaccurate, since it is a multiphase flow. At some locations, there are multiphase flows, which are challenging to measure. The common water flow to the fimp coolers were measured for that reason and because it was practically challenging to measure somewhere else. Due to these practical challenges of flow measures, it was desirable to keep the number of required flow measures as low as possible. However, all necessary flow data was collected in order to perform estimations of the thermal loads of the heat exchangers in the digester section, presented in Section 4.4.

In the digester section, the availability of data in INFOPLAN is very low, in particular data for inlet temperatures of the streams into the heat exchangers and volumetric flows. Temperatures can be measured quite accurately, meanwhile portable flow measures are way more tricky. First of all, it is inconvenient to measure the flow during longer periods of time with a portable flow meter, since the battery time is restricted and it is very sensitive, so it malfunctions easily. Investing in some more stationary flow meters at the water side of the heat exchangers in the secondary heating system of the digester section would ease the mapping of the secondary heating system with regards to flow data and thus also the thermal loads of those heat exchangers.

6

Pinch Analysis

Industrial energy systems typically consist of different streams with temperature targets for a certain process. In industrial processes the systems are usually very complex with different kind of industrial energy equipment and to perform an energy analysis for such a system is a hard task. To be able to analyze complex systems a method called pinch analysis was developed. To understand the background and the theory behind the analysis further information is found in the Handbook of process integration by Kemp [17]. Pinch analysis provides a set of tools by which heat recovery systems can be analyzed and designed. The pinch analysis will answer how much energy that must be added to a process by utilities and how much heat that is possible to recover through an internal heat exchanger network. From the pinch analysis it is also possible to design a heat exchanger network in order to maximize the amount of energy possible to recover by internal heat exchange.

The objective for the pinch analysis is to achieve financial savings by proposing a heat exchanger network in which the amount of external heating and cooling utilities are minimized. One of the strengths of pinch analysis is that the results are easy to represent in graphs, showing the minimum cooling and heating demand for the process.

In this chapter a brief description of the theory of pinch technology is given, along with energy targets from a performed pinch analysis and suggestions on how to improve the analysis for future studies.

6.1 Theory

The pinch analysis is based on the second law of thermodynamics, stating that heat can only be transferred from a heat source to a heat sink if the temperature of the heat source is higher than the temperature of the heat sink. Thereby there must be a temperature difference driving force, for achieving this heat transfer through conduction, convection or radiation. This minimum temperature difference allowed is defined as ΔT_{min}; a small ΔT_{min} will require a larger heat transfer surface.

In order to perform a pinch analysis, information regarding the streams in the process must be gathered. Stream data representing the supply temperature and target temperatures of the streams, their mass flow rates and specific heat capacities are extracted, and are usually presented in a stream table showing the total enthalpy change required to reach the target temperature. Streams in need of heating are defined as cold streams and streams in need of cooling are defined as hot streams. To establish energy targets showing the minimum heating and cooling demand and the potential to heat exchange the streams in the process, the composite curves are constructed. The composite curve (CC) is constructed by calculating the total enthalpy change of all the streams within different temperature intervals. One CC is constructed for the hot streams and one for the cold streams. The temperature intervals are chosen from the different start and target temperatures for the streams in the process.

An example of a process consisting of four different streams of which two are in need of cooling and two are in need of heating is presented in Table 6.1. The constructed CCs are presented in Figure 6.1.

Table 6.1: An example of a stream data table with two streams in need of cooling and two streams in need of heating.

Stream	H/C	T_{start} (°C)	T_{target} $(°C)$	F_p (kW/K)	ΔH (kW)
1	Cold	20	145	2.0	250
2	Hot	170	60	3.0	330
3	Cold	80	145	4.0	260
4	Hot	150	30	1.5	180

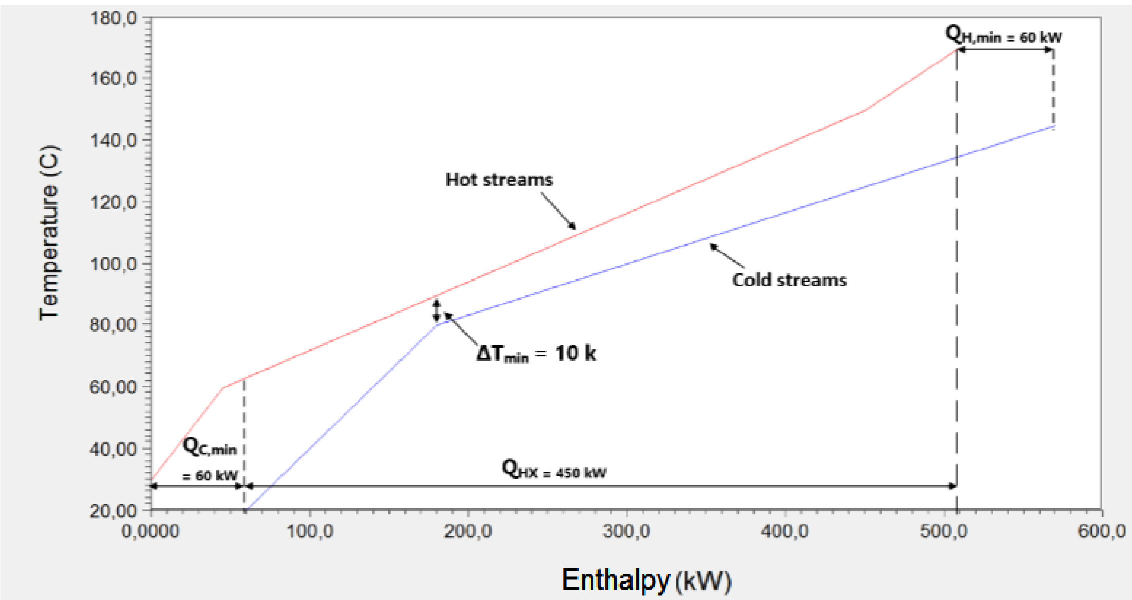

Figure 6.1: Hot (red) and cold (blue) composite curves for the given example. The minimum cooling ($Q_{C,min}$) and heating ($Q_{H,min}$) demand, the heat recovery (Q_{HX}) and the minimum temperature difference (ΔT_{min}) are pointed out.

