CHALMERS

Energy Efficiency Study at a Softwood Kraft Pulp Mill

Master's Thesis within the Sustainable Energy Systems and *Innovative and Sustainable Chemical Engineering* programmes

ALEXANDRA PEDERSÉN & ANTON LARSSON

Department of Energy and Environment
Division of Energy Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2017

MASTER’S THESIS

Energy Efficiency Study at a Softwood Kraft Pulp Mill

Master’s Thesis within the *Sustainable Energy Systems* and *Innovative and Sustainable Chemical Engineering* programmes

ALEXANDRA PEDERSÉN & ANTON LARSSON

SUPERVISORS:

Johan Isaksson & Linda Rudén

EXAMINER

Simon Harvey

Department of Energy and Environment
Division of Energy Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2017

Energy Efficiency Study at a Softwood Kraft Pulp Mill
Master's Thesis within the *Sustainable Energy Systems* and *Innovative and Sustainable Chemical Engineering* programmes
ALEXANDRA PEDERSÉN & ANTON LARSSON

Department of Energy and Environment
Division of Energy Technology
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Chalmers Reproservice
Göteborg, Sweden 2017

Energy Efficiency Study at a Softwood Kraft Pulp Mill
Master's Thesis within the *Sustainable Energy Systems* and *Innovative and Sustainable Chemical Engineering* programmes
ALEXANDRA PEDERSÉN & ANTON LARSSON
Department of Energy and Environment
Division of Energy Technology
Chalmers University of Technology

ABSTRACT

In order to achieve an increased energy efficiency within the Swedish industry the law about energy auditing in large companies has recently been implemented. The law is based on the EU Energy Efficiency Directive. The law requires that affected companies performs an energy auditing every fourth year. Besides mapping of energy supply and consumption, an analysis is required to be performed where suggestions for energy efficiency measures and related cost estimations are to be included. The result must thereafter be reported to the Swedish Energy Agency.

The pulp and paper industry accounts for more than 1/6 of Sweden's total energy usage which indicates the importance to study this specific industry from an energy perspective. This since implementation of energy efficiency measures can potentially result in large energy savings which can eventually result in a reduced climate impact. Södra Cell Värö is a Softwood Kraft Pulp Mill which has recently experienced a large expansion and reconstruction. Energy efficiency measures, such as a new secondary heating system, were included to improve the heat recovery within the process. In this master's thesis, an energy efficiency study has been performed in order to investigate whether additional measures can be implemented to save energy at the pulp mill.

Pinch analysis was utilized as a method to determine the potential for energy savings of the process. The result of the analysis shows that it is theoretically possible to save 66.7 MW steam, which corresponds to 23 % of the total steam consumption at the pulp mill. However, to achieve these savings a maximum energy recovery network is required which is rarely applied in industry due to technical limitations and that it is not feasible from an economic perspective to achieve such a heat exchanger network.

Retrofit suggestions were proposed that utilized an identified excess heat in terms of warm water, and moist air from the drying machine. By doing so, the energy efficiency in the existing heat exchanger network was improved resulting in 9.1 MW steam savings. By also utilizing heat from flue gases from the lime kiln and the bark boiler, it was shown that a total of 19.5 MW steam savings could be achieved. Furthermore, it was found that the saved steam could for example be utilized to generate additional green electricity in the newly installed condensing turbine which in turn would enable an increased delivery of electricity to the grid by 41 GWh/yr. Another alternative that was investigated was to save fuel in the form of bark by reducing the steam production of the bark boiler. The result shows that it would be possible to save 144 GWh/yr bark.

The potential for the process to deliver an increased amount of district heating was investigated and the result indicates that the theoretically maximum heat load for district heating delivery is 33 MW after the suggested energy efficiency measures have been implemented.

Key words: Energy auditing, Softwood Kraft Pulp Mill, secondary heating system, pinch analysis, potential for energy savings, heat exchanger network, district heating

Energieffektiviseringsstudie vid ett sulfatmassabruk
Examensarbete inom mastersprogrammen *Hållbara Energisystem* och *Innovativ och Hållbar Kemiteknik*
ALEXANDRA PEDERSÉN & ANTON LARSSON
Institutionen för Energi och Miljö
Avdelningen för Energiteknik
Chalmers tekniska högskola

SAMMANFATTNING

För att åstadkomma ökad energieffektivitet inom den svenska industrin har nyligen ”Lagen om energikartläggning i stora företag” implementerats. Lagen i sin tur grundar sig på EU:s energieffektiviseringsdirektiv. Lagen kräver att berörda företag utför en energikartläggning vart fjärde år. Förutom kartläggning av tillförd och använd energi, krävs att en analys utförs där förslag till åtgärder vilka förbättrar energieffektiviteten och relaterade kostnadsberäkningar inkluderas. Resultatet måste därefter redogöras i en rapport vilken Energimyndigheten ska ta del av.

Pappers- och massaindustrin står för över 1/6 av Sveriges totala energibehov vilket indikerar vikten av att studera denna industri ur ett energiperspektiv. Detta eftersom implementering av energieffektiviseringsåtgärder potentiellt sett kan leda till stora energibesparingar vilket på sikt kan minska klimatpåverkan. Södra Cell Värö är ett sulfatmassabruk som nyligen genomgått en omfattande expansion och ombyggnation. Energieffektiviseringsåtgärder, som exempelvis ett nytt sekundärvärmesystem, inkluderades för att öka värmeåtervinningen i processen. I detta examensarbete har en energieffektiviseringsstudie utförts för att ta reda på om ytterligare åtgärder kan implementeras för att spara energi vid massabruket.

Pinchanalys användes som metod för att bestämma processens potential för energibesparingar. Analysens resultat visar att det är teoretiskt sett möjligt att bespara 66.7 MW ånga, vilket motsvarar 23 % av massabrukets totala ånganvändning. För att uppnå denna besparing krävs dock ett värmeväxlarnätverk där maximal värmeåtervinning uppnås, vilket sällan tillämpas i industrin på grund av tekniska begräsningar och att det inte är ekonomiskt lönsamt att erhålla ett sådant värmeväxlarnätverk.

Åtgärder föreslogs vilka utnyttjade ett från processen identifierat värmeöverskott i form av varmvatten samt fuktig luft från processens torkmaskin. På så sätt förbättrades energieffektiviteten i det befintliga värmeväxlarnätverket vilket resulterade i 9.1 MW ångbesparingar. Genom att dessutom utnyttja värme från rökgaser från mesaugnen och barkpannan erhölls slutligen totalt sett en ångbesparing på 19.5 MW. Den besparade ångan kan förslagsvis användas för att generera ytterligare grön el i den nyinstallerade kondensturbinen vilket i sin tur skulle resultera i en utökad leverans av el till elnätet med ungefär 41 GWh/år. Ett annat alternativ som undersöktes var att spara bränsle i form av bark genom att minska ångproduktionen i barkpannan. Resultatet visar att det vore möjligt att spara 144 GWh/år bark.

Processens potential till att leverera en utökad mängd fjärrvärme undersöktes och resultatet tyder på att den teoretiskt maximala effekten för fjärrvärmeleverans är 33 MW efter att de föreslagna energieffektiviseringsåtgärderna införts.

Nyckelord: Energikartläggning, sulfatmassabruk, sekundärvärmesystem, pinchanalys, potential för ångbesparingar, värmeväxlarnätverk, fjärrvärme

Contents

Preface

The main part of this thesis work has been conducted at Södra Cell Värö and was carried out from January 2017 to June 2017. An energy efficiency study was performed in order to investigate the opportunities for energy efficiency improvements at the mill. A retrofitted heat exchanger network design was proposed which enabled steam savings.

Firstly, we would especially like to thank our supervisors at Södra, Linda Rudén and Johan Isaksson for all their help throughout this master's thesis. Without your excellent guidance and support, this master's thesis work would not have been possible.

Furthermore, we would like to express our gratitude towards the process engineers at the mill for all interesting discussions, for providing us with great answers to all our questions, and for helping us to locate process equipment at the mill.

A big thanks to the staff at Södra Innovation for making us feel very welcome and a part of the team. Also, we would like to thank the carpool group at Södra Innovation for making our trips to the mill enjoyable.

We would also like thank to our examiner Simon Harvey for all helpful comments regarding the report and guidance throughout the entire project time.

Gothenburg June 2017

Alexandra Pedersén & Anton Larsson

Notations

Abbreviations:

ADt/d	Air dry ton/day (90 % dry solid content)
CC	Composite curve
CW	Cold water
DH	District heating
ECF	Elementary chlorine free bleaching
GCC	Grand composite curve
HEN	Heat exchanger network
HP	High pressure
HTR	Heater (utility)
HW	Hot water
HX	Heat exchanger
LP	Low pressure
LWW	Lukewarm water
MER	Maximum energy recovery
MP	Medium pressure
PFD	Process flow diagram
RB	Recovery Boiler
SHS	Secondary heating system
TCF	Totally chlorine free bleaching
Värö mill	Södra Cell Värö
WW	Warm water

Symbols:

$Q_{H, min}$	Theoretical minimum heat load
$Q_{C, min}$	Theoretical minimum cooling load
ΔT_{min}	Minimum temperature difference for heat exchange

1 Introduction

The European Union (EU) has high ambitions to reduce their primary energy consumption. To achieve this, means such as the EU energy efficiency directive (EED) were introduced in 2012 for member countries. The goal with the EED is to achieve a reduction of 20 % of the primary energy consumption by 2020. The directive includes legally binding energy efficiency measurements and member countries are required to introduce national obligation schemes to show how they will contribute to achieve this reduction (European Commission, 2013).

The Swedish Parliament has specified 16 environmental quality objectives to be fulfilled by 2020 (Naturvårdsverket, 2016a). One of these is the objective *Reduce climate impact* which includes goals to decrease greenhouse gas emissions by 40 % by 2020, relative to 1990 levels (Naturvårdsverket, 2016b). Increased energy efficiency is an important necessity to achieve such goals. One important indicator of how energy efficient a country is, is *energy intensity*, a measure of how energy efficient a country is in relation to its GDP (Statistiska Centralbyrån, 2005). Policies have been introduced in Sweden aiming for a target of 20 % reduction in energy intensity (Regeringen, 2014).

One recent Swedish legislation is the law about energy audits in large companies (2014:266), a tool that has been introduced to facilitate the progress towards the above described energy and climate goals. It also covers parts of the EED and requires mapping of energy usage in larger companies. The energy auditing must be performed every fourth year and the result must be reported to the Swedish Energy Agency. The report should include an energy mapping of the annual energy supply and consumption and suggestions for energy efficiency measures and/or energy savings. A calculation of the cost of implementing the suggestions is also mandatory to include in the report. The overall goal is to improve the energy efficiency within companies (Statens energimyndighet, 2015b).

The industry sector accounts for 38 % of the total energy usage in Sweden. Furthermore, the pulp and paper industry accounts for approximately half of that energy usage (Statens energimyndighet, 2015a). Hence, one can roughly estimate that the pulp and paper industry, including chemical and mechanical mills, represents more than 1/6 of the total energy usage in Sweden. This provides an indication of the importance to perform energy efficiency studies in this specific industry because large amount of energy can potentially be saved by implementing energy efficiency measures. From a sustainability perspective, it should furthermore be emphasized that some pulp mills in Sweden today are self-sufficient in energy from the biomass raw material and even provide additional benefits such as green electricity to the grid, district heating for nearby cities and biofuels such as tall oil and dried bark. The various pulp mills situated in Sweden will fall under the law of 2014:266 and will therefore be obligated to perform the energy auditing.

Energy efficiency studies providing new solutions to decrease energy consumption and improved utilization of energy in industry are of great importance. This since, if the measures are implemented, it can often be translated to both economic and environmental advantages. With a reduction of the energy consumption, the climate impact can be reduced and natural resources can be used more efficiently. Through improved utilization more green electricity and useful heat can be generated, replacing fossil based heat and power production resulting in an overall decreased climate impact.

1.1 Background

This master's thesis involves an energy efficiency study at the softwood Kraft Pulp mill Södra Cell Värö with the main purpose to investigate if primary energy savings can be achieved.

1.1.1 Södra Cell Värö

Södra Cell Värö is a softwood Kraft Pulp mill located on the Swedish West Coast, more specifically in Väröbacka. An investment of four billion SEK was recently made in the mill resulting in an extensive expansion and rebuilding of it. This has enabled an increased annual pulp production capacity from 425,000 metric tons to 700,000 metric tons meaning that the mill is now one of the largest softwood Kraft pulp producers in the world. During summer 2016, the new process was started up and it is expected that full production capacity will be achieved in 2018 (Södra, 2016a).

Södra Cell Värö can be considered to be among the most modern pulp mills that exists because of new state-of-the-art process equipment and technology that was included in the investment. To only mention a few examples, the investment included a continuous digester replacing the previous ten batch digesters, expansion of the recovery boiler and a new condensing turbine (Södra, 2016a). Furthermore, extensive effort was devoted to achieving energy efficiency in the new mill. For instance, a new secondary heating system was installed with the aim of reducing the process primary heat demand. The new heat exchanger network in the expanded mill was designed utilizing predicted data. However, this heat exchanger network has not yet been evaluated using live data from the process in operation.

1.1.2 Södra Cell Värö energy and material flows

Figure 1 shows an overview of the main energy and material flows at Södra Cell Värö site, note that there are various flows entering, leaving and those which are used internally within the site. Nearby, there is a Södra Wood saw mill and a pellet plant which are connected to the pulp mill's energy network. Note that these sites are not explicitly shown in the figure. However, the biomass raw material entering the different processes is the same, namely softwood. Bark is a byproduct of both the pulping process and the saw mill and it is first dried and thereafter either sold as a biofuel on the market or utilized as fuel in the bark boiler located at the pulp mill. Sawdust and wood shavings are other byproducts originating from the saw mill and these are used to produce pellets. Sawdust is also transported to the lime kiln of the pulping process for fuel purposes. The sawdust needs to be dried and milled forming wood powder, before it can be combusted in the lime kiln.

The wood raw material consists of cellulose, hemicellulose, lignin and lesser amounts of extractives. These different constituents end up in a wide range of products and biofuels. The main product of Värö mill is pulp and it composed mainly of cellulose fibers. Volatile extractives forms turpentine, while non-volatile extractives are recovered as tall oil.

The pulp and the byproduct turpentine is extracted in the cooking section. Tall oil is a viscous liquid produced from a soap containing fatty acids and resin acids that is separated from the black liquor. Tall oil is used as a raw material in for example the company SunePine, in which Södra is a co-owner. Sunpine converts the tall oil into tall oil diesel and the byproduct tall oil pitch (TOP). Södra Cell Värö is using TOP as a startup and backup fuel in the recovery boiler, bark boiler and lime kiln. From a climate change perspective, the use of TOP is favorable because it reduces the use of fossil heating oil. Another byproduct produced from the mill is methanol which is combusted in the lime kiln and in the recovery boiler.

The recovery boiler and bark boiler produce high pressure steam which is expanded in turbines. Since the fuels combusted to produce steam arise from biomass, the electricity generated is considered green. Low and medium pressure steam is extracted from the turbines which is further used in the various parts of the process for heating purposes. The excess of low pressure steam is expanded in a condensing turbine. Today, Södra Cell Värö manages to achieve a surplus of both electricity and heat, meaning that these also can be sold on the market. Heat is delivered to the saw mill, the pellet manufacturing site and a nearby tomato farm. Excess heat is also used to provide district heating to the city Varberg.

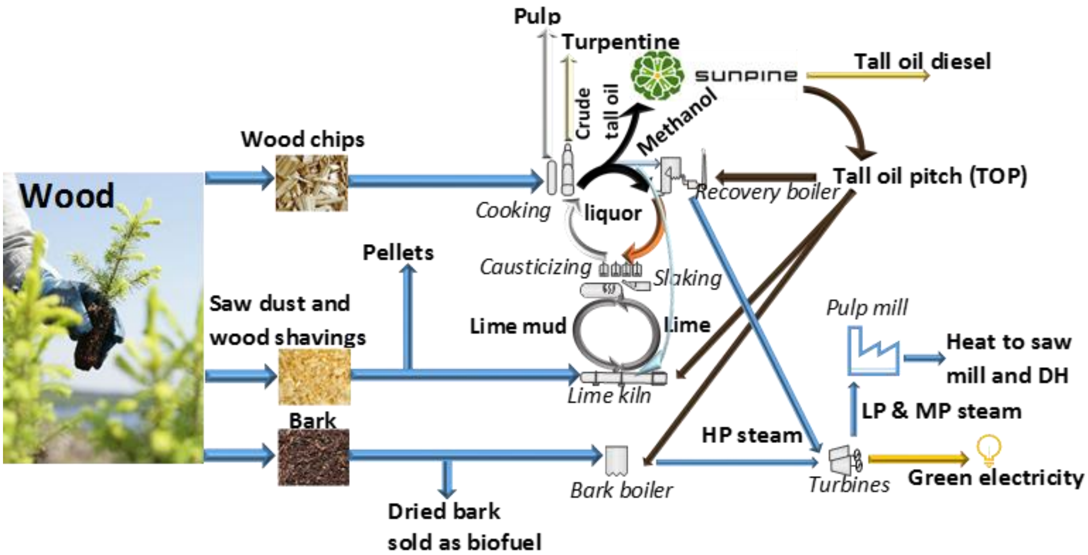

Figure 1. *Energy and material flows at Södra Cell Värö site (Rudén, 2017).*

See Figure 2 for quantities of some important energy products at the Södra Värö site. The amount in terms of energy in gigawatt hours per year of electricity, dried bark, tall oil and district heating delivered are predicted values for a maximum pulp production, 2330 ADt/d, for the expanded mill. The numbers are valid for what can be delivered to the market. Thus, the data does not represent the total electricity generation and bark biofuel since these are also used internally within in the process.

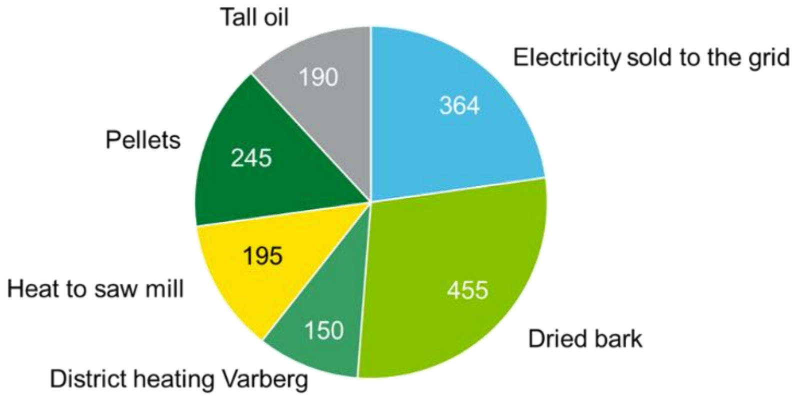

Figure 2. Energy products of the expanded mill in GWh/yr. The values are for a predicted maximum production case of 2330 ADt/d.