The graph shows the pinch point, which is determined by moving the cold stream curve in horizontal direction until reaching the minimum allowed temperature difference between the two curves. The CCs show the potential heat recovery (Q_{HX}), which is the region where the two curves overlap. The minimum cooling demand ($Q_{C,min}$) and the minimum heating demand ($Q_{H,min}$) can also be determined from the graph.

The streams can also be represented in a so called grand composite curve (GCC), which shows the net heat deficit and the net heat excess between different temperature intervals, after the possible internal heat exchange between the streams in the temperature intervals have been accounted for. The temperatures in the GCC is shifted, which means that the hot stream temperatures are subtracted with $\Delta T_{min}/2$ and the cold stream temperatures are increased with $\Delta T_{min}/2$. A GCC for the streams given in Table 6.1 is presented in Figure 6.2.

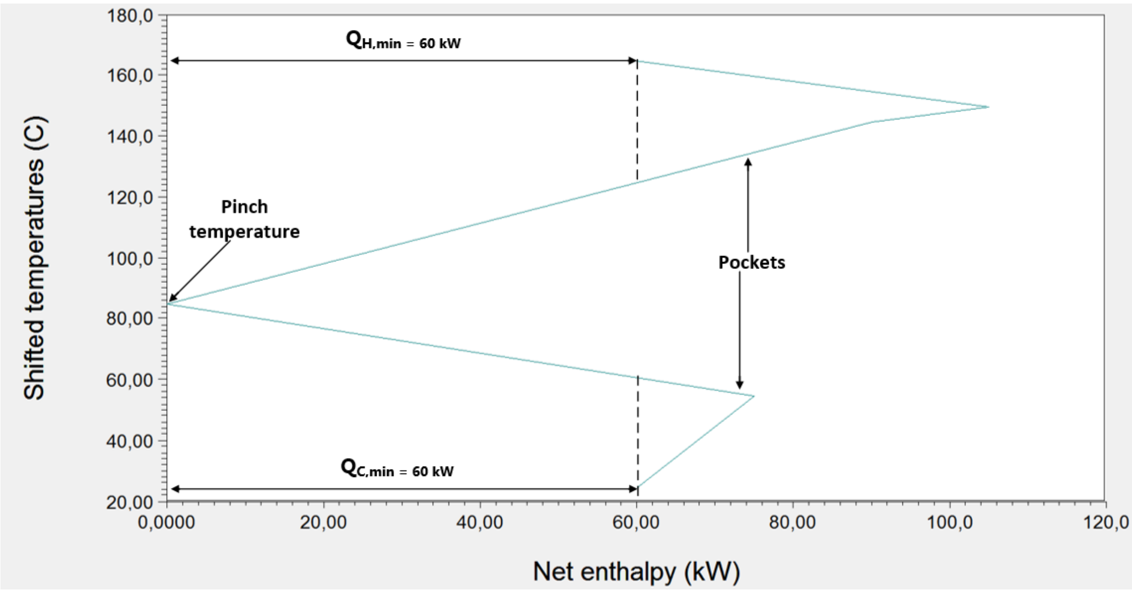

Figure 6.2: Grand composite curve for the given example. The pinch temperature, minimum heating/cooling demand and the pockets are pointed out.

The GCC is easier to use for analyzing the opportunities to integrate a process with the utility systems or another process such as a district heating network, since it represents an aggregated view of the process and shows between which temperature levels there is excess or deficit of heat and how much energy it corresponds to. The pinch temperature is found at the point plotted on the temperature axis, since there is no heat available at the pinch. Above the pinch point, there is a heat deficit of 60 kW and below the pinch there is a heat excess of 60 kW. These corresponds to the minimum hot and cold utilities of the process respectively. The pockets show between which temperature intervals the process is self-sufficient and therefore not in need of any cold or hot utilities. Observe that the minimum hot and cold utilities are achieved by designing a heat exchanger network with maximum energy recovery.

The ΔT_{min} is an important variable and represents the costs of the heat exchangers in the network. As stated, a small ΔT_{min} require larger heat exchanger area and will therefore cost more to manufacture and purchase. Thus the pinch analysis has to be considered an iterative process, using different values for ΔT_{min}, typically between 10 - 20K. The result will be a trade-off between higher initial investment cost and higher long term running costs for external utilities. However, the economical aspects of the pinch analysis are not considered in this project.

6.2 Energy Targets from Pinch Analysis

In order to perform a pinch analysis of the entire mill, streams which are involved in the pulping process, were had to be extracted. The extracted streams are represented in two stream data tables; one for the hot streams, given in Table 6.2 and one for the cold streams, given in Table 6.3. Not all the necessary streams to perform a high resolution pinch analysis were determined, meaning that the produced CCs and GCC only provide a coarse overview of the process minimum hot and cold utilities. In order to perform a more representative pinch analysis for the entire mill, the stream data missing, which is discussed in Section 6.4, have to be taken into account. Another limitation of the performed pinch analysis is that no individual minimum temperature difference has been set for various types of streams. Instead a minimum temperature difference of 10 K has been set globally.