The largest energy product is dried bark. The amount of dried bark will not increase linearly with the increased production compared to the old production. This since the bark boiler, using the dried bark as fuel, is expected to be operating more than prior to the expansion due to logistic problems with handling the increase of bark volumes in other ways. By operating the bark boiler more, it allows for an increased production of steam, and thus more electricity can be generated in the condensing turbine. District heating delivery to Varberg will not be affected by the increased production which is a strategic decision based upon how much district heating that can be delivered today. The amount of pellet produced at the saw mill will decrease due to the higher demand for sawdust in the lime kiln. Regarding tall oil production, it is expected to increase with the increased production capacity.

1.1.3 Law of energy auditing at Södra Cell Värö

Figure 3 shows how Södra Cell Värö is planning to perform their energy studies in accordance to the energy auditing law. As depicted in the figure, the work is divided into four different energy studies, namely inventory of steam consumption, pinch analysis, electricity consumption and fuel consumption.

During the first study, mapping of the steam consumption at the mill was performed and information from this study was available in the second energy study. The pinch analysis study is to provide suggestions for energy efficiency improvements. The third study, i.e. electricity consumption, will for example investigate the possibility of decreasing pump work at the mill. The general importance of the fourth study is to investigate how fuels can be utilized more efficiently, resulting in increased steam production or alternatively savings in terms of fuel which can be applied for other purposes.

The work of this master's thesis will be a major contributor to the second energy study, i.e. pinch analysis. It will provide information regarding the potential for energy savings and include suggestions for energy efficiency measures. These partly cover some of the requirements of the law of energy auditing.

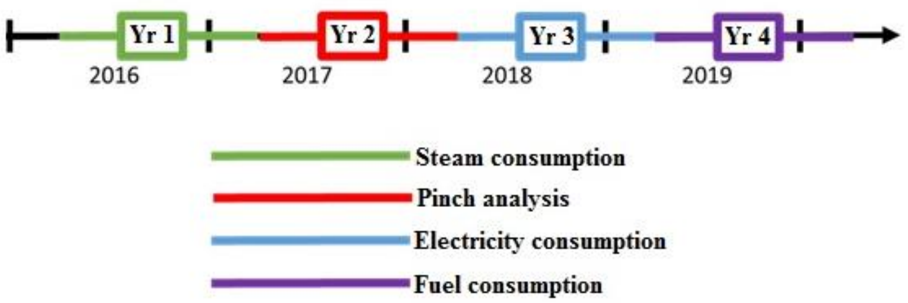

Figure 3. Planned energy studies at Södra Cell Värö for the next few years in accordance to the law about energy auditing.

When the above four energy studies have been completed, there will be a new four-year period of energy studies in accordance to the legislation.

1.2 Aim

The aim of this thesis is to increase awareness and knowledge of energy efficiency potentials at large process industry sites such as Södra Cell Värö. This in order to indicate advantages in terms of economic profit and climate change mitigation. Another aim is to provide insights regarding availability of process excess heat and how it is possible to utilize such energy in an efficient manner.

1.3 Objectives

The overall objective of this thesis was to perform an energy efficiency study at Södra Cell Värö, to identify opportunities for energy efficiency improvements that may be of economic interest and at the same time contribute to climate change mitigation. The new process energy system at Södra Cell Värö was designed using predicted performance data and is in theory highly energy efficient. However, the performance of the energy system has not yet been evaluated for real operation conditions, which is one of the main objectives with this study.

Data was extracted from the mill in operation and used as an input in a subsequent pinch analysis. The analysis provides an estimate of the potential for energy savings in the existing heat exchanger network. Thereafter, modifications to the existing heat exchanger network are proposed aiming for primary heat savings. To do so, a retrofitted heat exchanger network design is suggested. Important here is that the process should still, after the retrofits, be able to deliver district heating to Varberg. Furthermore, an objective is to evaluate how the saved primary heat can be utilized. Another task was to evaluate potential excess heat available at Värö mill and show how it can be used.

Another objective of this work is to contribute to the necessary energy mapping of Södra Cell Värö according to new legislation.

More specifically, this work aimed to achieve the following results:

- Find out to what extent the existing hot utility load at Värö mill deviates from the theoretical minimum load.

- Analyze the existing heat exchanger network to be able to identify and quantify any pinch violations occurring due to inefficient network design.

- Propose a retrofitted heat exchanger network that reduces the process hot utility demand, while at the same time considering potential constraints due to technical limitations of the process.

- Investigate how the saved steam can be used.

- Quantify amount and temperature range of excess heat and investigate ways of harnessing excess heat.

1.4 Limitations

The energy efficiency study is based on data collected from Södra Cell Värö pulp mill. Thus, the results obtained from this work are applicable for this specific pulp mill only. However, the general concepts and methodologies used may be of use for similar studies.

The data investigated in this thesis was collected for a time period when the production was deemed to have been sufficiently stable. As the new mill was recently started up, the most appropriate data was available for a rather recent period of time, i.e. the winter season. It is important to point out that the data and the subsequent analysis are representative for the specific season chosen, such as for instance the steam demand, need for district heating to nearby cities and thus demand for cooling will vary depending on ambient temperature which is related to seasonal variations. In addition, the energy analysis is valid for the specific pulp bleaching case that is utilized during the time period for data extraction, i.e. totally chlorine free bleaching. This since the energy balance of the mill is affected by the type of bleaching method that is used.

Economic performance for the heat exchanger network retrofit was not considered due to the time scope of this thesis. To do so one would need to take into account for instance piping cost, pumping cost, cost for downtime of process and investment cost of new heat exchangers.

2 Process description

In this chapter, the process involved at Södra Cell Värö is explained. Firstly, the Kraft process and some characteristics for the studied pulp mill is described. Thereafter, the energy system of the process is introduced. Lastly, the external heat users of Värö mill is explained.

2.1 Kraft process

Figure 4 shows a simplified layout of a typical Kraft process which involves chemical means in order to treat the wood. The process steps going from wood logs into pulp is firstly explained. Thereafter, the recovery cycle, i.e. the process steps needed to recover cooking chemicals and to produce steam are described.

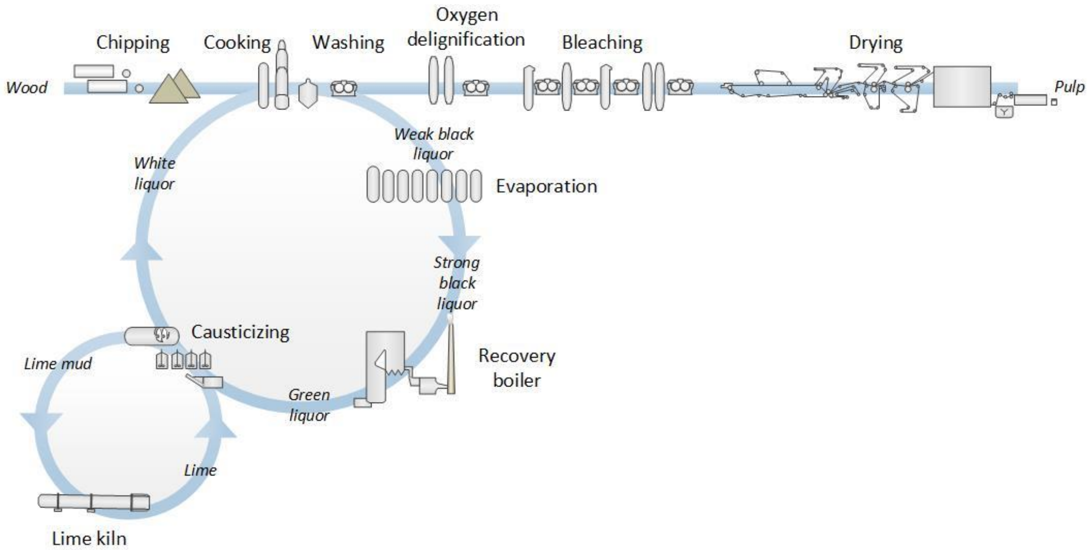

Figure 4. Simplified layout of the Kraft process showing some of the most important process steps (Rudén, 2017).

The raw material used at Värö mill is in the form of softwood, more specifically a mixture of spruce and pine. The pulping process aims at isolating the complex lignin polymer from the fibers in order to achieve an appropriate pulp quality, i.e. obtain desired brightness and other properties of the pulp (Södra, 2016c).

2.1.1 Wood handling

The wood raw material in the form of wood logs are transported to the mill by trains and trucks. Depending on outdoor conditions, de-icing of the logs might be necessary to facilitate debarking but also to remove stones and sand particles. Thereafter, the logs are subjected to a debarking step performed in a debarking drum. Removal of bark is done due to numerous reasons. For instance, any residual bark will be problematic in subsequent process equipment and in the end, cause a lower quality pulp. Additional remaining water, sand and bark is removed in a washing step. Next step is chipping of the logs into wood chips. Screening equipment ensure that inappropriate chips does not continue to the digester (Brännvall, 2009a).

2.1.2 Cooking

In the cooking section, the main objective is to liberate the fibers by dissolving the lignin which was holding the fibers together. At Värö mill, the cooking occurs in a large capacity continuous digester unit.

The first step in the cooking process is to remove air from the wood chips and this is achieved by treating the wood chips with steam which makes the process of penetrating liquor into the wood chips easier. Thereafter, the wood chips enter an impregnation unit where the wood chips are blended with the active cooking chemicals. In Kraft pulping, the active cooking chemicals present are sodium hydroxide (NaOH) and sodium sulfide (Na_2S). This specific cooking liquor mixture will henceforth be known as white liquor. After being impregnated with liquor, the wood chips continue to the digester. Delignification of the wood chips occurs in the cooking zone of the digester, and it is done by treating them with white liquor at elevated temperature and pressure. After the wood chips have been cooked, they enter the washing zone of the digester. Washing liquor enters at the bottom of the digester meaning that it flows counter-currently to the chips. Washing liquor is used to wash the pulp. By doing so, used cooking chemicals and dissolved organic compounds are removed forming a mixture called black liquor (Brännvall, 2009b). The formed pulp is taken out of bottom of the digester with a scraper (Södra, 2016c).

At Värö mill, the feed of white liquor to the digester is preheated with black liquor leaving the digester. The black liquor leaving the digester enters a flash unit separating a volatile compound called turpentine to the gas phase, while the black liquor continues in the process as liquid phase. The black liquor is thereafter further cooled for heat recovery purposes and to avoid overflow in the tanks in which the black liquor is stored.

2.1.3 Oxygen delignification and bleaching

After being cooked the pulp has a brown color. To achieve a bright and clean pulp, it is further treated in an oxygen delignification step followed by bleaching stages. The oxygen delignification can be seen as an extension of the cooking. During oxygen delignification, an oxidation of lignin occurs. This incorporates hydrophilic groups in the lignin molecule enabling dissolution of lignin. Here, over 50 % of the lignin which was not removed in the digester is now removed (Germgård, 2009).

In the bleaching process, almost all residual lignin is removed. At Värö mill, two different types of bleaching processes are utilized and these are either total chlorine free (TCF) or elemental chlorine free (ECF) bleaching. In the ECF bleaching process chlorine dioxide is used and in the TCF process hydrogen peroxide is used. The bleaching is performed in stages with washing in between to not harm the fibers (Södra, 2016c).

2.1.4 Drying

The pulp needs to be dried to facilitate transportation and to prevent it from molding. Removal of water is done in several steps. First, the pulp enters the wire section where it is dewatered to a dry solids content of about 20-25 %. Next step of the dewatering is to press out water in a press section, decreasing the water content to 45-50 %. In the last step, pulp is transferred to a drying machine where it is dried to a dry solids content of 90 % (Södra, 2016c).

The drying machine at Värö mill is divided into a drying and a cooling section. The drying machine uses preheated air to dry the pulp. A large amount of LP steam is also necessary for the drying operation. The drying air is preheated by flash steam from the drying machine and through heat recovery of moist air leaving the drying machine. The heat from the moist air is also used for local heating and heating of water. In the cooling section, air is used to cool down the dried pulp before it leaves the drying section.

At Värö mill, pulp can also be dried in a cyclone dryer to produce flash-dried pulp. For this dryer, there are two intakes of air. This air is necessary to heat to make it suitable for drying purpose. The difference between these two air feed streams is that one of them is firstly preheated through heat exchanging with a split stream of moist air from the drying machine and the other one being preheated with a circulating glycol stream. Thereafter, heating is performed in the same way, first with LP steam and then with MP steam.

2.1.5 Evaporation

In black liquor, both organic and inorganic components are present. The organic material arises from dissolved lignin and carbohydrates. The inorganic compounds include chemicals, water and lesser amounts of inorganic elements arising due to the treatment of wood. In the chemical recovery process, black liquor is further treated in order to recover the spent cooking chemicals and utilize the organic material as a fuel (Theliander, 2009a).

Evaporation of weak black liquor is necessary to concentrate it to strong black liquor so as to make it a suitable fuel, i.e. increase the dry solids content of the black liquor. Mostly water is removed in this process, however some other compounds such as methanol is too removed. Typically, weak black liquor has a dry solids content of 15-20 % while strong black liquor has a dry solids content of 70-80 %. In order to achieve a good heat economy, evaporation is performed in multiple effects. An evaporator has a heating zone, i.e. a heat exchanger, and a separation zone. In a multiple effect evaporation, saturated steam is fed to the first effect and is condensed in order to provide heat to the feed of black liquor. Heating of black liquor results in formation of steam which is separated from the black liquor. Because of boiling point rise, which increase with higher dry content of the black liquor, the steam is superheated. To achieve an improved heat transfer, the superheated steam is typically saturated by adding a small amount of condensate. The steam formed is thereafter reused in the next effect which has a decreased operating pressure, forming new steam which is used in the effect after that with a further deceased pressure, and so on until the desired dry solids content of the black liquor has been achieved. The steam from the last effect is condensed in surface condensers. The condensate which is contaminated with for instance methanol, needs to be further treated in a stripper unit (Theliander, 2009a). At Värö mill, evaporation of black liquor is performed in a 7-effect economy (Ivarsson, 2014) which is followed by a super concentrator. The state-of the art evaporation plant at Värö mill makes it possible to achieve an 82 % dry solids content black liquor today.

2.1.6 Recovery boiler and recovery of white liquor

Combustion of the highly energy containing organic material present in strong black liquor occurs as it is sprayed into the furnace of the recovery boiler. Here, a large amount of heat is formed which is utilized for production of high pressure steam and to reduce sodium sulfate to sodium sulfide (Theliander, 2009a). There is a formation of a salt smelt at the bottom of the furnace. The major compounds present in the smelt are sodium sulfide and sodium carbonate. The smelt is taken out from the bottom of the recovery boiler and is dissolved in a smelt dissolver. The formed dissolved smelt is called green liquor and it continues to a slaker unit in which calcium oxide in burnt lime from the lime kiln is added as well. Reaction with water result in slaking of calcium oxide forming calcium hydroxide. The liquor is transported to causticizing vessels, in which most of the causticizing reactions take place, that is calcium hydroxide reacting with the sodium carbonate in the liquor forming sodium hydroxide and solid calcium carbonate. The slurry is then filtrated, the filtrate being white liquor while the solid phase lime mud. The lime mud (mainly calcium carbonate) is burnt in the lime kiln forming burnt lime (mainly calcium oxide) (Theliander, 2009b).

2.2 Energy System at Södra Cell Värö

The following subsections describes the energy system at Södra Cell Värö. More specifically, the steam production system, the secondary heating system, the district heating system and the saw mill and pellet manufacturing are explained.

2.2.1 Steam production

Figure 5 visualizes the steam network at Södra Cell Värö. The largest steam producer at the mill is the recovery boiler which provides high pressure steam, 85 barg and 485 ° C, to the back-pressure turbine and to the condensing turbine. The bark boiler also produces steam but at a level of 58 barg and 455 ° C. When the bark boiler is under operation, its steam is provided to the back-pressure turbine. This results in that more steam from the recovery boiler instead can go to the condensing turbine enabling an increased electricity production. The current plan is to operate the bark boiler more than what has been done previously in order to reduce the need for storing bark and to produce more electricity. The back-pressure turbine and the condensing turbine have a maximum capacity of approximately 63 MW electricity each.

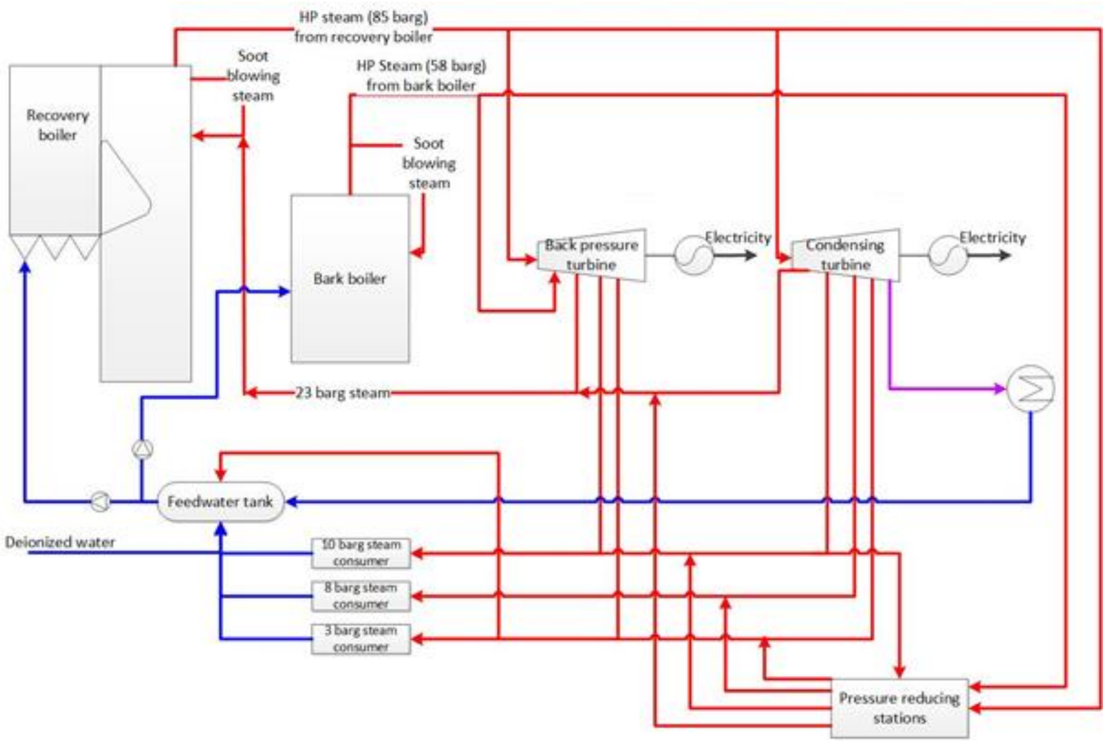

Figure 5. Steam network at the mill including for instance the two turbines and the different steam pressure levels required in the process (Rudén, 2017).

From the turbines steam at four different pressure levels are extracted, 23, 10, 8 and 3 barg. The steam at 23 barg is recirculated to the recovery boiler used as soot blowing steam and to preheat combustion air and feed water. The other steam levels are used for heating purposes in various parts of the process, in for instance the evaporation plant and the drying machine. Excess of steam is condensed in a dumping condenser, producing hot water (HW).

The condensate system of Värö mill can be seen in Figure 6. The recycled condensate arising from condensation of steam in the process is collected in a tank. Before being used to produce steam, it is necessary to pass the condensate through mixed bed filters. This is important to completely desalinate the condensate and it is performed by ion-exchange. The mixed bed filters are sensitive to heat and therefore the hot condensate needs to be cooled before entering the filters. Cooling is done by heat exchanging the condensate stream with feed water. Before entering the filters, deionized water and condensate from the condensing turbine is mixed with the condensate. Cold deionized water from the VKT-tank, see to the left in the figure, is also added to the system to cover losses in terms of feed water.

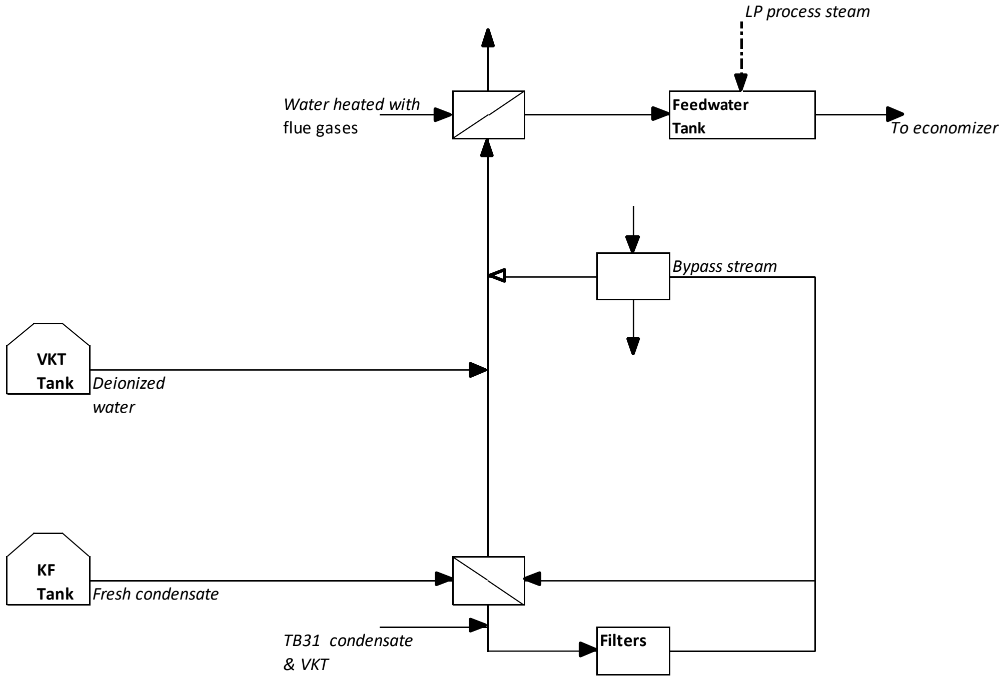

Figure 6. The condensate system at Värö.

The boiler feed water is preheated by an indirect heat exchange with the flue gases from the recovery boiler, see the heat exchanger in the top the figure above. Pressurized circulating water acts as a transport medium, transferring heat from the flue gases to the boiler feed water. After being preheated, the boiler feed water enters the feed water tank. In the feed water tank, there is a direct injection of low pressure steam which is used to heat the feed water and to remove air. Regarding air removal, it is especially important to ensure that oxygen is removed. This since if oxygen continues in the feed water system, it can cause severe corrosion problems in for example the inside of tubes of the boilers. After passing the feed water tank, the feed water is thereafter pumped entering the economizer of the recovery boiler and the bark boiler.

2.2.2 Secondary heating system

Värö mill has several different water types. These includes fresh water intake from the river Viskan, mechanically cleaned water, chemically purified water and deionized water. The different water types are important because the required degree of purity of water varies for the different process demands at the site.

During the Värö mill expansion, a new modern secondary heating system (SHS) was constructed. In the SHS of Värö mill, chemically purified water is used in order to recover heat from process streams. The water is thereby heated producing lukewarm, warm or hot water which is stored in different tanks depending on the temperature level. See Table 1 for a list of approximate temperatures for the different grades of water included in the SHS. The heated water can thereafter be transported around the process site to meet the heat demand of various streams. Thus, the water in a SHS acts as transport medium, transporting heat from heat sources to heat deficits and in that way providing heating or cooling wherever it is needed. See Figure 24 in appendix 5 for an overview of the SHS of Värö mill.

Table 1. Approximate temperatures of the chemically purified water included in Södra Cell Värö's secondary heating system.

Name	**T [°C]**
Cold water (CW)	22
Lukewarm water (LWW)	50
Warm water (WW)	70
Hot water (HW)	90

There are two cooling tower connected at Värö mill, one for the condensing turbine and one for the process SHS. The cooling towers cools excess heat from the process and thus minimizes the fresh water intake from the river Viskan.

2.3 District heating system

Excess heat from the process is today used to provide the nearby city Varberg with district heating. The demand for district heating (DH) varies with the ambient temperature and for obvious reasons the highest demand occurs during the winter season. Figure 7 shows how the cold DH return water, see the stream to the left in the figure, is reheated through heat exchange. The numbers in the figure are from balance data which was set up for the expansion project. The balance data is for a winter case with TCF bleaching and a pulp production of 2330 ADt/d. The first HXs are placed in a parallel configuration to each other. Here, heat to the DH water can be provided through either heat exchanging it with a hot alkaline bleaching effluent stream and/or with HW. Thereafter, a hot stream with weak black liquor is heat exchanged with the DH stream. If even more heat is required, it is performed by using a LP steam heater. The final delivery temperature of the DH water in this specific case is set to 93 °C (Rudén & Olowson, 2016).

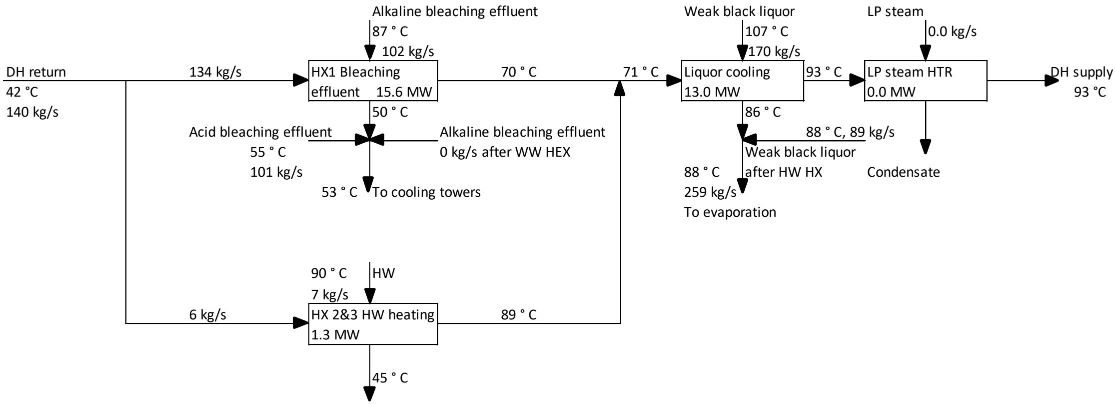

Figure 7. District heating delivery to Varberg.

In addition, there is also a delivery of HW to a nearby tomato farm.

2.4 Saw mill and pellet manufacturing

Apart from the DH to Varberg and the tomato farm, there are other external heat users at the Värö site, i.e. heat users which are not actual process requirements necessary to produce pulp. These includes the timber kilns and sawdust dryer which are located relatively close to the pulping process. Pressurized circulating water is heated utilizing energy from the pulp mill. The circulating water is in turn used to heat the air to the dryers through a large number of HXs. Figure 8 visualizes the circulating water and how heat is provided to it. The data included in the figure is from balance data for a pulp production of 2330 ADt/d and TCF bleaching. The heat demand for the timber kilns and sawdust dryer is provided using HW, black liquor deductions from the evaporation plant and is finally topped with LP steam (Rudén & Olowson, 2016). Regarding the sawdust dryer, its feed is a fraction of the flow of the stream leaving the timber kilns. The stream leaving the sawdust dryer is heated with HW and is thereafter mixed with a fraction of the flow of the timber kilns outlet stream.

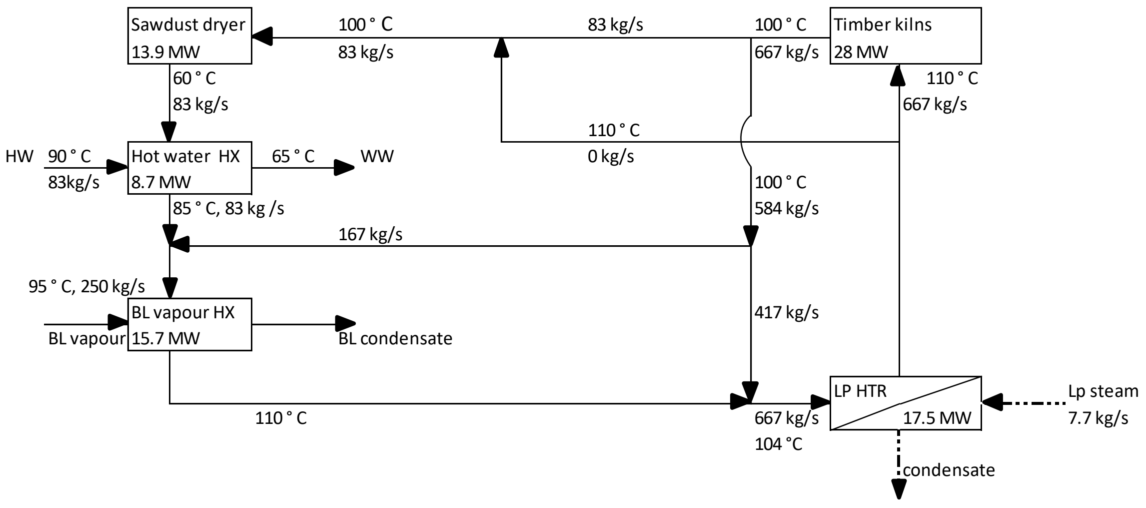

Figure 8. How heat is provided to the pressurized circulating water for the sawdust dryer and the timber kilns.

3 Theory

In the theory section, some important pinch analysis theory is presented. The main focus here is on the concepts that are utilized extensively throughout this specific thesis work.

3.1 Pinch analysis

Industrial plants are typically associated with a high complexity due to the large number of different units required. Such a process involves many streams, i.e. flows demanding either heating or cooling without any composition change (Kemp, 2007a). These energy demands can be met in two different ways. It can be done by external heat exchanging of the desired stream using hot or cold utility, i.e. heaters or coolers. The alternative is heat exchanging internal streams within the process. Even though the latter is preferred from an energy savings perspective, external utility will almost always be necessary. Thus, the question arises how one should design large heat exchanger networks (HEN)s in an appropriate manner such that energy efficiency is achieved. There exists a tool for investigating precisely this, namely pinch analysis. An advantage with this tool is that it can be utilized to evaluate HENs in both grassroots and retrofit designs (Kemp, 2007a; Hackl et al., 2010).

Pinch analysis is a systematic method to analyze heating and cooling demands for an industrial process. For instance, the method can be used as a tool for investigating utility options, determining what is the minimum external cooling and heating and the potential for internal heat exchanging. Thus, the main objective with pinch analysis is to identify opportunities for energy savings by improved process heat integration. (Kemp, 2007b).

3.1.1 Data extraction

The first step in pinch analysis is to extract stream data from the industrial process of interest. The data extraction is a crucial step and it is important for achieving a true representation of the process. Start and target temperature, heat load or flow rate and heat capacity are extracted for each relevant stream. The streams are then categorized as hot or cold. A hot stream has a demand for cooling while a cold stream has a demand for heating (Kemp, 2007c).

In pinch analysis one often assumes constant heat capacity for the hot and cold streams. However, in real processes heat capacities are functions of temperature. Therefore, consideration should be done whether it is appropriate to assume a constant heat capacity. If not, it is possible to perform a linearization of the heat capacity flow rate (Kemp, 2007c).

During selection of streams it is of great importance to consider whether the target temperature of the stream is a *soft* target or a *hard* target. Hard target means that it is necessary to meet the target temperature of the stream since it is a process requirement. For instance, the feed to a reactor typically demands a certain temperature, thus a hard target. A hard target is easy to handle and understand. On the other hand, a soft target is much trickier to handle because it involves flexibility of the target temperature. For instance, effluent streams and storage temperatures are often not set, thus a soft target. What final target temperature is decided here depends on how much heat recovery that is deemed appropriate. However, in order to investigate the potential for heat recovery, the hot stream target temperature can be set to a temperature close to the ambient temperature, if there are no related practical limitations of doing so (Berntsson et al., 2015).

3.1.2 Composite curves and Grand composite curves

Before an energy targeting can begin, it is necessary to select a start value for the driving force for heat exchange ΔT_{min}. It can either be a global ΔT_{min} for the entire HEN or individual values which are dependent on heat transfer coefficients of the different streams. Choosing an appropriate ΔT_{min} is important as it exists a trade-off between capital and energy cost related to it. For instance, a low ΔT_{min} implies that a large heat transfer area is necessary (high capital cost) but decreases the requirement for cold and hot utility (low energy cost).

To facilitate the energy targeting cold and hot Composite Curves (CC) can be plotted in the same graph. To be able to plot the hot CC, the different hot stream temperature ranges are first identified. Within each temperature range, one calculates the individual stream duty contributions and summarize them. The heat flow capacities are summarized within each interval in a similar manner as well. For each interval, a straight line can thus be plotted using temperature ranges [°C] and its corresponding heat load [kW], the slope given as heat flow capacity [kW/°C]. The cold CC is constructed analogously.

A value for maximum heat recovery by internal heat exchanging is given by the load corresponding to the region in which the hot and cold CC overlap. Hot and cold demand that cannot be recovered needs external hot or cold utility. This also means that the minimum external hot and cold utility can be obtained from this graph (Kemp, 2007b). Figure 9 visualizes how typical hot and cold CC may appear and some of the important information that can be obtained from such a plot.

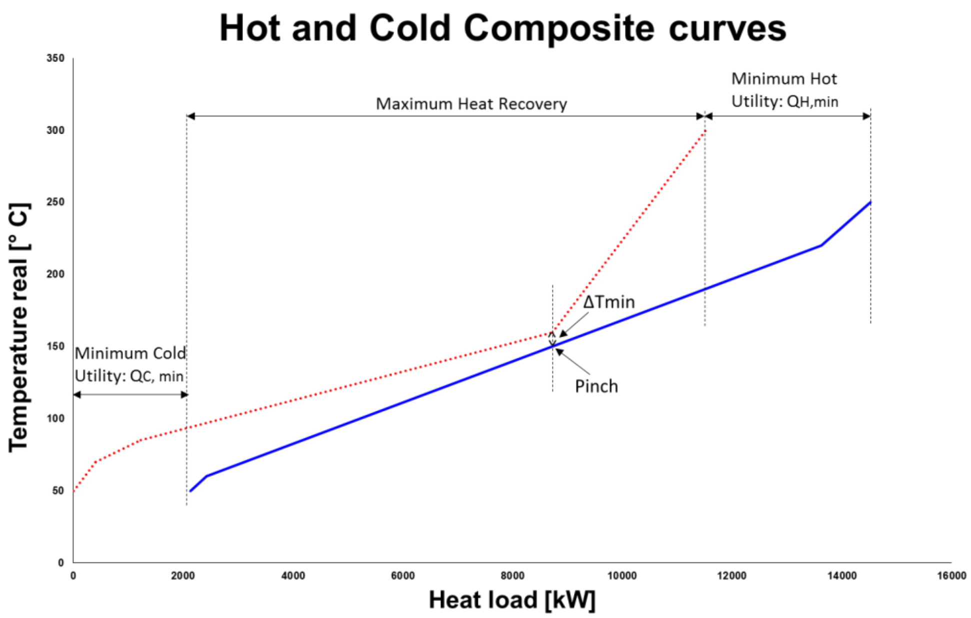

Figure 9. An example of hot and cold composite curves plotted in the same T/Q diagram. The dotted line, i.e. the above red curve, represents the hot composite curve. The filled line, i.e. the lower blue curve, represents the cold composite curve.

In Figure 9 above, the hot and cold pinch points can be seen. The pinch point, or pinch temperature, determines where the minimum driving force should be located when designing a HEN. Hence, the pinch point is the starting point and reference point for the design.

The Grand Composite Curve (GCC) is another plot used extensively in pinch analysis. Here, the real temperatures are turned into shifted temperatures. Shifting temperatures are done by raising all cold stream temperatures by $\Delta T_{min}/2$ and decreasing all hot stream temperatures by $\Delta T_{min}/2$. It is possible to construct the GCC from the CCs. This is done by first converting temperatures of the cold and hot CCs to shifted temperatures. Thereafter, the difference in heat load for the two curves is calculated for every temperature level present. By accounting for whether there is an excess or deficit of heat available for each temperature level, the GCC graph can thus be drawn.

From the GCC the minimum hot and cold utility demand and the pinch point can be obtained. The GCC also provide additional useful information. Firstly, the GCC provides the opportunity of identifying different levels of utility. Secondly, it shows any heat pockets present in the process, i.e. places in the process that is self-sufficient in energy, which can be utilized to improve the energy efficiency of the process. Thirdly, it provides a convenient way of investigating opportunities for process integration of for instance evaporation effects through utilization of background/foreground analysis. Here, the unit operation of interest is placed in the foreground while the rest of the process is placed in the background. By altering the foreground, opportunities to save utility may then arise. Lastly, the GCC can also be used to analyze potential delivery of excess heat to nearby district heating networks in a background/foreground analysis.

Figure 10 shows an example of a GCC. Note that the pinch point is situated where the net heat flow is zero. It can clearly be seen that the minimum hot and cold utility can be obtained from the figure. Furthermore, two heat pockets can be identified in this specific example.