Looking at Table 6.2, the condensation of steam in the evaporation sections' surface condensers are based on the warm water production effect. Further, all process streams in the digester section are represented as hot streams in the pinch analysis. These correspond to stream H8 - H18. The live steam heat exchanger was, however, excluded, since its thermal load was small in comparison to the others and the streams for each fimp cooler are aggregated to one, since fimp cooler K4 was malfunctioning. The different systems at the mill are interconnected, i.e. streams involved in the pulping process are utilized and used in other systems, like heating of facilities, heating of ventilation and heating water supplied to the municipality of Mönsterås. These streams are disregarded from the Pinch analysis, since the aim of the analysis is to find the minimum heating and cooling demand and the possibility for internal heat exchanging within the pulping process itself. Therefore stream H19 is taken from after VVX1 BQ1/VVF Mönsterås. The flue gases from the recovery boiler was included, since currently it is blown out to the atmosphere instead of being used as heat source in for instance a flue gas cooler. The flue gases from the power boiler and the lime kilns have a start temperature of 142 and roughly 250 °C respectively and rather small flows. Since the target temperature of the flue gases was set to 140 °C to avoid condensation of the flue gases, the flue gases from the power boiler and the lime kilns were excluded, since there are almost no available heat to utilize. The start temperature of the flue gases was estimated by mill process engineers. In Table A.1 in Appendix A, a description of how data for all hot streams were extracted and from where it was extracted are given.

Table 6.2: The hot stream data extracted for the entire mill.

Stream	Location	T_{start}	T_{target}	F	$F{\cdot}C_p$	Q
		°C	°C	kg/s	MW/K	MW
H1	Steam condensation first evaporation section surface condenser	65	65	-	-	33.64
H2	Steam condensation second evaporation section surface condenser	65	65	-	-	72.90
H3	Cooling of liquor in the oxygen bleaching section	94	84.4	114.6	0.48	4.60
H4	Cooling demand in mist condenser for the recovery boiler	90	50	-	-	11.69
H5	Liquor condensate from the evaporation sections supplied to condensate tank	85	78	257.5	0.11	7.53
H6	Cooling demand of thin liquor before being supplied to evaporation section in liquor coolers 1 & 2	106.7	95.6	371.1	0.15	17.18
H7	Liquor condensate supplied to the bleaching sections	95.3	90	221.7	0.93	4.9
H8	Heat exchanger for uncondensed turpentine - Digester section	103.7	60.7	-	-	7.04
H9	Backwater cooling in BSO-cooler 1 - Digester section	89.8	86.4	-	-	1.21
H10	Backwater cooling in BSO-cooler 2 - Digester section	89.7	83	-	-	0.10
H11	Turpentine condenser K6 - Digester section	98.7	67.2	-	-	1.56
H12	Primary turpentine condenser - Digester section	112.3	94.9	-	-	5.15
H13	Cooler turpentine condenser - Digester section	102.1	81.6	-	-	0.58
H14	Deduction liquor heat exchanger 2 - Digester section	112.8	104.1	225.7	0.98	8.50
H15	Liquor cooler - Digester section	95.4	67.2	-	-	1.60
H16	Fimp coolers K4 & K5 - Digester section	132.7	114.0	-	-	4.00
H17	Flash steam condenser - Digester section	110.9	93.5	-	-	6.13
H18	Deduction liquor heat exchanger 1 - Digester section	113.6	106.7	159.5	0.35	2.40
H19	BQ1-backwater used for heating of heating water to the sawmill	86.7	40	313	1.31	61.01
H20	BPO-backwater used for feed water heating	93	85.6	188.5	0.79	5.83
H21	VVX LO/VVF using oxygen liquor to heat heating water for sawmill	94	88.6	149.7	0.63	3.50
H22	PO-gas used to heat heating water for sawmill	100	96	-	-	2.30
H23	Flash steam condensate used to heat heating water for sawmill	114	100	-	-	8.00
H24	Flue gas released from recovery boiler	197	140	188.4	0.19	10.83
H25	Mixing warm water from the second evaporation section with raw water	35.5	12	236.4	0.99	23.22
H26	Moist air from the drying section blown out to the atmosphere	56	30	113.3	0.96	25.03

In Table 6.3, the sections with a steam demand are represented as cold streams with temperatures equal to the steam temperatures and are shifted with ΔT_{min}. The steam consumption for soot removal in the recovery boiler and in the lime kilns are not included as heat demands in this analysis, since it can not be replaced. Also, the steam consumed in the heating networks are disregarded as well, since they are not involved in the pulping process. Further, Also, the district heating delivered to the sawmill is represented as a cold stream, since the energy is required and considered to be a part of the pulp mill heat demand. The process demand of warm and hot water as a diluent and/or dissolvent, i.e. where not only the heat content of the stream, but the water properties itself is desired, are considered to be heated from the raw water temperature to the demanded temperature and are thus represented as three cold streams by aggregating all flows between the different temperature intervals. However, the heating demand of cold streams using water as heat source, is included in the stream data table as cold streams. In Table A.2 in Appendix A, a description of how data for all hot streams were extracted and from where it was extracted are given.

Table 6.3: The cold stream data extracted for the entire mill.