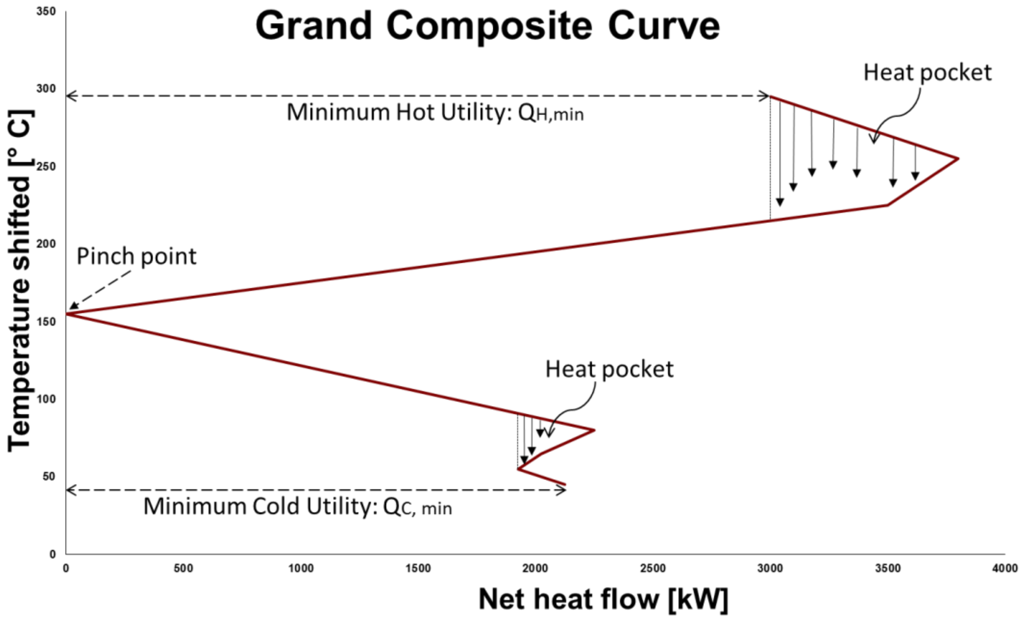

Figure 10. Grand composite curve example indicating some of the information that can be obtained for such a plot.

3.1.3 Maximum energy recovery network

In the region below the pinch there is a heat surplus and above the pinch there is a heat deficit. Consequently, the result of cooling streams above the pinch is that external heating is needed to compensate for it. In a similar manner, heating below the pinch requires additional external cooling. To avoid inefficient heat exchange, there are three rules that must be obeyed. If one or more of these rules are disobeyed, pinch violations are present in the HEN (Kemp, 2007d). The rules are presented below.

- Do not transfer heat through the pinch
- Do not heat below the pinch point by utilizing external hot utility
- Do not cool above the pinch point by utilizing external cold utility

By strictly obeying the pinch rules, a maximum energy recovery (MER) network is obtained. In a MER network one achieves the minimum external cold utility usage $Q_{C,min}$ the minimum external hot utility usage $Q_{H,min}$, and therefore also the maximum amount of internal heat exchange.

To avoid pinch violations, the network is divided into two sub networks, one above the pinch and one below. In each temperature interval, hot and cold demands are matched, starting at the pinch where the driving force is lowest. Where there is no possible match external utility is added.

However, constructing a MER network in a real process is seldom economically worthwhile and is therefore typically not done in industry. For instance, a MER network would imply an excessive amount of heat exchangers (HX)'s, many of which would have a very small heat transfer area. In addition, these HXs would require a large amount of piping.

3.1.4 Retrofitting of existing heat exchanger networks

Retrofitting of existing HENs is done to investigate potential savings in external utility. However, these modifications need to be profitable if they are to be implemented. A good start is typically to first locate and determine the size of the pinch violations. The most severe pinch violations are often favorable to start investigating as those indicates the largest potential energy savings. Pinch violations can be solved by new HXs, re-use old ones or adding additional area to the already existing ones.

The following guidelines can be applied in order to keep the cost down for a HEN retrofit to some extent (Berntsson et al., 2015):

- Investments in new heat exchangers should be avoided as much as possible.
- Use the existing heat exchangers at their original position.
- Avoid an excessive amount of new piping.

4 Methodology

The thesis work was divided into four main parts namely planning, data extraction, energy analysis and report writing together with a presentation. Literature studies of the pulping process, pinch technology and energy auditing were included in the planning. An understanding of the pulping process is of immense importance when performing stream data extraction and energy analysis, hence it was included in the literature review.

Data extraction and energy analysis were two major necessities to be able to perform this master's thesis. These were divided into different blocks as is shown in Figure 11. Some important information that was needed to complete each block can also be seen in the figure. How the work was executed is described in more detail in the following subsections.

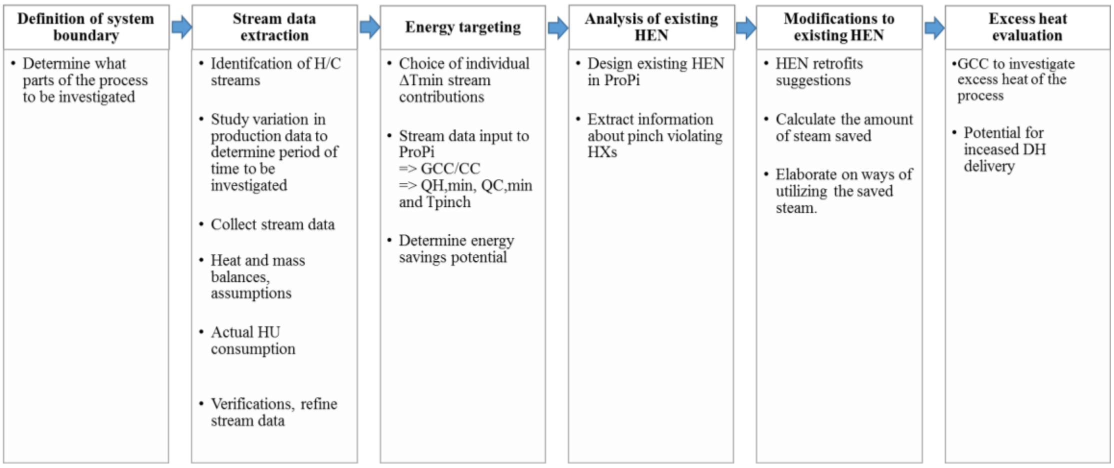

Figure 11. Procedure for the data extraction and energy analysis performed during the thesis.

4.1 Definition of system boundary

The first step was to define the system boundary for the investigation to decide what parts of the process to be included. By studying control systems and schematics of the SHS, system boundaries were decided including streams of the entire pulp mill.

The bark boiler has normally only been running during the colder months of the year. However, in order to include the potential of running the bark boiler more frequently than what has been done previously, it was determined to account for it in this study. In addition, the nearby saw mill, pellet plant and tomato farm were decided to be included, due to their strong connection to the pulp mill in terms of energy and material flows. Since data was missing for the chlorine dioxide production line, it was decided to extract data for a period in which TCF pulp bleaching was running. By doing so, there was no need to study and collect data for the chlorine dioxide production which simplified the work.

4.2 Stream data extraction

The subsections below describe how the work of extracting stream data from the process in operation was executed.

4.2.1 Data collection

The most time-consuming work of this thesis was to identify hot and cold streams and to collect relevant data at the mill. Not only were there a rather high number of hot and cold streams, but also many situations occurred in which a more detailed understanding of the process was required. For those situations consultation was done with supervisors at the mill or alternatively engineers within specific process areas. Furthermore, useful information was obtained from the previous master's thesis "Energy analysis of Hemicellulose Extraction at a Softwood Kraft Pulp Mill" performed at Värö mill in 2013 by Jon Bood and Linus Nilsson. Their work provided with insight regarding the mill and its stream data. However, it should be emphasized that the thesis was based on the old mill meaning that the stream data is now not the same. Moreover, a factory report by Rudén & Olowson (2016) as well as a report regarding energy balances for the expansion project by Ivarsson (2014) provided with very useful information regarding the SHS and other relevant process information (Rudén & Olowson, 2016; Ivarsson, 2014).

To obtain information regarding streams and measurement devices, a plant operator program in combination with process flow diagrams (PFDs) were utilized. It was necessary to check if for instance flowmeters, temperature sensors and valves in the plant operator program were placed on the corresponding position according to the PFD of the process. This was done to confirm that the correct measurement devices had been found and that these were measuring at relevant positions where information was needed. Furthermore, the PFDs facilitated the identification of where streams started and ended.

Whenever possible, heat loads of both the cold and hot side of the HXs were calculated. If the heat loads were not the same, one had to determine which one that was more likely to be representative as the true heat load. This was mainly done by comparing the type of streams that were heat exchanged. For instance, if water was present on one side of the HX and some stream with unknown physical and chemical data on the other, the heat load for the water side was typically deemed more appropriate.

It was also important to not divide the flows into more streams than necessary. Some streams therefore involve more than one HX, still making it possible to design today's network, but also enabling the design of a new HEN with improved heat integration. Water that was used directly as a process requirement, i.e. process water, in for instance washing and dilution, were extracted as streams. The start temperature of those streams was set to the fresh water intake temperature, i.e. the temperature of the river Viskan, while the target temperature was set to the actual temperature demanded.

The steam consumers at the pulp mill were sorted into two different categories. Streams consuming steam which would be possible to replace from a technical perspective were defined as cold streams at their true process temperatures. Streams requiring steam in such a way that it is irreplaceable was considered as cold streams at the temperature in which the steam used as heating medium condenses. Direct injection of steam to the digester and live steam to the evaporator effects are examples where steam cannot be replaced.

To be able to convert steam mass flows into heat loads, temperatures and pressures of the different types of steams were extracted. It has thus been taken into account whether the steam is saturated or super-heated. For most of the steam users, saturated liquid condition was assumed for the formed condensate when calculating the enthalpy of liquid water. However, for some steam consumers there is an obvious sub cooling of the condensed water, and for those the enthalpy for liquid water is calculated as the mass flow times the heat capacity and the temperature of the subcooled liquid. Furthermore, for some HXs the heat load of steam was calculated on the cold side of the HX. The steam demand for the saw mill is one example where this was done.

How to account for the SHS in a pinch analysis is not obvious. In this work, the SHS water has not been extracted as streams. However, an investigation was performed in to investigate the effect that the SHS might have in a pinch analysis study, for more details regarding this see section 5.10.

4.2.2 Streams excluded in the analysis

Steam for soot blowing purpose was decided not to be included because it is irreplaceable. In addition, the steam is used for blowing soot and is therefore not used for the purpose of heating. Steam going to the dumping condenser was excluded as it is assumed that when the pulp mill is operating at full capacity, there will not be any excess of steam meaning that it is not required. Steam to the causticizing plant is omitted since its load is negligible and that there should not be any consumption of steam related to the causticizing plant. The trim condenser of the evaporation plant is not included since it is not supposed to run.

4.2.3 Time period

The time period chosen for collection of data was 2017-03-27 18:00 to 2017-03-28 17:00. Time-averaged values were collected for the data at a time interval of one hour using the ID of identified measurement devices. These values were studied to investigate the variation over time and to confirm that the signals were not characterized by some unusual disturbances. To make the data appropriate for pinch analysis, an average was calculated. It was of great importance to collect data for the various parts of the process from the same time period. However, for a few streams, for instance the stream "weak gas from bleaching plant", data had to be collected from another period due measurement or signal problems.

The time period was chosen as it was deemed that the mill had had a production capacity that was rather close to the maximum production capacity. The digester, bleaching plant, drying machine, cyclone dryer and the two turbines were all running relatively stable during this time period although some disturbances in the signals were experienced for the drying machine. However, as full production capacity was not fully achieved, it was decided to scale up data to approach this scenario more.

Once all relevant data had been collected it was thereafter sorted and presented in a stream data table to get a good overview and prepare for the subsequent analysis.

4.2.4 Measurements and other data input

Whenever possible, data was extracted from existing process measurement devices measuring temperatures, volumetric or mass flow rates, pressure levels and densities. However, many situations arose when there was lack of data necessary for the pinch analysis. Therefore, for some streams, temperatures and flow rates were measured manually with measurement equipment on the outside of pipes by the authors and staff at Värö mill. However, some data had to be obtained by other means because of practical limitations. For some situations, missing data could be obtained by setting up energy and mass balances. For instance, mixing point calculations turned out to be especially useful to calculate missing data.

For some streams, in particular for the cooking section, the stream data is approximative and was obtained through discussion with process engineers at Värö mill. Furthermore, in some situations, there were design data available for HXs which was used to calculate what was required to finalize a stream, for example for the primary condenser in methanol production and preheating of outdoor air to the recovery boiler.

Also, some target temperatures were extracted from design data. The target temperatures for the flue gases from the recovery boiler, bark boiler and lime kiln was set to a temperature as low as possible, 140 °C. A lower temperature might result in that some gases start to condense resulting in a corrosion risk for equipment. Effluents going to biological treatment were given a target temperature of 37 °C because that is a requirement to achieve a favorable microorganism environment.

For the stream related to heating of feed water to the feed water tank, the target temperature was set to a design temperature of 123 °C. Steam is today added to the feed water tank to heat the feed water and to remove air. The feed water in the feed water tank thereafter holds a temperature of about 140 °C. A target temperature of 123 °C was specified to include the potential for replacing the steam used only for heating. The steam for air removal is irreplaceable and it also performs the temperature increase from 123 to 140 °C. Having feed water of 123 °C entering the feed water tank should be sufficient to achieve the desired air removal (Ivarsson, 2014).

4.2.4.1 Cooking section data

During the time period for data extraction two important HXs were not running due to design problems. These HXs involve heat exchanging a flow of white liquor entering the digester with weak black liquor leaving the digester. In addition, the turpentine production was not stable during the time for data extraction. Such factors affect the energy balance of the cooking section and the entire mill to a large extent. Since it was desired that the data was to be representative for high and stable production, in accordance with the new production numbers, data for the entire cooking section has been approximated through discussion with process engineers at Värö mill.

4.3 Energy targeting

See Table 2 for a list of the different ΔT_{min} contributions chosen depending upon type of stream. The values are from another energy investigation (Axelsson, 2008). For some HXs present in the process it was found that the actual temperature difference for heat exchange was lower than what is stated in the table below. For those situations, the ΔT_{min} contributions for the involved streams had to be lowered.

A sensitivity analysis was performed to evaluate the choice of ΔT_{min}.

Table 2. Individual temperature difference for heat exchange for various types of streams.

Stream type	**$\Delta T_{min}/2$ [K]**
Live steam	0.5
Steam (contaminated)	2
Water (clean)	2.5
Water (contaminated)	3.5
Air	8
Moist air	7
Flue gases	7

Data was controlled and refined for streams which turned out to be near the pinch. This was especially important for streams where assumptions had been done to evaluate the impact on the energy analysis.

4.3.1 Software tool

A software program which was utilized extensively during the pinch analysis part of the thesis was ProPi. ProPi was developed by Chalmers Industriteknik AB and it was useful as it provided an efficient means of plotting important graphs, i.e. hot and cold CCs and GCCs. At the same time, it calculated the pinch temperature and minimum hot and cold utility demands. ProPi also provided the opportunity to design HENs and performed calculations for the HX matches. In addition, it revealed any pinch violation that occurred in the HEN that had been set up.

4.4 Analysis and modifications to the existing HEN

The most severe pinch violations were identified and solutions were presented to decrease the extent of these. The suggested solutions were in terms of a retrofitted HEN design with improved heat integration. The modifications to the existing HEN were discussed with the engineers at Värö mill. By doing so, technical limitations and difficulties related to the some of the solutions could be identified.

Furthermore, when performing retrofits, it was good to keep in mind the general rule of thumb that it is much more efficient from an economical perspective to transport liquid water than gases such as air and flue gases. This since water can be transported around the pulp mill rather easily by pumps, while gases would require fans.

Generation of additional electricity in the condensing turbine was deemed as the most appropriate use of the primary heat savings achieved, as that would probably be most beneficial for Värö mill. As an alternative use of the LP steam savings, the possibility to reduce the load of the bark boiler to save bark was also investigated.

4.5 Excess heat evaluation

A study was conducted to identify the amount of excess heat from the process and its temperature range. The GCC of the process was used together with stream data for DH to Varberg in a background/foreground analysis. This was done to evaluate the potential for delivering an increased amount of DH than what is done today. In addition, it was also investigated whether it is possible to still deliver the same amount of DH that was produced during the studied period if a MER network of the process is achieved.

5 Results

In this section production data is presented followed by important pinch analysis graphs. Thereafter, pinch violations and retrofit suggestions are presented for the existing HEN. Alternatives for utilizing the saved steam are described and the result from the DH evaluation is presented. Some of the pinch violations are also later in the report investigated with a pinch temperature interval approach. Information regarding how one may account for the SHS in a pinch analysis is also presented.

5.1 Production data

In Table 3 some production data for the process is presented. As can be seen in the table, the actual pulp production during the investigated time period is not fully at its maximum. To be able to represent the maximum pulp production data, the stream heat loads are scaled up with the assumption that the heat loads would increase linearly with an increased production. The stream heat loads are scaled up by 6 % for all streams except in the cooking section where the stream heat loads are scaled up by 8 % to account for pulp losses which occurs during the process steps from the digester to the drying machine. However, some streams are unaffected by the observed difference in pulp production and are therefore not adjusted. These streams include the bark dryer, sawdust dryer, timber kilns, local heating, DH to Varberg and delivery of HW to the nearby tomato farm. The actual extracted heat load for DH delivery to Varberg is present in the stream data table. The rest of the production data in the table below is to compare general production data with its corresponding maximum production data.

Table 3. Production data for the investigated time period, i.e. 2017-03-27 to 2017-03-28, and the corresponding predicted maximum production values.

Type	**Actual values**	**Maximum values**
Production of pulp	2199.4 ADt/d	2330 ADt/d [1]
Raw water intake from the river Viskan	1.1 m^3/s	2 m^3/s [2]
Recovery boiler, production of steam	310.2 MW	340.9 MW
Bark boiler, production of steam	33.0 MW	39.2 MW (bark) 54.8 MW (bark + oil)
Production of electricity Condense turbine (TB31)	46.2 MW	63.8 MW
Production of electricity Back pressure turbine (TB21)	43.1 MW	63 MW
District heating to Varberg	16.2 MW	30 MW [3]

[1] The value is for a TCF winter case (Ivarsson, 2014).
[2] There is a maximum limit of how much fresh water intake that is allowed due to restrictions.
[3] 30 MW is what can be delivered to Varberg today during the winter. However, the district heating system capacity is approximately 50 MW (Rudén & Olowson, 2016).

5.1.1 Steam consumption

Table 4 shows a list of LP steam consumers at the plant. In total, approximately 224 MW LP steam is used. By studying the numbers in the table, it can be concluded that the two major LP steam consumers, i.e. live steam to the evaporation plant and the drying machine accounts for over 60 % of the total demand for LP steam.

Table 4. List of all LP steam consumers at the plant including in what process section the demand is required and the respective heat loads for the cold streams.