Stream	Location	T_{start}	T_{target}	F	F·C_p	Q
		°C	°C	kg/s	MW/K	MW
C1	Heating of desalinated warm water in VVX 18A + 18B	30.9	82.2	116	0.48	24.83
C2	Heating of desalinated hot water in VVX 11A	82.2	85.7	18.5	0.08	0.27
C3	Heating of desalinated hot water in VVX 11B	82.5	84.1	50.1	0.21	0.34
C4	Heating of chemically treated cold water in VVX 10B	8.3	19.7	63.3	0.27	3.02
C5	Heating of chemically treated warm water in VVX 7	51.9	83.1	38	0.16	4.96
C6	Heating of raw water to warm water	4	55	208.8	0.87	44.50
C7	Heating of warm water to hot water	55	85	167.2	0.70	20.93
C8	Hot water mixed with liquor condensate to bleaching section	85	90	88.8	0.37	1.85
C9	Heat demand of the heating network connected to the sawmill	59	105	140	0.59	27.00
C10	Air preheating for the recovery boiler	4	160	101.8	0.10	15.96
C11	Heat demand degassing process in the digesters	150	150	-	-	49.49
C12	Heat demand cooking liquor in digesters	190	190	-	-	32.13
C13	Preheating the oxygen before the O_2-reactors	190	190	-	-	4.23
C14	Heating the bleaching backwater	150	150	-	-	1.40
C15	Heat demand of pulp before PO- and OP-reactors	207	207	-	-	11.91
C16	Heat demand evaporation effects	150	150	-	-	100.92
C17	Heat demand evaporation effects	190	190	-	-	17.50
C18	Heating of the feed water in feed water tanks	150	150	-	-	20.00
C19	Heat demand diluting and dissolving chemicals	150	150	-	-	1.40
C20	Heating of air used for drying the pulp	27	105	684.3	0.69	53.64

Figure 6.3 shows the cold and hot composite curves for the process and Figure 6.4 shows the GCC of the process. The current heat demand for the pulping process by utilities is 309 MW, which is calculated by aggregating the various steam demand for the different sections according to Table 4.4 and excluding those that can not be replaced. The energy targets for the studied system is given in Table 6.4, stating that the minimum energy demand by hot utilities is 230 MW. Assuming that the studied system is representative of all the heating requirements of the pulp mill process, this gives a primary energy savings potential of 79 MW. In order to achieve these savings a maximum energy recovery (MER) heat exchanger network has to be constructed. To build such a network, pinch violations should be avoided, i.e. no cooling above the pinch temperature, no heating below the pinch temperature and no heat transfer through the pinch should be occurring. In reality this is a very hard task to accomplish, since building an optimal MER network would require different streams located at different parts of the mill to be heat exchanged. Therefore the energy saving potential is a trade-off between energy savings cost and retrofit investment cost, i.e. costs for new heat exchangers and for piping. Another option to achieve some of the energy savings potential would be to install flue gas cooling. Since no heat recovery is taking place through flue gas cooling, it is an interesting retrofit option. The flue gases with a high temperature can be heat exchanged with pressurized water, to generate very hot water, which could replace steam at various places, for instance when preheating the combustion air in the recovery boiler. Thus

the corresponding amount of energy could be saved in form of steam, which instead could be used either to reduce the need of bark or to generate more electricity, which could be sold to the grid.

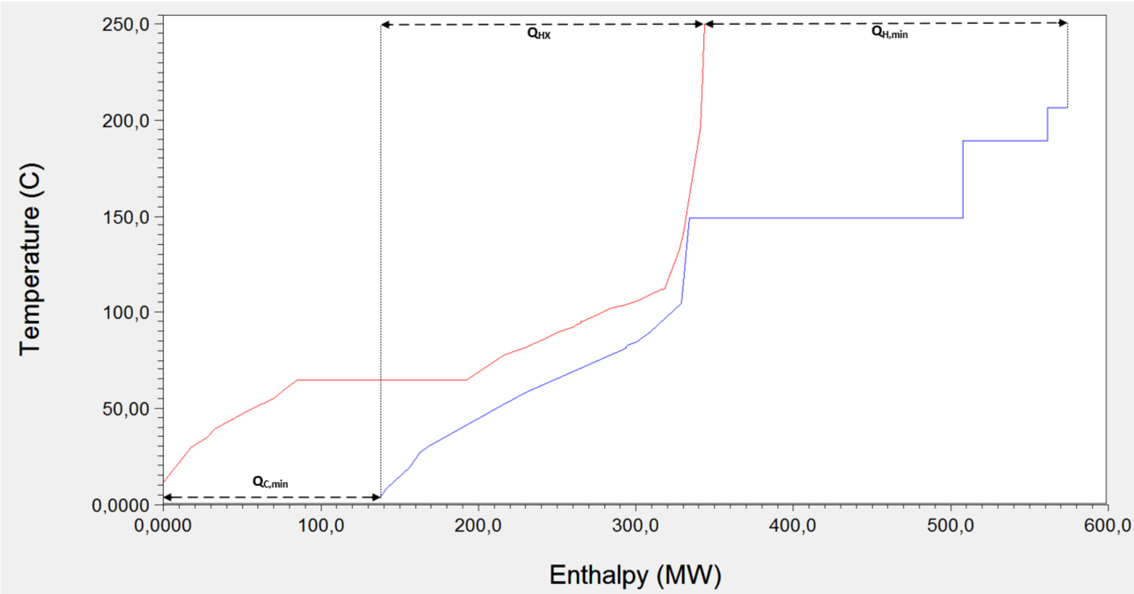

Figure 6.3: Cold and hot composite curves for the process with a $\Delta T_{min} = 10K$.

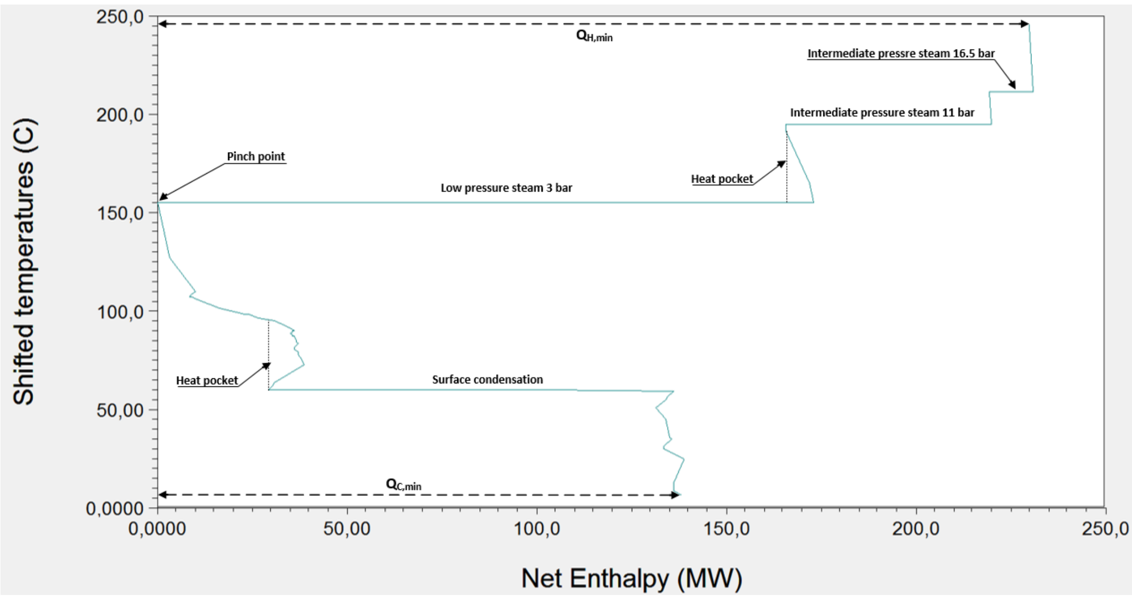

Figure 6.4: Grand composite curve for the process with a $\Delta T_{min} = 10K$.

Table 6.4: The energy targets from the pinch analysis.

Energy	**MW**
$Q_{H,actual}$	309
$Q_{H,min}$	230
Potential for primary energy savings	79
$Q_{C,min}$	138

6.3 Possibilities to Increase the Water Temperature in the Digester Section

The hot shifted composite curve was established for the digester section. This was done to decide the maximum water temperature that would be possible to achieve if all hot process streams that are currently heat exchanged with water, were to be cooled in a way that maximizes the temperature of the produced hot water. In order to find the maximum temperature possible to achieve the hot streams are assumed to be cooled by supplying cold water at 12 °C into the digester section, using heat exchangers with ΔT_{min} = 10 K. The interconnections with other sections at the plant via the secondary heating system is ignored. From the composite curve in Figure 6.5, it can be seen that the cooling demand for the digester section is 38.3 MW, which also corresponds to the heat production in the digester section today. Thus, it should be possible to produce 90 l/s hot water at 114 °C (or 155 l/s if the water is heated from 55 °C).

The current hot water demand is 20.9 MW, as can be seen in Table 6.3, which includes the total demand of hot water for the pulping process and the heating network of the sawmill. Theoretically it would be possible to cover this heat demand with the higher temperature level with an excess of 17.4 MW. The excess hot water at 114 °C could be used to replace the steam consumption at various places, for instance replacing some steam used to heat the water in the heating networks and/or replacing some steam used to heat the feed water and/or replacing some steam preheating the air for the recovery boiler and/or replacing some steam used to preheat bleaching backwater. Theoretically, 17.4 MW of steam could be saved by being partly or entirely replaced by this excess of hot water at 114 °C. In order to produce this hot water and utilize the energy from the hot streams, a heat exchanger network must be built for this purpose.

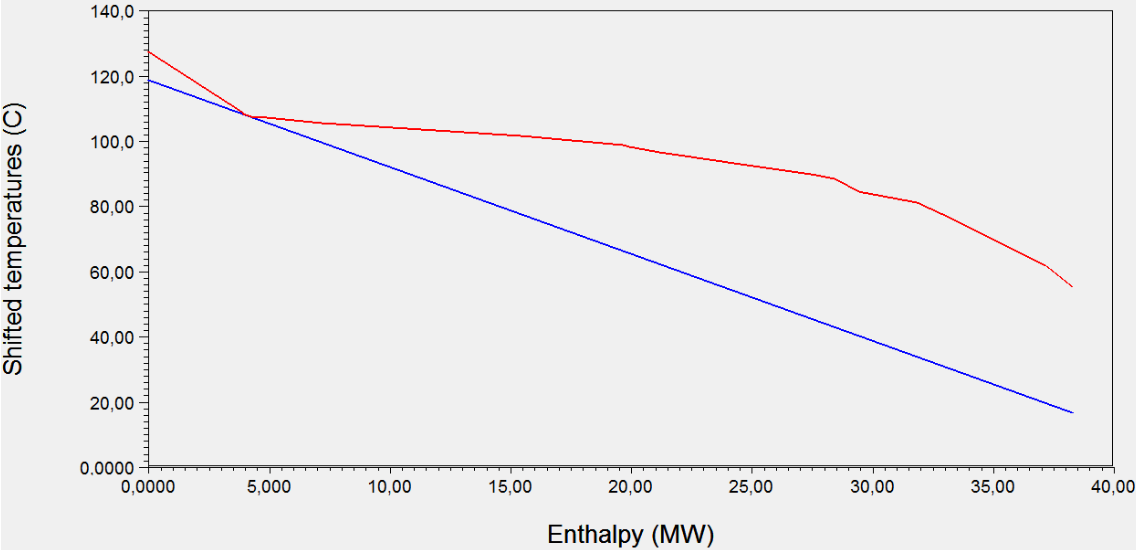

Figure 6.5: Theoretical maximum temperature for the hot water produced in the digester section. The red line is the shifted hot composite curve and the blue line is the shifted cold utility composite curve.