LP steam consumers (4.2 bar, 145 °C)		
Name	**Plant section**	**Q [MW]**
Weak black liquor to impregnation vessel (impbin)	Cooking	7.7
Impregnation vessel (impbin)	Cooking	9.2
Evaporator effects 1A, 1B, 1C	Evaporation	89.6
Methanol column	Evaporation	0.6
Weak gas to cyclone	Evaporation	0.4
BB4 heater	Bleaching	2.1
BB2 heater	Bleaching	2.1
Feed water tank (heating)	Condensate treatment	11.6
Feed water tank (removal of air)	Condensate treatment	11.3
Combustion air to recovery boiler	Recovery boiler	3.8
Chemical plant	Chemical plant	1.0
Drying machine	Paper room	48.5
Cyclone dryer	Paper room	10.3
Wire steam box	Paper room	3.0
Bark dryer	Wood handling	4.3
Timber kilns	Saw mill	18.2
	Total	**223.7**

See Table 5 for a summary of the MP1 and MP2 steam demands included in the analysis. The two largest consumers of MP are the direct injection of steam into the digester, and the live steam provided to the super concentrator of the evaporation plant. The cooking section has its own MP1 steam level at 9.6 bar and 178 °C. The rest of the demands in the table are met by MP2 steam at 11.7 bar and 185 °C.

Table 5. The MP1 and MP2 steam consumers included in the analysis including pressure levels and heat loads for the cold streams.

MP1 and MP2 steam consumers			
Name	**Plant section**	**P [bar]**	**Q [MW]**
Digester	Cooking	9.6	17.3
Liquor mix to digester	Cooking	9.6	1.0
Super concentrator	Evaporation	11.7	19.2
Weak gas to cyclone	Evaporation	11.7	0.05
Black liquor to nozzles	Evaporation	11.7	1.5
Combustion air to recovery boiler	Recovery boiler	11.7	9.7
Feed water to economizer 1	Recovery boiler	11.7	3.0
Bleaching step 2	Bleaching	11.7	2.6
Bleaching step 4	Bleaching	11.7	5.7
O_2 reactor	Oxygen bleaching	11.7	0.2
Cyclone dryer	Paper room	11.7	3.8
	Total		**64.0**

Table 6 lists the MP3 steam consumers included in the analysis and these are heating of combustion air to the recovery boiler and heating of feed water between economizer 1 and 2 in the recovery boiler. MP3 steam has a pressure of 23.7 bar and a temperature of 221 ° C.

Table 6. MP3 steam consumers at the mill. The MP3 consumers are related to the recovery boiler plant section.

MP3 steam consumers (23.7 bar, 221 ° C)		
Name	**Plant section**	**Q [MW]**
Combustion air to recovery boiler	Recovery boiler	2.5
Feed water heating between economizer 1 and 2	Recovery boiler	5.7
	Total	**8.2**

The sum of the heat loads for all steam consumers at the plant gives the actual hot utility usage. It can be concluded that the hot utility usage corresponds to 295.9 MW steam.

5.2 The hot and cold composite curves of Värö mill

The hot and cold CCs of the process can be seen in Figure 12. In Table 16 in Appendix 1 the stream data table used to plot the CCs is listed. The hot CC is represented as the red line while the cold CC is represented as the blue line. The maximum heat recovery, minimum hot utility demand ($Q_{H,\ min}$) and minimum cold utility demand ($Q_{C,\ min}$) are shown in the figure. There are many hot and cold streams in the area around the process pinch point, and the process is close of having other potential pinch points, or rather a pinch temperature interval. This can be seen in the hot and cold CCs as the region in which the curves are close of being rather parallel to each other.

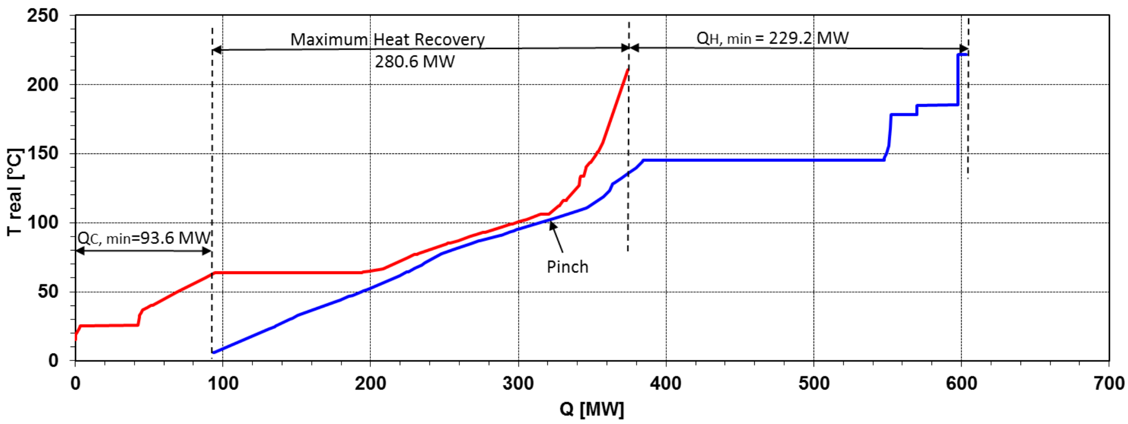

Figure 12. Hot and cold composite curves of Värö mill.

An analysis was conducted in order to identify the pinch temperature interval. The result from the analysis is listed in Table 7. For the entire interval see Table 17 in Appendix 2. The pinch temperature interval starts with a shifted temperature of 80.4 °C and ends with the true shifted pinch temperature of 104 °C. The ΔT_{min} for the pinch point determined by the pinch analysis is about 16 % lower than the second lowest ΔT_{min} within the interval. Therefore, identification and quantification of pinch violations in the existing HEN is performed with respect to the true process pinch point. However, later in the report the effect of a pinch temperature interval is investigated for a selected number of examples.

Table 7. Shifted pinch temperature interval, including its corresponding hot and cold real pinch temperatures and the resulting values for ΔT_{min}. The shifted pinch temperature of 104 °C is determined by ProPi and is referred to as the true shifted pinch temperature of the process.

T_{Cold}^{Pinch} [°C]	T_{Hot}^{Pinch} [°C]	ΔT_{min}	T_{shift} [°C]
77.4	83.4	6.0	80.4
101.9	106.0	4.1	104.0

5.3 The grand composite curve of Värö mill

The GCC of the process investigated can be seen in Figure 13. Note that DH to Varberg is not included as a stream in this specific GCC. The individual ΔT_{min} contributions chosen for the various types of streams involved can be seen in Table 2.

The net heat flows and the shifted temperature levels for LP steam users and the three different levels of MP steam users can clearly be seen in the figure as horizontal lines. Other distinct horizontal lines that can be observed in the figure are the final surface condensers of the evaporation plant and condensation occurring in the condenser after the condensing turbine at a very low pressure. Furthermore, some heat pockets are also depicted in the figure. The three heat pockets at above 144.5 °C shifted temperature, which can be seen to the right in the figure, arises due to cooling of hot flue gases from the recovery boiler. These pockets imply that there should be no requirement of external utility in this region. The demands for LP and MP steam seen in the GCC in the area around the pockets are irreplaceable, however the CCs reveals that there are cold streams that potentially could be used to exploit the pockets. The pocket related to the surface condensation of the evaporation plant, could theoretically be utilized for heat recovery purposes for some of the streams within the temperature interval of the pocket.

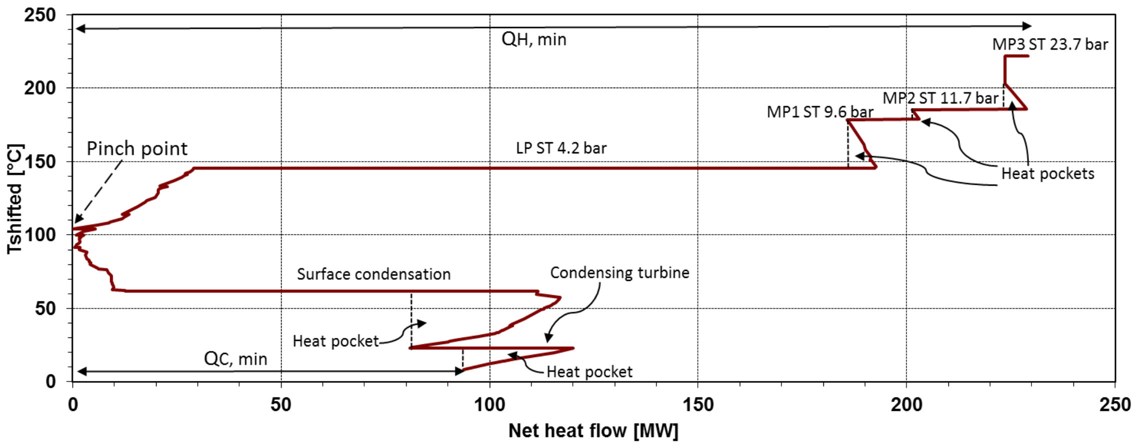

Figure 13. The GCC of Värö mill.

From GCC it can be concluded that the existing process has a shifted pinch temperature of 104 °C, a $Q_{H,\ min}$ of 229.2 MW and a $Q_{C,\ min}$ of 93.6 MW, see Table 8.

Table 8. Important results obtained from the pinch analysis.

Pinch temperature	104 [°C]
$Q_{H,\ min}$	229.2 [MW]
$Q_{C,\ min}$	93.6 [MW]

A sensitivity analysis was conducted by studying the demand curves for the process. From the demand curves a linear relationship between global ΔT_{min} and the heat load could be observed for both the hot and cold demand curves. This implies that there are no threshold effects using global ΔT_{min}.

In Table 9 the potential for primary energy savings for the process is shown. This is calculated as the difference between the actual hot utility usage and the minimum heat load determined by the pinch analysis. The potential for primary energy savings corresponds to approximately 23 % of the total steam consumption at Värö mill.

Table 9. Potential for primary energy savings at Värö mill.

Energy	**Q [MW]**
$Q_{H,\ actual}$	295.9
$Q_{H,\ min}$	229.2
$Q_{H,\ potential\ for\ primary\ energy\ savings} = (Q_{H,\ actual} - Q_{H,\ min})$	66.7

5.4 Pinch violations

As stated in the theory section, reaching a MER network and thus achieving $Q_{H,\,min}$ and $Q_{C,\,min}$ is typically not realistic in industry. Therefore, not unexpectedly, pinch violations are present in the existing HEN at Värö mill. Identified pinch violations larger than 2.5 MW in the existing HEN are listed along with the type of violation in Table 10. Individual pinch violations lower than 2.5 MW are deemed to be of less economic interest to investigate. An expanded list of all individual pinch violations can be seen in Table 18 in Appendix 3. A total of 66.7 MW pinch violations are present in the existing HEN which corresponds to the calculated potential for primary heat savings. The pinch violations listed in Table 10 accounts for approximately 77 % of all the existing violations and are therefore the main focus of this retrofit study.

Table 10. Pinch violations greater than 2.5 MW in the existing HEN. For an in-depth explanation of the pinch violations and the retrofit proposals, the reader is referred to the respective report section.

Name	**Process part**	**Pinch violation [MW]**	**Type of pinch violation**	**Report section**
RB flue gas cooling/feed water heating	Recovery boiler	18.2	Heat transferred through the pinch	5.7.1
Heat demand saw mill	Saw mill	10.8	Heating below pinch	5.8.1
Heat demand air feed to cyclone dryer	Paper room	8.3	Heating below pinch	5.7.3
Combustion air to RB (total)	Recovery boiler	7.8	Heating below pinch	5.7.2
Condensate HX with feed water	Condensate treatment	3.6	Heat transferred through the pinch	5.8.3
Heating of air to bark dryer	Wood handling	2.7	Heating below pinch	5.8.2
	Total pinch violations > 2.5 MW	**51.4**	**Corresponding to 77 % of total pinch violations**	

5.5 Retrofit summary

The information below summarizes the results from the retrofit study. More detailed information regarding the individual retrofit suggestions are explained in sections 5.7 and 5.8. Firstly, some general retrofit suggestion results are proposed. Thereafter, suggestions utilizing unused energy from the hot flue gases of the bark boiler and lime kiln are presented.

Table 11 shows the results from the retrofit study in terms of solved pinch violations and saved steam without utilizing the hot flue gases mentioned above. A total of 9.1 MW LP steam is saved by implementing the suggestions. This value corresponds to 13.6 % of the potential for primary energy savings and 3.1 % of the total steam demand.

Table 11. Retrofit results without utilizing the heat from the flue gases from the bark boiler and the lime kiln.

Name	**Pinch violation before [MW]**	**Pinch violation after [MW]**	**LP Steam savings [MW]**
RB flue gas cooling/feed water heating	18.2	12.7	5.5
Cyclone dryer	8.3	6.1	2.2
Combustion air to RB	7.8	6.4	1.4
		Total	**9.1**

Today, the flue gases from the lime kiln and the bark boiler are not used for heat recovery purposes, instead these are released to the atmosphere after they have been cleaned. The flue gases have high temperatures which means it is of great interest to investigate the possibility of utilizing these as heat sources to replace utility steam.

The flue gases arising from the bark boiler is suggested to be utilized to heat circulating HW to the saw mill in a new flue gas cooler. The result of this retrofit is that 2.1 MW LP steam is saved.

Table 12 shows a summary of the pinch violations before and after the retrofits for the case when recovering heat from the flue gases from the lime kiln through a proposed flue gas cooler. However, this results in a new pinch violation due to the flue gases providing heat from above the pinch to below the pinch in the retrofit. Furthermore, a new pinch violation emerges due to mixing in the condensate treatment system. Note that the pinch violation mitigation related to the RB flue gas cooling and feed water heating is an extension of the retrofit for the condensate treatment system.

Table 12. Retrofit results with the introduction of flue gases from the lime kiln.

Name	**Pinch violation before [MW]**	**Pinch violation after [MW]**	**LP Steam savings [MW]**
Air to bark dryer	2.7	0	4.3
New: air to bark dryer/flue gases lime kiln	0	4.0	-
RB flue gas cooling/feed water heating	18.2	8.7	9.5 [4]
Condensate HX with feed water	3.6	0	-
New: Mixing point feed water/deionized water	0	3.3	-
		Total	**13.8**

By comparing the amount of pinch violations before and after the retrofits, the introduction of the flue gases from the lime kiln does not result in solving pinch violations to any larger extent compared to the case were these were not utilized at all. However, what can be said is that more steam is saved.

By implementing all the suggested retrofits, a total of 19.5 MW steam can be saved which corresponds to 6.6 % of the entire steam demand. See Table 13 for a list denoting the individual steam savings.

Table 13. Total amount of LP steam saved when including all retrofit suggestions.

Name	**LP steam savings in total [MW]**
Flue gas cooling/feed water heating	9.5
Saw mill	2.1
Cyclone dryer	2.2
Combustion air to RB	1.4
Bark dryer	4.3[5]
Total	19.5

[4] This LP steam saving is both due to a new suggested WW HX and utilization of the existing HW HX within the condensate treatment system.

[5] Regarding heating of air to the bark dryer, more steam is saved than the pinch violation related to this stream. This is because by utilizing the lime kiln flue gases, the entire amount of LP steam consumed to heat air to the bark dryer (4.3 MW) can be replaced.

5.6 Potential uses of the saved steam

An option for utilizing the saved steam is to decrease the flow of extracted LP steam from the condensing turbine and let a larger flow of steam expand further in the turbine to generate more electricity. By doing so, the 19.5 MW LP steam saved can be converted into 5.3 MW additional electricity that can be sold to the grid.

The bark boiler produces 35.0 MW steam, up scaled value, during the studied time period. The bark boiler can however run at a lower capacity for the purpose of lowering the steam production and thereby save bark. The bark boiler has a minimum production load of 19.6 MW meaning that 15.4 MW steam or 18.6 MW bark (the bark boiler has a thermal efficiency of about 83 %) can be saved. This means that all the saved steam cannot be used for this purpose.

Värö mill has an estimated operation time of 7750 h/yr. By taking this into consideration it is possible to convert the above explained measures of saving steam into the unit gigawatt hours per year, see Table 14. The measures have not been converted into economic values. The reason behind this is that it is easy to overestimate the economic value of bark. This since there are some problems related to saving bark which are difficult to take into account in an economic evaluation, see the discussion section for more information regarding this. The economic value for the electricity production could be calculated using spot prices. However, the calculated value would be underestimated as there are additional revenues due to certificate for producing green electricity and the allocation quota for this is not known.

Table 14. Summary of the ways of utilizing the saved steam in terms of GWh/yr. Note that the saved steam is either used for electricity production or for saving of bark.

Energy product	Load [MW]	Energy [GWh/yr]
Electricity	5.3	41.1
Bark	18.6	144.2

5.7 Retrofit suggestions for the existing HEN

When thinking about how to decrease pinch violations in an existing HEN, it is effective to investigate the excess of heat available in the process. The excess heat can for instance be hot effluent streams not used for heat recovery purposes, and in the case of a pulp mill, excess of heated water within the SHS. Also, when making changes which in turn affects the SHS, it is of great importance to make sure that it does not result in deficit of any water type in the SHS. The SHS at Värö mill is very extensive and many of the streams in the stream data table is either provided heat from it or alternatively produces heated water.

Today, there is an excess of LWW and WW which is cooled in the process cooling towers to minimize the demand of fresh water intake from the river Viskan. The excess of LWW could potentially be used to preheat for instance streams involving cold ambient air. It would probably not be economically beneficial to do so compared to the primary energy that would be saved due to the rather low temperature of LWW, therefore this idea is not investigated further. However, the excess WW is of great interest for retrofit purposes due to its higher temperature, and the excess of it is calculated to 39.8 kg/s.

A revamp to the secondary heating system which would increase the amount of WW further, is to use LWW instead of WW during the production of deionized water which is done today. This is deemed appropriate since the target temperature for the deionized water is 24.9 °C, which should be fine to heat with LWW having a temperature of approximately 50 °C. By performing this modification, a total of 70.7 kg/s WW is free for use in retrofits. It will however result in an increased area requirement for the heat exchanger related to the production of deionized water. See Table 20 in Appendix 4 for a list of the different WW producers and Table 21 for a list for of WW users.

5.7.1 Retrofit: RB flue gas cooling and feed water heating

The largest pinch violation identified is related to boiler feed water heating with heat from the flue gases of the recovery boiler, which is performed using an intermediate pressurized circulating water system. The flue gases are entirely above the pinch point and the feed water is to a large extent below the pinch, resulting in that heat is transferred through the pinch with a heat load of approximately 18 MW.