6.4 Improvements for a Future Pinch Analysis at Södra Cell Mönsterås

To perform a pinch analysis with higher resolution, all relevant hot and cold streams must be identified across the pulp mill. In this project, the streams in various sections have been aggregated. Instead of aggregating the demands, i.e. only looking at the total heat or steam demand for a certain section, each one of the consumers and producers should be identified. Furthermore, there are various process streams that are heat exchanged directly with other process streams. These types of process-to-process heat exchangers have not been identified completely during this project. The reason for this was due to the lack of stationary temperature and volumetric flow measuring equipment. Identifying more of these heat exchangers and gather data for those, would improve future pinch analysis further. Mapping individual consumers/producers of heat would also give a better understanding of how the consumers/producers operate during different operating conditions. However, to be able to evaluate how consumers/producers operate over time, more stationary measurements for both temperature and volumetric flow should be installed at locations where it is lacking.

In order to perform a state of the art pinch analysis, temperature measurements are not enough. The actual target temperatures should be identified. To do so it is necessary to understand the purpose of the different streams. A process stream might have a hard target, i.e. a temperature it must reach in order for the process to operate as desired, or it might have a soft temperature target, i.e. making the process stream more flexible in regards to heat transfer.

Carrying out a pinch analysis, the total heat extracted or delivered by a certain consumer/producer must be identified, but also between which temperatures the heat transfer has to take place. As of today, many measurements must be carried out in order to determine the heat demand for many processes. Temperature measurements are rather easy to handle and are more reliable than volumetric flow measurements, which are more challenging from a practical point of view. The volumetric flow of liquids is easier to measure compared to multiphase flows and gas flows, which is common at a pulp mill. To better cope with the challenge of estimating consumer/producer heat demands through calculations based on measured flow data, mass and energy balances with reasonable assumptions could be established to remove the necessity of flow measurements. Also, certain liquid properties, such as specific heat capacity, density and heat of condensation, for various liquids used across the pulp mill, must be determined, since it would provide more accurate estimations than assuming properties of water.

Performing a pinch analysis based on aggregated demands is an approach good enough to give a hint of the energy targets of the mill. However, to perform a complete pinch analysis building heat exchanger networks, the various consumers and producers has to be identified in a first step, in order to determine individual minimum temperature differences for the streams involved in the pulping process in a second step. The minimum temperature difference, which is an important parameter, has not been investigated for different streams in this project. Instead a global $\Delta T_{min} = 10$ K has been used. Changing the individual minimum temperature differences for various streams in accordance with findings and typical values from earlier studies did not change the energy targets in this project to an extent motivating further investigation, since no heat exchanger network was to be built.

Stream classification requires both knowledge of the pulping process, but also experience to know how a certain stream should be represented, i.e. as a cold or hot stream, and how the representation of the stream will affect the pinch analysis. Various sections across the mill are rather complicated, for instance the evaporation sections. This is due to the various types of energy equipment used for heating and separating purposes, which requires an in-depth understanding of how the energy components work. The evaporation sections are in this project represented as black boxes, with the aggregated steam demand being supplied treated as a cold stream and liquor condensate and steam condensate being delivered to the secondary heating system treated as hot streams. It is a simplification that is justified due to the recent reconstruction of the evaporation sections, and therefore it would not be realistic to suggest any new retrofits in the evaporation sections. The heat demand of the digester section has been represented by aggregating the energy in the steam supplied to the different digesters, although since the steam is used to both heat the pulp and to heat the white liquor, it does not give a fair picture of the potential energy savings, since the steam used to heat the pulp actually is constrained and must be delivered, since it is a part of the pulping process. However, this is not the case for the white liquor heaters named calorisators. Mapping of heaters such as calorisators and determine the actual temperature required for each one of the calorisators could give a different GCC and thereby also different energy targets.

For many processes where steam is delivered for heating purposes and where the actual steam is nor injected or is constrained in order for the pulping process to continue, the heat and temperature demand should be mapped in order to find potential energy savings. This is true for various components across the plant, particularly in the drying section. The air used to evaporate the water content within the pulp in the drying section and the combustion air in the recovery boiler have been assumed to be heated in one step, where in reality the air is heated in several steps. For an improved pinch analysis the sub-streams should be mapped, because the temperature interval in which the air is heated is quite big and it could be possible to heat exchange with other streams in order to lower the demand of steam. Also various streams ending up in the sewage water system, mainly from the drying section, the chemical preparation section, the chemical water section and cooling water from the digester section should be mapped and regarded as hot streams with a heat content that can be possible to utilize.

To be able to better estimate the minimum cooling demand, the cooling demand of the condensing turbine has to be considered. This cooling demand depends on how much excess steam that is sent through the turbine. This has been completely neglected in this project. Also, the two cooling towers at the mill have not been considered except their interconnections with the secondary heating system, mainly through the second evaporation section, the chemical water treatment section and the warm water tank. These streams should be regarded as hot streams since it would be possible to utilize the heat instead of releasing the heat to the atmosphere. This is also the case for several streams only working as cold utilities, for instance turbine blade coolers, which are connected to the cooling towers.

7
Conclusions and Future Work

The aim of this project was to increase the knowledge of the design and function of the secondary heating of Södra Cell Mönsterås, with special attention to the digester section and to collect and evaluate data to support future energy efficiency studies. In order to achieve the aim of the project, the five defined objectives in Section 1.1 had to be accomplished.

The secondary heating system of Södra Cell Mönsterås for both the entire mill and the digester section have been mapped and described by showing interconnections between producers and consumers of warm and hot water and water tanks in flowcharts. From this, thermal loads and the function of the heat exchangers have been determined and presented for the digester section. Also, the internal and external heating networks have been similarly mapped and described. Furthermore, the process description of the pulping process made it possible to map the producers and consumers of steam. For all these systems, data has been extracted by measurements and from Södra Cell Mönsterås process control monitoring system (INFOPLAN). All the gathered data for the systems has been evaluated in terms of variations, data availability, data sources and extraction period and presented in tables and graphs. All this together increases the knowledge of the design and function of the presented systems and serves as a support for future energy efficiency studies or energy audits. Also, it serves as a basis for the carried out pinch analysis in order to identify energy targets. Through all this work, objectives 1 to 4 has been accomplished.

Concluded from the pinch analysis, there is, in theory, a potential to save 79 MW of primary energy. The pinch analysis also showed a possibility to produce 38.3 MW of hot water at 114 °C in the digester section, by constructing a heat exchanger network for this purpose. The current hot water demand is 20.9 MW and given that 38.3 MW of hot water at 114 °C is produced, this makes it theoretically possible to achieve energy savings of 17.4 MW at various parts of the mill. With other words, the performed pinch analysis gives a hint that there is large potential for primary energy savings, but in order to get more accurate energy targets, some improvements are necessary. In order to perform a more high resolution pinch analysis, the aggregated energy consumers/producers must be mapped separately. Also, more consumers/producers have to be mapped with regards to start and target temperatures along with thermal loads. Further, for individual streams, it most be determined whether the target temperature is a hard or soft target. Besides, individual minimum temperature differences should be applied for different streams. Lastly, at heat exchangers where calculations for thermal loads have to be performed, liquid properties are desired. All this is in accordance to objective 5 and provides additional inputs to future pinch studies at Södra Cell Mönsterås.

Except from improving the current pinch analysis as stated above, other future work that would facilitate energy efficiency projects is to continuously update and develop the piping and instrumentation diagrams of Södra Cell Mönsterås and the flowcharts constructed in this project, since it would increase the knowledge of the design and function of the systems. From the constructed flowcharts and data collection in the project, it could be seen that streams of different temperatures were mixed and consequently it would be interesting to investigate further the possibly of introducing another water tank temperature level, especially also concerning the possibly to increase the temperature of the hot water in the digester section. Furthermore, it should be investigated if it possible to replace low-pressure steam at some locations by hot water at 114 °C. Further, installing more stationary measuring equipment for temperatures in general and volumetric flows in particular, would increase the monitoring of the systems and thereby making it easier to extract data and identify malfunctioning equipment. By increasing the available data, it would be easier to analyze and evaluate the dynamic behaviour of the energy components. Besides, variations in stream data should further be evaluated for longer periods of time to see what data that can be represented by its average value in a pinch analysis, but also to be able to evaluate variations in thermal loads for the heat exhangers during different operating conditions. Lastly, additional future work would be to investigate the practical feasibility and economical profitability of constructing an improved energy recovery heat exchanger network and introducing flue gas cooling as a measure for achieving primary energy savings.

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Appendix A

Sources for Stream Data

Here the sources for all hot streams making up the hot stream data table in Table 6.2 are presented in Table A.1 and the sources for all cold streams making up the cold stream data table in Table 6.3 are presented in Table A.2.

Table A.1: A description of how and from where data for all hot streams were extracted.

Stream	Source
H1	Temperatures extracted by engineering estimates. Cooling demand estimated on the water side; the warm water production equals the steam condensation. Q from Table 4.6.
H2	Temperatures extracted by engineering estimates. Cooling demand estimated on the water side; the warm water production equals the steam condensation. Q from Table 4.6.
H3	Temperatures and flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data extracted from Table 5.3.
H4	Start and target temperatures estimated by mill process engineers. The thermal load is calculated on the water side, based on data extracted from INFOPLAN. Data extracted from Table 5.3.
H5	Start and target temperatures along with flow estimated by mill process engineers. Data extracted from Table 5.4.
H6	Temperatures and flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data extracted from Table 5.3.
H7	The start temperature and the flow were extracted from INFOPLAN and target temperature was calculated from mixing with hot water. Data extracted from Table 5.4.
H8	Start temperature measured and target temperature extracted from INFOPLAN. The thermal load was estimated on the water side. Data extracted from Table 4.7.
H9	Start temperature measured and target temperature extracted from INFOPLAN. The thermal load was estimated on the water side. Data extracted from Table 4.7.
H10	Start temperature measured and target temperature extracted from INFOPLAN. The thermal load was estimated on the water side. Data extracted from Table 4.7.
H11	Start and target temperatures were measured and the thermal load was calculated on the water side. Data extracted from Table 4.7.
H12	Start temperature measured and target temperature extracted from INFOPLAN. The thermal load was estimated on the water side. Data extracted from Table 4.7.
H13	Start and target temperatures were measured and the thermal load was calculated on the water side. Data extracted from Table 4.7.
H14	Start temperature measured and target temperature extracted from INFOPLAN. The thermal load was estimated on the water side by first calculating the water flow. Data extracted from Table 4.7.
H15	Start and target temperatures were measured and the thermal load was estimated on the water side after measuring the water flow. Data extracted from Table 4.7.