The idea for this retrofit is to preheat cold deionized water leaving the VKT-tank (C13), see to the left in Figure 14. This to increase the boiler feed water temperature (C14) prior to heat exchanging it with the hot flue gases (H18). To achieve this, an investment into a new HX within the SHS is suggested (HX4). The proposal is that HX4 is to use 53.4 kg/s of the identified excess of WW. WW has a temperature of 69.5 °C and with a ΔT_{min} of 5 °C for a water-water HX, it is possible to preheat the deionized water to a temperature of 64.5 °C. With this new HX, the resulting mix temperature of C13 and H16 would increase from 77.5 °C to 84.8 °C. The adjustment makes it possible to heat C14 to a temperature of 115.0 °C with H18, meaning that the pinch violation related to HX3 would decrease from 18.2 MW to 12.7 MW. Consequently, 5.5 MW LP steam is saved due to a reduced amount of process steam injection required in the feed water tank (C15). Another positive aspect of this solution is that HX3 can be retained as it is without any modifications.

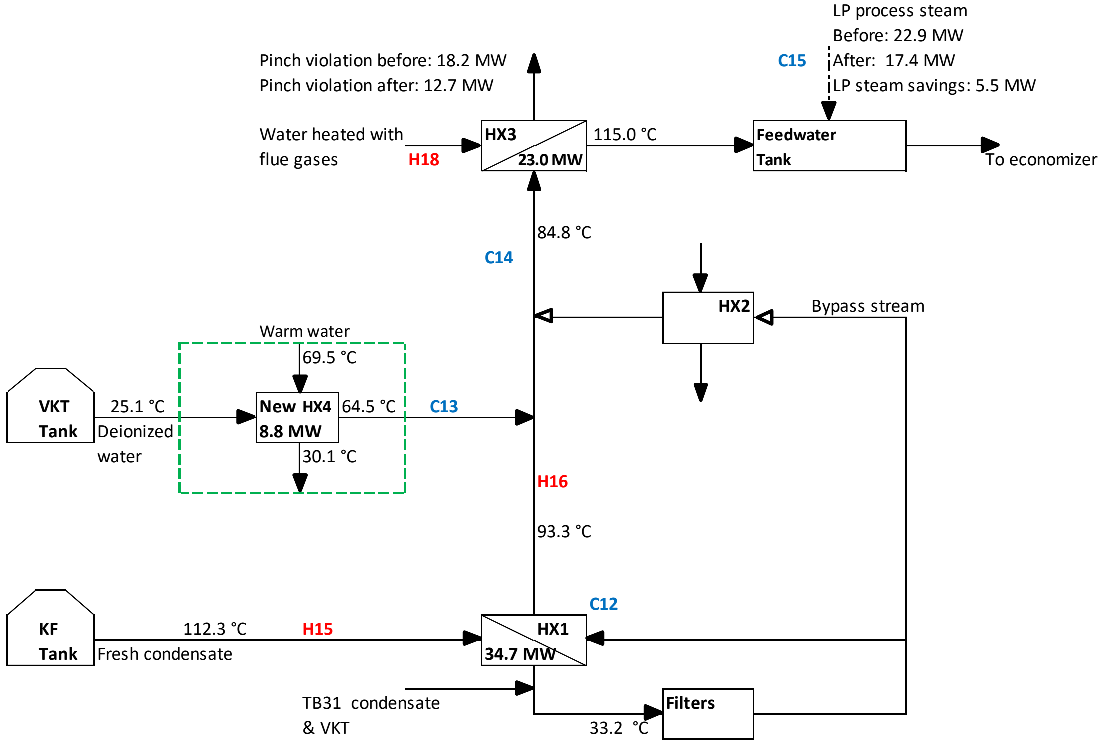

Figure 14. Retrofit proposal for the RB flue gas cooling and feed water heating. The dashed green lines show where the new heat exchanger is suggested to be installed. The resulting LP steam saved is 5.5 MW.

5.7.2 Retrofit: Combustion air to RB

The combustion air to the recovery boiler is heated with LP, MP and HP steam. As the three intakes of air, i.e. primary air, secondary air and quaternary air have a start temperature below the pinch point, there are pinch violations related to this type of heating with utility. As for a retrofit proposal, 16.1 kg/s of the remaining WW is suggested to be utilized in two new HXs, see Figure 15. The new HXs are placed prior to the LP HTRs on the primary and quaternary air. To decrease the number of new units, it would be preferable to place a heat exchanger at the total air stream before it is split into primary and secondary air, see to the left in the figure. Unfortunately, there is a practical limitation of doing so since the fan for transporting secondary air is not designed for the temperature that would be achieved with this solution. All new heat exchangers are placed after the fans to avoid any potential technical difficulties related to this.

There is not enough WW to install another HX on the secondary air stream which is why it has been left out. For air-water heat exchanging ΔT_{min} is 10.5 °C which means that it is possible to heat the air to a maximum of 59 °C with the WW. The result is that 542 kW LP steam is saved related to the primary air stream, and another 830 kW for the quaternary air stream.

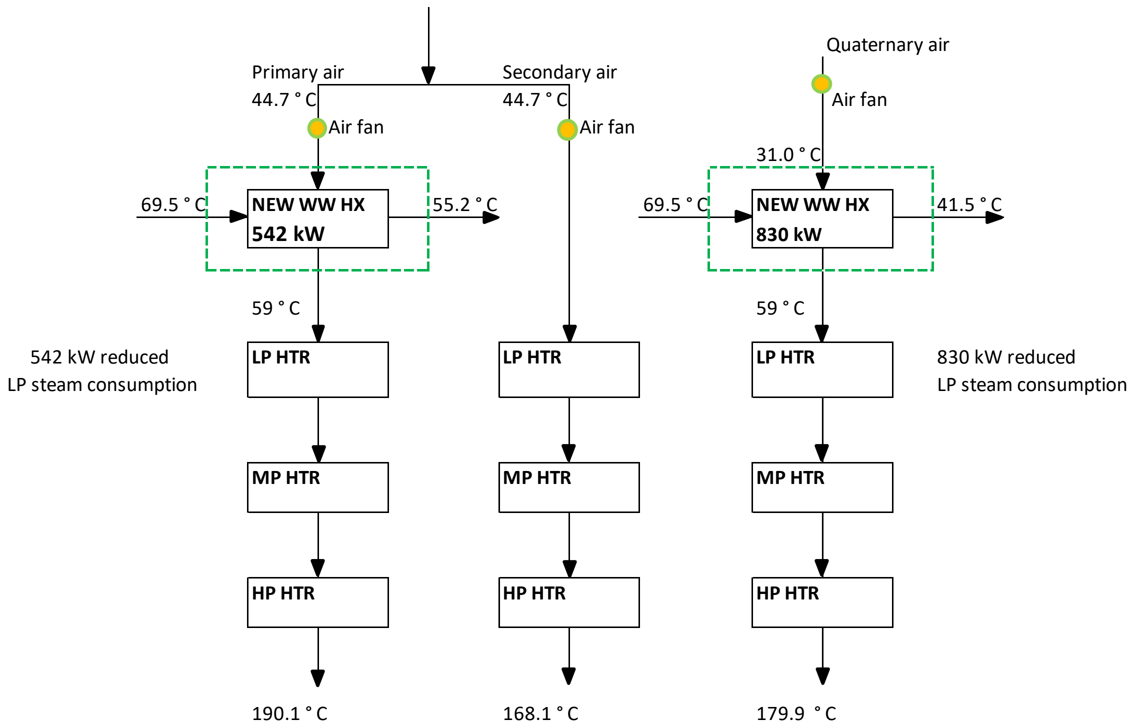

Figure 15. Retrofit proposal for combustion air to the recovery boiler. The two new heat exchangers use WW to preheat the primary and quaternary combustion air intakes enabling a steam savings of 1.4 MW.

5.7.3 Retrofit: Cyclone dryer

There is a pinch violation related to the operation of the cyclone dryer because cold air to the dryer is heated with LP steam below the process pinch point. See Figure 16 for a simplified illustration of the cyclone dryer and how the drying air to it is heated.

Today, there exists a heat recovery system extracting heat from the moist air arising from the drying machine. After this, the moist air has a temperature of approximately 64.5 °C. By setting this stream's target temperature to soft, more energy can be extracted from it. Theoretically, more cooling is achieved by further following the saturation line in a Moliere diagram and thus condensing water.

Since moist air from the drying machine today heats one of the two feeds of air to the cyclone dryer, a retrofit suggestion is to also heat the other feed of air in a similar manner, see Figure 16. The air feed to the cyclone dryer is present as one cold stream in the stream data table, however for this retrofit a stream split is performed, which probably resembles reality better. Here, an approximation is made that the two air streams would then have the same heat flow capacity.

The start temperature of air to the cyclone dryer was 6.1 °C during the sampling day, and it would be possible to heat it to a maximum temperature of 49.5 °C using moist air from the drying machine having a temperature of 64.5 °C. This since ΔT_{min} for heat exchanging of moist air with air is 15 °C. The moist air leaving the heat exchanger has a temperature of 62.9 °C. By performing this retrofit, 2160 kW of the pinch violation is resolved through more internal heat exchanging. Steam can be saved in the LP heater placed after the new heat exchanger and the glycol heat exchanger.

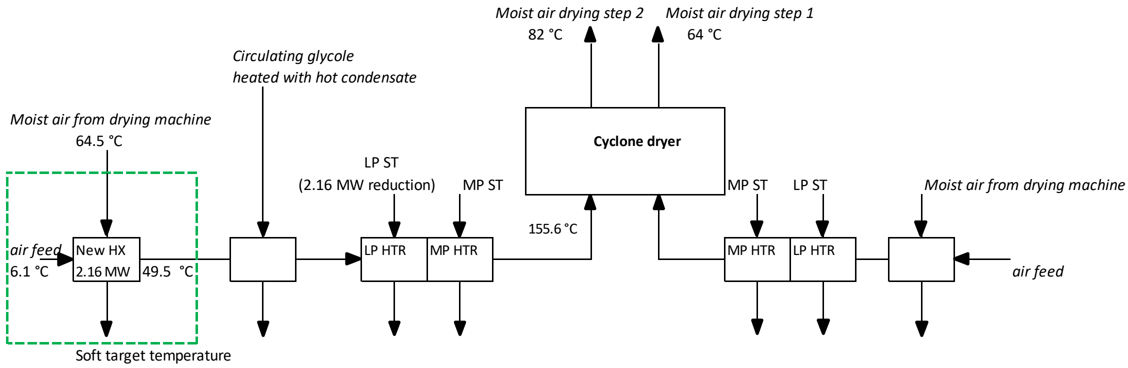

Figure 16. *New moist air-air heat exchanger for the cyclone dryer. The HX is placed before the circulating glycol, LP and MP heating. The result is a 2.2 MW decreased demand for LP steam.*

5.8 Retrofit suggestions including flue gases

The heat available from the hot flue gases from the lime kiln and the bark boiler is not utilized for heat recovery today. These heat sources are however interesting to include in order to investigate the possibility of achieving steam savings through improved heat recovery. In Table 15 the flue gases start and target temperatures are listed along with the heat load available for these streams. At a first glance, one may think that these streams have such high temperatures that it could replace any steam consumption related to a cold stream. However, it is necessary to consider that it is not realistic to heat streams located far away from the flue gases. The flue gases cannot be transported around the process site and it is important to minimize the amount of new piping required to be able to transport a cold stream to the location of the flue gases and a new flue gas cooler.

Table 15. Start and target temperatures and loads of flue gases from the lime kiln and the bark boiler.

Flue gas source	T_{start} [°C]	T_{target} [°C]	Q [MW]
Lime kiln	280	140	5.6
Bark boiler	192.7	140	2.1

5.8.1 Retrofit: Heat demand saw mill

Pressurized HW to the saw mill is heated with LP steam resulting in heating with utility below the process pinch with a pinch violation of 10.8 MW. About 59 % of the total LP steam load supplied to the heat the stream is a pinch violation. The rest of the LP heating occurs above the pinch point and is therefore no pinch violation. The pinch violation is not very easily solved because pressurized water is heated from a temperature of 94 °C to 111 °C. According to the hot CC, there exists hot streams for internal heat recovery within this temperature interval. Extracting heat from these streams is however complicated because it implies that many new HXs would be required to still able to meet all process requirements.

However, with the introduction of hot flue gases from the bark boiler, the possibility of saving steam emerges. The retrofit suggestion includes an installment of a new flue gas cooler. The idea is that the already pressurized saw mill HW is to go through the cold side of the HX. By studying the plant layout, it can be concluded that the bark boiler is located relatively close to the recovery boiler house in which the saw mill HW already passes extracting heat from a LP HTR, meaning that the additional piping distance related to the flue gas cooler would not be that long.

The new flue gas cooler in question and where it is suggested to be placed in the existing process can be seen in Figure 17. It is assumed that 10 % of the pressurized HW flow is reasonable to pass through the flue gas HX. There is no reduction in pinch violation related to the LP steam HTR since it is still heating the entire saw mill HW flow below the pinch. However, since the bark boiler flue gases provides 2059 kW heat, an equal amount of LP steam is saved in the LP HTR by energy balance. In other words, the temperature of the cold stream leaving the LP steam HTR is now lower, 109 °C compared to 111 °C. From a pinch analysis perspective, this way of utilizing the hot flue gases is appropriate because heat is provided to a cold stream above the pinch where there is a deficit of heat.

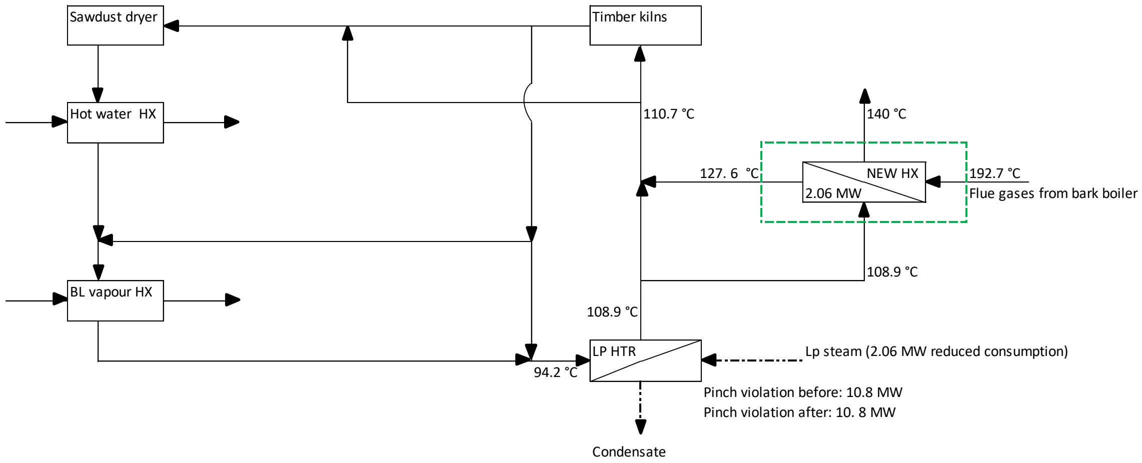

Figure 17. Introduction of a flue gas cooler to heat hot water to the saw mill. The flue gases arise from combustion of bark in the bark boiler. With this retrofit, 2.1 MW LP steam is saved.

5.8.2 Retrofit: Air to bark dryer

For this equipment, ambient cold air is heated firstly with HW followed by LP steam. The identified pinch violation is that LP steam is to some extent used to heat the cold air stream below the pinch.

This retrofit idea is based upon the utilization of flue gases from the lime kiln to heat the feed of air to the bark dryer. The lime kiln flue gas treatment is performed close to the location of the bark dryer. In practice, a new flue gas cooler would be required, and to replace as much steam as possible, a cooling system similar to that of the recovery boiler is suggested, i.e. to heat recirculating pressurized water which in turn can perform the final heating of the air to the bark dryer. The retrofit requires, in addition to a new flue gas cooler, that three existing LP HTRs are replaced by new HXs suitable for water-air heat exchange.

Nevertheless, with this solution, it is possible to replace all the current 4.3 MW LP steam demand for the bark dryer. In addition, 1.3 MW of HW is saved. A 2.7 MW pinch violation is solved, however at the cost of the introduction of a new one of 4.0 MW heat transferred through the pinch due to this way of utilizing the flue gases. There is however another interesting aspect related to this solution because the saved HW can be used to solve other pinch violations.

5.8.3 Retrofit: Condensate heat exchanged with feed water

In the condensate treatment system, see Figure 18, a flow with fresh condensate (H15) is heat exchanged with feed water (C12). The heat exchanger HX1 is responsible for 3.6 MW heat being transferred through the pinch. The underlying reason why this results in a pinch violation is because condensate from the condensing turbine and deionized water is mixed on to H15 before it enters the cold side of the HX. The added flow results in that the resulting temperature for steam C12 leaving HX1 is lowered.

The suggestion for this retrofit is to preheat a bypass flow equal to the flow mixed on before the filters. The introduction of the lime kiln flue gases resulted in savings in terms of HW. A total of 23 kg/s of HW is saved and the idea is to use this in the already existing bypass HX2, see Figure 18. By doing so one eliminates the pinch violation related to HX1, however another pinch violation emerges due to mixing between C13 and H16. By still retaining the new WW HX introduced in section 5.7.1, the temperature of stream C14 is increased to 90 °C prior to HX3 resulting in a total of 9.5 MW reduced LP steam consumption in the feed water tank. Furthermore, it is still possible to retain HX3 since the temperature of the feed water is 120.3 °C when entering the feed water tank.