H16	The values for fimp cooler K5 was used, since K4 was malfunctioning. The start temperature were measured and the target temperature was extracted from INFOPLAN. The common water flow to the heat exchangers was measured and the thermal load could then be determined. Data extracted from Table 4.7.
H17	Start and target temperatures were measured and the thermal load was estimated on the water side after measuring the water flow. Data extracted from Table 4.7.
H18	Start temperature measured and target temperature extracted from INFOPLAN. The thermal load was estimated on the water side by first calculating the water flow. Data extracted from Table 4.7.
H19	Start temperature and flow gathered from INFOPLAN and target temperature estimated by mill process engineers. The thermal flow could then be estimated. Data is not explicitly presented in this paper.
H20	Start and target temperature along with the flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data is not explicitly presented in this paper.
H21	Start and target temperature along with the flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data is not explicitly presented in this paper.
H22	Start and target temperatures are based on the water side temperatures extracted from Table 4.5 for the PO-condenser, but a ΔT_{min} of 10 K has been added to both temperatures. The thermal load is based on the calculated thermal load on the water side.
H23	Start and target temperatures are based on the water side temperatures extracted from Table 4.5 for the sawmill condenser, but a ΔT_{min} of 10 K has been added to both temperatures. The thermal load is based on the calculated thermal load on the water side.
H24	Start and target temperatures along with flows are estimated by mill process engineers. From this a thermal load could be calculated as well.
H25	Start and target temperatures along with flows are extracted from INFOPLAN and thereby the thermal load. could be calculated. Data was extracted from sensors around VVX 1 + 2.
H26	Start and target temperatures along with flows are estimated by mill process engineers. From this a thermal load could be calculated as well.

Table A.2: A description of how and from where data for all cold streams were extracted.

Stream	Source
C1	Temperatures extracted from INFOPLAN and the flow, and thereby also the thermal load, calculated from energy balance over the heat exchangers. Data is extracted from Table 5.3.
C2	Temperatures and flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data is extracted from Table 5.3.
C3	Temperatures extracted from INFOPLAN and the flow, and thereby also the thermal load, calculated from energy balance over the heat exchanger. Data is extracted from Table 5.3.
C4	Temperatures and flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data is extracted from Table 5.3.
C5	Temperatures extracted from INFOPLAN and the flow, and thereby also the thermal load, calculated from energy balance over the heat exchanger. Data is extracted from Table 5.3.
C6	Start temperature corresponds to the raw water extraction temperature, which is extracted from INFOPLAN and the target temperature corresponds to the warm water temperature. The flow is based on the actual demand of warm water during the studied period.
C7	Start temperature based on warm water tank temp. and target temperature based on hot water tank temp. The flow is based on the actual demand of hot water during the studied period.
C8	Start temperature based on hot water tank temp. and target temperature calculated when being mixed with hotter liquor condensate. The flow of hot water is calculated by subtracting the flow of liquor condensate, estimated by mill process engineers, from the total going to the bleaching sections extracted from INFOPLAN. Data is extracted from Table 5.4.
C9	Temperatures and flow extracted from INFOPLAN and thereby the thermal load could be calculated. Data is extracted from Table 4.5.
C10	Start temperature based on the average outdoor temperature extracted from INFOPLAN for the studied period. Target temperature based on engineering estimate by mill process engineer. Then all intermediate and low pressure steam used in the recovery boiler are assumed to be used for air preheating. Steam data is extracted from Table 4.4.
C11	The consumption of low-pressure steam in the digester section extracted from INFOPLAN during the studied period are expressed as a heat demand for the degassing process in the digesters. Steam data is extracted from Table 4.4.
C12	The consumption of intermediate pressure steam in the digester section extracted from INFOPLAN during the studied period are expressed as a heat demand for heating of the cooking liquor in the digesters. Steam data is extracted from Table 4.4.
C13	The consumption of intermediate pressure steam in the oxygen bleaching section extracted from INFOPLAN during the studied period are expressed as a heat demand for preheating the oxygen before oxygen reactors. Steam data is extracted from Table 4.4.
C14	The consumption of low-pressure steam in the bleaching section extracted from INFOPLAN during the studied period are expressed as a heat demand for preheating the backwater before being used as heat source at different parts (for instance heating networks and feed water heating). Steam data is extracted from Table 4.4.
C15	The consumption of intermediate pressure steam in the bleaching section extracted from INFOPLAN during the studied period are expressed as a heat demand for heating the pulp before PO- and OP-reactors. Steam data is extracted from Table 4.4.
C16	The consumption of low-pressure steam in the evaporation effects extracted from INFOPLAN during the studied period are expressed as a heat demand for the evaporation section. Steam data is extracted from Table 4.4.
C17	The consumption of intermediate pressure steam in the evaporation effects extracted from INFOPLAN during the studied period are expressed as a heat demand for the evaporation section. Steam data is extracted from Table 4.4.
C18	The consumption of low-pressure steam in the feed water tanks extracted from INFOPLAN during the studied period are expressed as a heat demand for feed water. Steam data is extracted from Table 4.4.
C19	The consumption of low-pressure steam in the chemical preparation section extracted from INFOPLAN during the studied period are expressed as a heat demand for diluting and dissolving chemicals. Steam data is extracted from Table 4.4.
C20	Start temperature based on the indoor temperature from engineering estimates. Target temperature based on engineering estimate by mill process engineer. Then all the low-pressure steam used in the drying section are assumed to be used for heating the air used for drying the pulp. Steam data is extracted from Table 4.4.