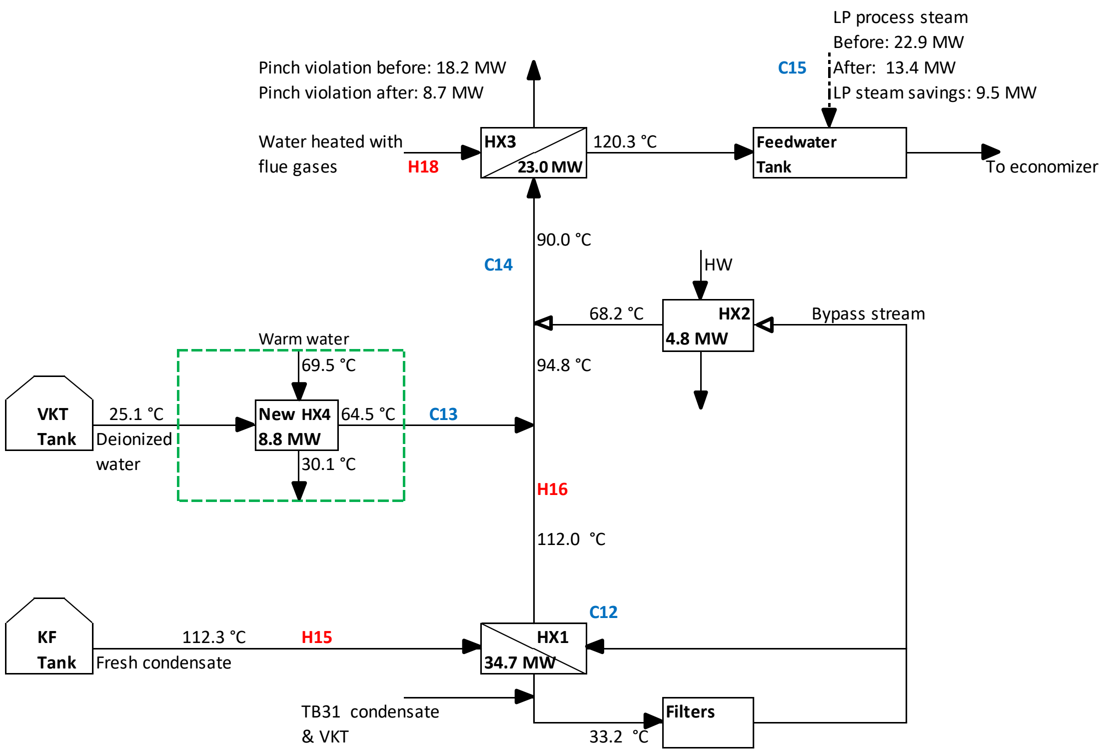

Figure 18. Further mitigation of the pinch violation related to the recovery boiler flue gases heating boiler feed water. Here, with utilization of the existing HW heat exchanger and in addition retaining the suggested new WW heat exchanger. A total of 9.5 MW LP steam is saved in the feed water tank.

5.9 District heating evaluation

The result from the background/foreground analysis of the DH delivery to Varberg can be seen in Figure 19. The foreground represents the DH in question while the rest of the process is placed in the background. The background process is the original GCC with the individual ΔT_{min} contributions from Table 2. As is illustrated in the in the figure, it is not possible to deliver the 16.2 MW DH that was delivered during the investigated time period if a MER network of the background process is achieved. However, by performing top heating of the DH water with approximately 1.5 MW LP steam it is possible to reach the supply temperature of 96 °C. It should be emphasized that there already exists a LP HTR that can perform top heating of the DH water and that a total of 235 kW of LP was consumed for this purpose during the investigated time period. An alternative of using utility would be to decrease the supply temperature of the DH water.

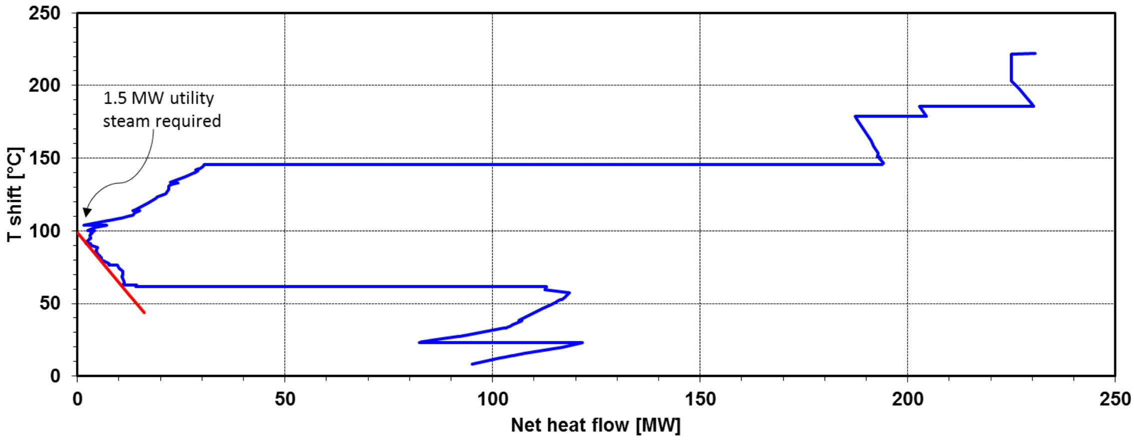

Figure 19. Background/foreground analysis of district heating delivery to Varberg. The blue curve represents the GCC of Värö mill (background), while the red line represents the demand for DH during the investigated time period (foreground). The black arrow in the figure depicts where the process excess heat does not match the DH demand. 1.5 MW LP steam would be sufficient to reach the DH target temperature and thus the demand.

The potential of delivering an increased amount of DH to Varberg after implementing the retrofit suggestions was also evaluated through a background/foreground analysis. In Figure 20 the GCC for the process is illustrated but here with a global ΔT_{min} of 21 K, representing the system after the suggested energy efficiency measures have been implemented. This specific global ΔT_{min} was extracted from the demand curves of the process, corresponding to the new actual hot utility demand. The green dashed line in the figure represents the theoretically maximum delivery of DH that the process can achieve, which is approximately 33 MW. The red line shows the DH delivered during the studied period, i.e. 16.2 MW.

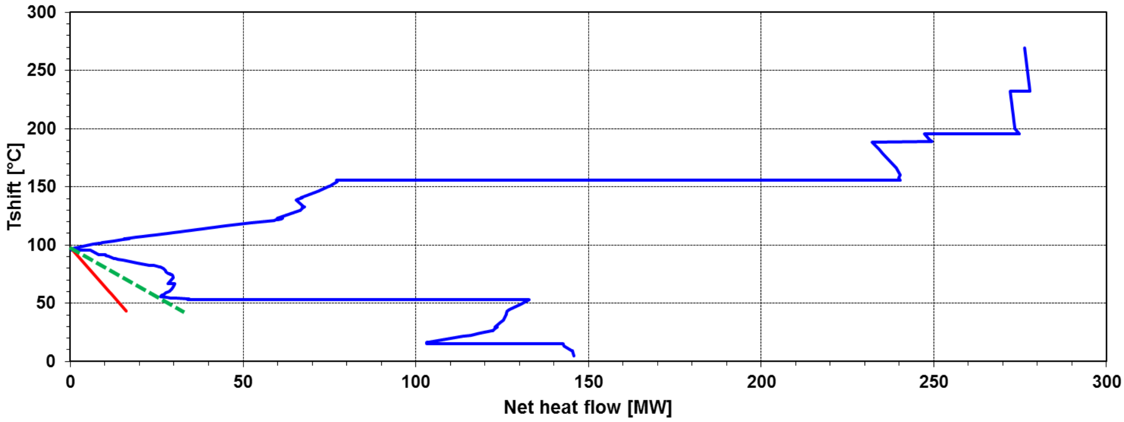

Figure 20. Background/foreground analysis for the delivery of DH to Varberg. The blue curve represents the GCC curve for the process with a global ΔT_{min} of 21 K (background). The red line represents the demand for DH during the investigated time period and the green dashed line represent the total delivery that the process in theory can manage.

5.10 Ways to account for the secondary heating system in pinch analysis

Figure 21 illustrates an example of process streams being heat exchanged with water within the SHS. Here, the hot and cold CCs only includes streams heat exchanged with SHS water. The dotted blue line in the middle of the figure represents SHS water which is heated by hot process streams, while the dotted red line represents SHS water which is heating cold process streams.

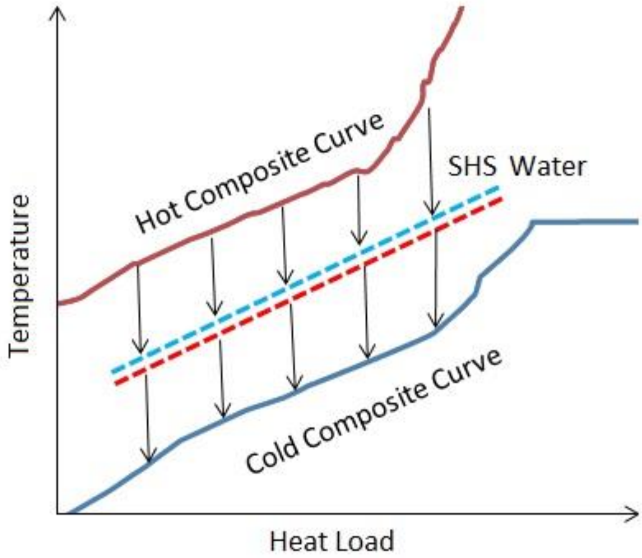

Figure 21. Hot and cold composite curves including an illustration of heat exchanging with the secondary heating system water.

Two ways of accounting for the SHS were investigated to identify potential drawbacks and advantages with the methods. One way is to extract the stream data for the true hot and cold process streams, which is what has been done for the energy targeting and retrofit study in this work. By doing so, one excludes the SHS water as streams, see the streams in the middle of Figure 21. An alternative method is to include the true hot streams, i.e. the streams that are present in the hot CC in the figure above, and the heating of water within the SHS as cold streams. Thus, for this case one does not include the true heat demands as streams, i.e. the streams that are present in the cold CC in the figure. For this method, the included SHS water will be representing the heat demand of the process provided from the heated SHS water.

When including the true hot and cold streams and excluding the SHS, it can become problematic to identify and quantify pinch violations if a pinch is achieved such that heat exchange with the SHS is a pinch violation. Furthermore, a situation may occur where the SHS water only partly can be considered as responsible for pinch violations. Since the heated SHS water is collected in different tanks depending on the temperature level, it then becomes difficult to allocate specific pinch violations related to cold streams using SHS water. Then, one can only say that a certain percentage of the cold streams using the SHS has a related pinch violation.

With the alternative way of accounting for the SHS, it becomes easy to quantify and identify any pinch violations related to the production of heated SHS water. However, by doing so, the true cold streams are not included. Consequently, if the SHS is over dimensioned such that there is an excess of heated water, this needs to be considered by representing the excess as a hot stream requiring cooling. This is necessary so as not to not overestimate the heating demand in the process.

It is not possible to foresee whether the SHS will be responsible for pinch violations before an energy targeting of the process has been performed. It is recommended at first to consider the real hot and cold demands for the energy targeting. Before designing the existing HEN, one can briefly analyse the heat exchange between process streams and the SHS by comparing the pinch temperature with the temperatures of the streams. If problems arise regarding how to consider pinch violations related to the SHS, it is recommended to instead proceed by including the true hot streams and the production of heated SHS water as cold streams.

For a pulp mill with a very complex SHS, which is included in many parts of the process, only including the true hot streams and the heating of SHS water as cold streams would be the easiest way to quantify the pinch violations. However, whenever possible it is probably most favourable to include the real hot and cold demands for the studied system.

5.11 Pinch temperature interval

The pinch temperature for the studied system is very sensitive to changes. As was noted when observing the CCs and the GCC of the process, there is no clear pinch, rather a pinch interval. If one is to analyze the existing HEN in terms of a pinch temperature interval instead of a distinct pinch point, a more extensive investigation must be performed to identify what HXs are responsible for pinch violations, and to quantify the amount of pinch violations occurring. This cannot be done in the software program ProPi. The effect of a pinch interval is described for most of the pinch violations in which retrofit suggestions have been proposed. Also, another interesting example which was not identified as a pinch violation with the true pinch point, but can be considered as one if the concept of a pinch interval is introduced, is also described.

When performing a pinch temperature interval approach, especially pinch violations related to process-process heat exchange becomes more difficult to comprehend. For these streams, it is only allowed to transfer heat within the pinch temperature intervals.

By studying the pinch violations with a pinch temperature interval approach, some new pinch violations were identified and some pinch violations investigated in the retrofit study increased to some extent. This indicates the complexity of how to find appropriate solutions for the pinch violations and how to evaluate the existing HEN to determine the potential for primary energy savings.

5.11.1 Example 1

The flue gases from the recovery boiler are entirely above the hot pinch temperature interval. The boiler feed water being heated by the flue gases has a start temperature below the cold pinch temperature interval and a target temperature above the cold pinch temperature interval. The resulting pinch violation will be heat transferred through the pinch until the end of the cold pinch temperature interval, which was also the case for the true pinch point. The result is thus that this pinch violation remains unchanged.

5.11.2 Example 2

Heating with steam below the pinch is a pinch violation which was observed for several heat exchangers using the true pinch point. When the concept of a pinch temperature interval is introduced, there is a related pinch violation of using LP steam as long as the cold stream being heated with it is below or within the cold pinch temperature interval. Since the end temperature of the pinch interval is the same as the true pinch temperature, the result is that these pinch violations will be unaffected. For example, the pinch violations related to the cyclone dryer and the saw mill will remain the same.

5.11.3 Example 3

The temperature profile for the condensate flow which is heat exchanged with feed water is illustrated in Figure 22. This heat exchanger has a very low ΔT_{min} as can be seen in the figure. The condensate, H15, has a start temperature of 112 °C which is above the hot pinch temperature interval. Since the cold stream, C12, has a target temperature of 93 °C, the hot stream will transfer heat from above the hot pinch temperature interval into the cold pinch temperature interval, hence this results in a pinch violation. When there is a heat transfer between the streams from the hot to the cold pinch temperature interval, no pinch violation occurs. As can be seen in the figure, heat will also be transferred from H15 within the hot pinch temperature interval to C15 below the cold temperature interval which results in a pinch violation.

With a pinch temperature interval approach the total pinch violation related to this heat exchanger is 9.8 MW. This value can be compared to the previous pinch violation of 3.6 MW which was obtained when a considering a shifted pinch temperature of 104 °C

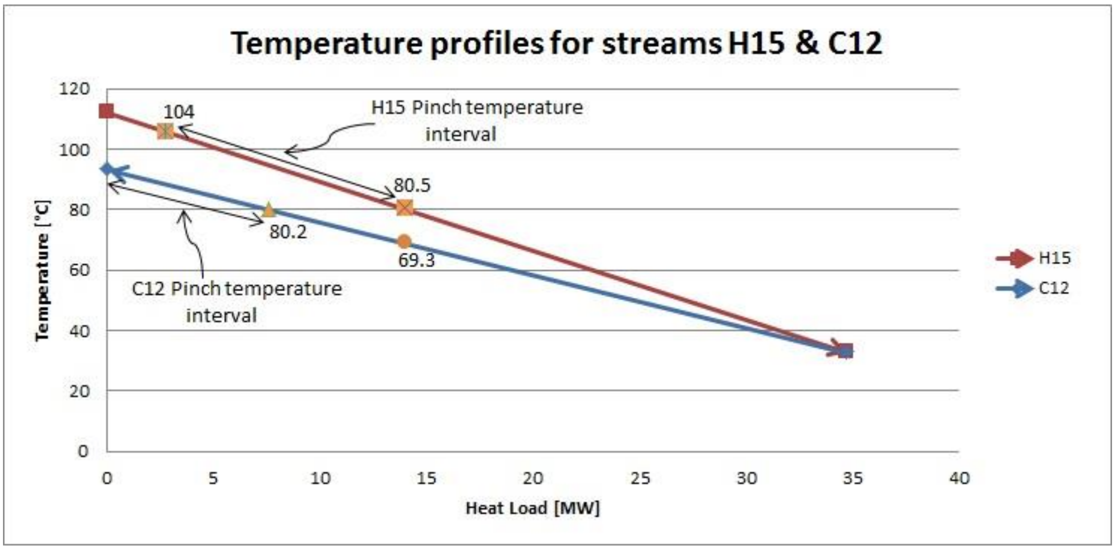

Figure 22. Temperature profiles for streams H15 and C12. In the figure the pinch temperature intervals for the hot and cold streams are shown.

5.11.4 Example 4

The heating of air to the bark dryer is performed with HW followed by LP steam. See Figure 23 for a temperature profile for this stream. The pinch violation related to heating of air with LP steam is unchanged compared to the case with the true pinch point. However, the usage of HW is problematic because when considering a pinch temperature interval, heat exchange with HW will to some extent be a pinch violation.

In order to simplify the analysis, it is assumed that the temperature of HW decreases from 90 to 70 °C during heat exchange with it. In addition, for a best-case scenario one might assume that there will be no losses related to heat exchanging hot and cold process streams through the SHS, meaning that ΔT_{min} is zero for HW. If applying this assumption, HW enters the pinch region at 80.4 °C, i.e. the shifted start temperature of the pinch interval. Heat exchanging cold streams that are below the cold pinch temperature interval with HW will result in a pinch violation. The related pinch violation is usage of HW within the temperature range of 80.4 - 90 °C, i.e. within the hot pinch temperature interval. As it was assumed the temperature of HW decreases from 90 to 70 °C, a pinch violation of approximately 50 % of the HW can be considered. However, in reality the return temperature for HW varies depending on where it is used.

When considering a pinch temperature interval, there is thus a pinch violation related to the usage of HW heating the cold air stream. The pinch violation related to the HW and LP steam adds up to a total pinch violation of 5.8 MW. This number can be compared to the previous 2.7 MW pinch violation which was observed for the true pinch point.

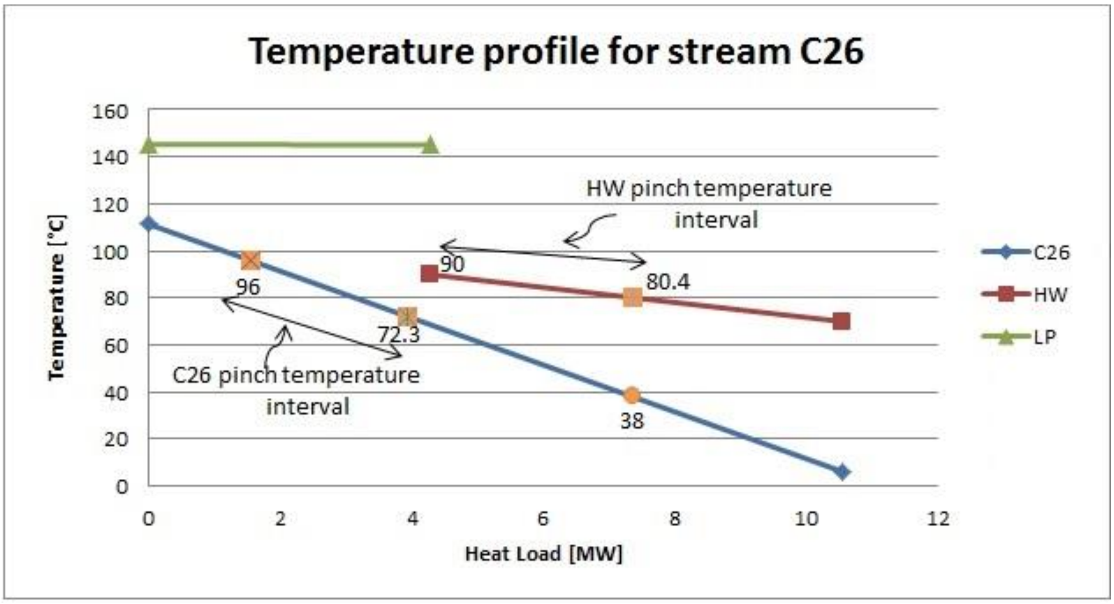

Figure 23.Temperature profile for heating of drying air in the bark dryer. The heating is done by firstly preheating the air with HW and then heating with LP steam. In the figure the pinch temperature intervals for both the drying air (C26) and the HW are shown.

5.11.5 Example 5

An example of a heat exchanger which causes a pinch violation when considering the pinch temperature interval approach is heat exchange of green liquor with water in the causticizing plant section. The hot green liquor has a start temperature of 100.6 °C and a target temperature of 85 °C meaning that the entire stream is within the hot pinch temperature interval. The cold-water stream has a start temperature of about 49 °C and a target temperature of 69 °C, which means that the stream is completely below the cold pinch temperature interval. The entire heat load for this HX will consequently be a pinch violation of about 6.2 MW.

6 Discussion

This energy efficiency study has shown that primary energy savings can be achieved by implementing the suggested retrofit solutions. Firstly, reliability of the data collected is briefly discussed. Thereafter, a deeper analysis regarding implementation of the retrofits is presented. Lastly, the two ways of utilizing the saved steam investigated are further discussed.

6.1 Measurements and reliability of data

The data used in the analysis has as far as possible been collected from the process in operation using existing measurement devices. It ought to be remembered though that these devices have a certain level of accuracy when measuring. Especially, when measuring the mass flow rate of gases such as steam, the accuracy is typically within a ± 20 % range. Some potential problems were identified when collecting time-dependent data. For instance, it was observed that some signals were rather flat, indicating a malfunctioning measuring device, while others were fluctuating to a rather high extent. Factors like these indicates the great complexity of obtaining stable data, and it is probably not possible to achieve stable operation for a large-scale process regardless.

Another issue regarding the stream data was that in some parts of the process, mass- and heat balances did not add up. This is because extracted data from the process in operation, approximated data from mill process engineers, and design data has been used. For instance, the energy balance for the stream DH to Varberg was not possible to close as extracted data and approximated data by process engineers were used for this specific steam. In addition, problems regarding closure of the mass balance for the HW production and consumption arose. This since the cooking section has two large HW producers, and for those data was obtained through discussion with mill process engineers.

6.2 Implementation of the retrofits

The suggested new WW heat exchanger within the condensate system is deemed as an appropriate solution which makes use of the excess WW at the mill to save steam. What is needed to implement this solution is a new HX and some additional piping from the WW tank to the HX. In addition, to transport the WW, new pumps may be necessary. Another solution which made use of the excess WW, was the introduction of preheating combustion air to the RB with WW.

By using the additional WW in these ways, it will result in a decrease of this water's temperature. There will thus be a decreased demand on the existing process cooling towers. The fans in the cooling towers can run at a lower effect and thereby electricity is saved. In addition, there are savings related to flow losses. Some of the flow entering the cooling towers are lost because it is evaporated and released to the atmosphere. Achieving a lower temperature on the water entering the cooling towers, there should thus be a savings in terms of water flow.

As for the cyclone dryer, adapting steps in a Moliere diagram and using the total flow of moist air from one of the two heat recovery aggregates of moist air from the drying machine, the resulting temperature of the stream is about 62.9 °C. However, it might be more economical to transport a lower flow of moist air from the drying machine to the cyclone dryer in order to reduce the capacity of the fan for transporting wet air that is required for this solution. Instead, it is probably more reasonable to transport a lower flow, still reaching 2160 kW of heat recovery, but cooling the moist air further. On the contrary, this solution would put a higher demand on the heat exchanger equipment.

Furthermore, today moist air resulting from the cyclone dryer is not utilized, instead it is released to the atmosphere, for a visualization of this see Figure 16. Theoretically, the heat from drying step 1 (65 °C) and step 2 (84 °C) of the cyclone dryer might be possible to utilize in a similar manner as is done in the drying machine today, i.e. heat the feed of air with hot moist air. This suggestion was however not evaluated further because that would require the flow of moist air and its moisture content in kg H_2O/kg dry air and these are not measured as of today.

Also, there are some uncertainties related to the circulating glycol system related to preheating of air to the cyclone dryer, because the data that is necessary to be able to calculate the heat load contribution of the glycol system is missing. Therefore, it has been left out from the study. The glycol flow is heated with hot condensate from the drying machine having a temperature of 117 °C. Since the temperature difference for heat exchange for the glycol-air heat exchanger would decrease with the suggested retrofit solution, it might be necessary to add additional HX area to still be able to deliver the same heat load as today.

By including the lime kiln and bark boiler flue gases in the GCC, the heat pockets observed for the cooling of flue gases from the recovery boiler, as was seen in the original GCC, are enlarged slightly. This is because the flue gases of the lime kiln and bark boiler are within a similar temperature interval compared to the recovery boiler flue gases. From a pinch analysis perspective, a good way of utilizing this heat is to perform a pocket solution because then it would be possible to achieve savings in terms of fuel. For instance, to produce LP or MP steam with the flue gases which can be used in the process to decrease the load of the bark boiler. There however practical limitations of finding ways of achieving savings in this temperature region. Therefore, it was instead decided to use the available flue gas heat from the lime kiln to heat air to the bark dryer and the flue gas heat from the bark boiler to heat circulating water for the saw mill. An engineering judgement was made here that this is appropriate based on the site location of the bark boiler and the lime kiln. The result of the modifications is that steam is saved.

6.3 Utilization of the saved steam

The LP steam saved through the retrofit proposals could be used for several different purposes. The investigated alternatives include increased electricity production through expanding the steam in the condensing turbine or to save bark by operating the bark boiler less. The alternatives are discussed in more detail in their respective subsections below.

6.3.1 Increased electricity production

Probably the most straightforward choice would be to run the additional steam available, due to the proposed retrofits, through the condensing turbine. This to increase the production of green electricity that can be distributed to the grid. There is unfortunately a limit how much LP steam than can be used for this purpose because the condensing turbine has a maximum capacity of 63.8 MW. Modelling performed previously indicates that when Värö mill is in balance, there is no additional capacity left to run LP steam through the turbine to increase the condensing power output. This in turn implies that additional turbine capacity would be required to produce more electricity. However, it was found that it would have been possible to produce 5.3 MW electricity during the studied period.

6.3.2 Saving bark

A response to the savings in steam can also be that less steam is needed to be produced and hence save fuel. One way of doing so is to decrease the burning of bark in the bark boiler. The demand for bark on the market varies over the course of the year, it is highest during the winter and lowest during the summer. Therefore, due to the demand curve, the selling price of the bark would be most profitable during the winter. It ought to be remembered that the saving of bark would result in that more storage capacity would be required, especially during the summer when the demand for bark is lower. At the process site, there is very limited plant area available for such storage and even though Södra has possibilities for external storage, the handling of large amounts of bark is deemed problematic. Furthermore, when storing large amounts of bark there is an increased risk of self-ignition of it. Hence, it might be problematic to both find space to store the bark and to handle it.

In addition, if one decides to save bark, it is important to consider that the flow rate of flue gases from the bark boiler would then decrease. This would in turn lower the amount of heat available in the flue gases resulting in that the retrofit suggestion utilizing this heat would be less viable compared to when running the bark boiler on its maximum production. As was noted however, all saved steam could not be utilized for the purpose of saving bark. Thus, if the intention is to only save bark, then there will be an excess of steam. If this additional steam is not possible to run through the condensing turbine, and no if other process equipment demanding steam is installed, then one might need to consider not implementing all the suggested retrofits. Then probably one should question whether the flue gas cooler related to the bark boiler is worth implementing.

7 Further work

An economic evaluation of the suggested retrofit solutions needs to be conducted to determine whether it is feasible to continue with an implementation of the solutions. The retrofit proposals are characterized by different levels of difficulty to implement, and some suggestions might turn out to have a better economic performance than others.

The stream data for the hot and cold streams included in the cooking section were approximated through discussion with process engineers at Värö mill. It is therefore recommended as further work to compare this data with extracted process data from the cooking section in operation. This to ensure that the data used in the pinch analysis study is truly representative for a stable and high production.

For the cyclone dryer, it is suggested to determine the flow rate and moisture content of the hot moist air leaving drying step 2. This to investigate whether it is technically feasible to preheat the air entering the cyclone with this moist air. The result from this further work can thereafter be compared to the retrofit suggested in this thesis, i.e. to use moist air from the drying machine.

Värö mill has been thinking about the opportunity of running a new bark dryer using excess heat from the process. The dried bark could potentially replace the sawdust used as a fuel in the lime kiln today. As a future study, one could evaluate the potential of running such a bark dryer partly by extracting the energy in the flue gases arising from the lime kiln. The economic performance of this solution can thereafter be compared with the retrofit suggested in this thesis related to the lime kiln flue gases.

A more comprehensive analysis regarding the observed pinch region is suggested. The main focus of this study should be to continue investigating potential additional implications of having a pinch temperature interval. Identification and quantification of any remaining pinch violations should be included in the study.

8 Conclusions

During the last few years Värö mill has experienced an extensive reconstruction in which many energy efficiency measures were implemented indicating that the process should theoretically be highly energy efficient. To evaluate the energy efficiency of the process, a pinch analysis study was conducted and the information obtained here contributes to some of to the requirements that were introduced with the law about energy auditing.

The pinch analysis performed shows that the potential for primary energy savings still are 66.7 MW. However, in industry it is not realistic achieve this scenario as that would be difficult to achieve from a technical perspective and in addition require an enormous investment. By identifying and quantifying individual pinch violations, it was found that some pinch violations were more severe than others. To be able to save as much steam as possible, with as few modifications as possible, the main focus was therefore to mitigate some of the larger pinch violations.

Retrofit solutions have been suggested to increase the heat recovery within the process. When designing the new heat exchanger network, potential process constraints were considered. Without utilizing the hot flue gases of the lime kiln and the bark boiler, it was shown that 9.1 MW of low pressure steam could be saved. By also introducing the flue gases from the lime kiln and bark boiler as heat sources, it was found that a total of 19.5 MW of low pressure steam could be saved.

The saved steam could for instance either be utilized to produce 41 GWh/yr of electricity in the existing condensing turbine, or alternatively to reduce the bark boiler load enabling a savings of 144 GWh/yr bark.

Foremost lukewarm water, but also warm water was identified as sources of excess heat from the process. How the warm water excess could be used was shown in two retrofit proposals. Furthermore, from the background/foreground analysis of district heating to Varberg, it was concluded that Värö mill can manage to deliver the demanded amount of district heating even after implementing the suggested retrofits. It was also concluded that the process can, without any utility, deliver a maximum of 33 MW district heating after the retrofits have been implemented.

9 References

Axelsson, E. 2008, *Energy Export Opportunities from Kraft Pulp and Paper Mills and Resulting Reductions in Global CO2 Emissions*, Chalmers University of Technology, Göteborg.

Berntsson, T., Franck, P-Å,. Persson Elmeroth, E. (2015). *Pinch Analysis Methods for Retrofitting of Existing Processes Heat Exchanger Networks.* Gothenburg: Chalmers University of Technology. Course material in Industrial Energy Systems, 2015

Brännvall, E. (2009a), *'Wood Handling'* in Ek, M., Gellerstedt, G. & Henriksson, G (eds). (2009), *Pulping chemistry and technology*, Walter de Gruyter, Berlin, chap. 2: pp. 13-34

Brännvall, E. (2009b), *'Pulping Technology'* in Ek, M., Gellerstedt, G. & Henriksson, G (eds). (2009), *Pulping chemistry and technology*, Walter de Gruyter, Berlin, chap 6: pp. 121-147

European Commission, (2013), *Guidance for National Energy Efficiency Action Plans*, Brussels, 22.5.2013. [Online] Available from: https://ec.europa.eu/energy/sites/ener/files/documents/20131106_swd_guidance_neeaps.pdf
[Accessed 20th February 2017]

Germgård, U. (2009) *'Bleaching of Pulp'* in Ek, M., Gellerstedt, G. & Henriksson, G (eds). (2009), *Pulping chemistry and technology*, Walter de Gruyter, Berlin, chap 10: pp. 240-264

Hackl, R., Harvey, S., Andersson, E. (2010). *Total Site Analysis (TSA) Stenungsund*. Chalmers University of Technology & Department of Energy and Environment, Heat and Power Technology

Ivarsson, M. (2014). *Energibalanser expansion Södra Cell Värö*. Stockholm: ÅF Industry AB.

Kemp, I.C. (2007), *Pinch analysis and process integration: a user guide on process integration for the efficient use of energy*, 2nd ed., Butterworth-Heinemann, Oxford, UK, a) chap 2: pp. 15-40, b) chap 1: pp. 1-13, c) chap 3: pp. 41-98, d): chap 4: pp. 99-157.

Naturvårdsverket. (2016a). *Sveriges miljömål.* [Online] Available from: http://www.miljomal.se/sv/Miljomalen/
[Accessed 28th February 2017]

Naturvårdsverket. (2016b). *Begränsad klimatpåverkan.* [Online] Available from: http://www.miljomal.se/sv/Miljomalen/1-Begransad-klimatpaverkan/
[Accessed 28th February 2017]

Regeringen. (2014). *Mål för energi.* [Online] Available from: http://www.regeringen.se/regeringens-politik/energi/mal-och-visioner-for-energi/
[Accessed 3rd March 2017]

Rudén, L. (2017). *Energy coordinator, Södra Cell Värö.* Personal communication.

Rudén, L, Olowson, P. (2016), *Vattenbalans och Hetvattenssytem Expansion Södra Cell Värö*.

Statens energimyndighet, 2015/07/ET, September 2015b, *Vägledning för energikartläggning i stora företag Inför energikartläggningen.*

Statens energimyndighet, 2015/08/ET, October 2015a, *Energiläget 2015*

Statistiska Centralbyrån. (2005). *Ekonomins energiintensitet.* [Online] Available from: http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/22678/Allmant/Sveriges-ekonomi/Aktuell-Pong/31243/EK0104/Energiintensitet-EU/
[Accessed 4th June 2017]

Södra. (2016a). *Ett av världens mest moderna massabruk*. [Online] Available from: https://www.sodra.com/sv/massa/om-sodra-cell/expansion-sodra/
[Accessed 18th January 2017]

Södra. (2016b). *Vår produktionsprocess.* [Online] Available from: https://www.sodra.com/sv/massa/vara-fabriker/var-produktionsprocess/
[Accessed 18th January 2017]

Södra. (2016c). *Södra Pulp Faction.* [Online] Available from:
http://www2.sodra.com/upload/sub-siter/pulpfaction/fabriken.html
[Accessed 18th January 2017]

Theliander, H. (2009a), '*Recovery of Cooking Chemicals: The Treatment and Burning of Black Liquor',* in Ek, M., Gellerstedt, G. & Henriksson, G (eds). (2009), *Pulping chemistry and technology*, Walter de Gruyter, Berlin, chap 12: pp. 297-331.

Theliander, H. (2009b), 'The *Recovery of Cooking Chemicals: The White Liquor Preparation Plant',* in Ek, M., Gellerstedt, G. & Henriksson, G (eds). (2009), *Pulping chemistry and technology,* Walter de Gruyter, Berlin, chap 13: pp. 335-362

Appendix 1: Stream data table

Table 16. Hot and cold streams included in the pinch analysis.

Number	Hot streams	HX with	Tstart [°C]	Ttarget [°C]	Q [MW]	$\Delta T_{min, contribution}$ [°C]	Process section	Data info
H1	Weak black liquor 1 from digester to flash	C2	150	130	4.0	3.5	Cooking	2
H2	Weak black liquor 2 from digester to flash	C1	130	110	10.0	3.5	Cooking	2
H3	Weak black liquor from flash to evaporation tank	C54 (DH), WW	105	90	18.0	3.5	Cooking	2
H4	Turpentine gas from flash to primary condenser	WW	105	104.9	6.0	2.0	Cooking	2
H5	Turpentine liquid to decanter	LWW	105	60	1.0	3.5	Cooking	2
H6	Weak black liquor 1 from digester to impbin (mix)	C4	160	140	3.0	0	Cooking	2
H7a	KLR from stripper to tank (stream split)	C7	112.1	84.8	14.0	1.9	Evaporation	1
H7b	KLR from stripper to tank (stream split)	C8	112.1	84.8	4.7	3.5	Evaporation	1
H8	MeOH gas from MeOH column	CW	64.6	64.5	3.2	2.0	Evaporation	3
H9	MeOH from primary condenser	CW	40.3	40.2	0.8	2.0	Evaporation	3
H10	Surface condenser evaporation plant	CW	63.8	63.7	99.0	2.0	Evaporation	1
H11	Evaporation vapor from line 5	LWW	77.2	77.1	1.9	0.5	Evaporation	1
H12	Evaporation vapor from line 3	LWW	92.9	92.8	1.2	1.5	Evaporation	1
H13	Evaporation vapor from line 1C	LWW, C30	115.9	115.8	1.8	2.0	Evaporation	1
H14	Evaporation vapor from line 2, 2B	C30	102.0	101.9	1.9	2.0	Evaporation	1
H15	Fresh condensate to BB filter 1-3	C12	112.3	33.2	34.7	0.15	Condensate	1
H16	Feed water from HX to mixing point (mix)	C13	93.3	77.5	12.4	0	Condensate	1

H17	Cooling to dissolving tank scrubber	WCC	85.4	36.8	20.9	3.5	Recovery boiler	1
H18	Flue gases from recovery boiler	C14	210.3	140.0	23.0	7.0	Recovery boiler	1
H19	Blowdown steam from steam drum	CW	143.6	143.5	0.6	2.0	Recovery boiler	1
H20	Alkaline effluent from bleaching to biocleaning	LWW, C54 (DH), WCC	89.9	37.0	21.8	3.5	Bleaching	1
H21	Acid effluent from bleaching to biocleaning	LWW, WCC	87.0	37.0	22.9	3.5	Bleaching	1
H22	Weak gas from bleaching	MCW	75.0	49.9	1.9	7.0	Bleaching	1, 5, 6 ****
H23	Green Liquor	C38	100.6	85.0	6.2	3.5	Causticizing	1
H24	Turbine cooling TB31	CW	34.8	15.5	2.0	0	Turbine hall	3
H25	Leakage steam from TB31	TB31 condensate	151.3	151.2	0.4	0.5	Turbine hall	1
H26	Condenser TB31	CW	25.5	25.4	39.4	2.5	Turbine hall	1, 5
H27	Turbine cooling TB21	CW	23.5	19.9	2.0	0	Turbine hall	3
H28	Leakage steam from TB21	CW	99.0	98.9	0.4	0.5	Turbine hall	1*
H29	Bark boiler roster cooling	-	50.0	25.1	0.3	0	Bark boiler	1
H30	Sulfuric acid	MCW	38.7	32.1	0.1	3.5	Chemical plant	1
H31	Tall oil	WW	69.3	54.8	0.0	3.5	Chemical plant	1
H32a	Moist air from drying machine step 1	C45-C48, C51	97.3	66.4	4.4	7.0	Paper room	1, 4, 6
H32b	Moist air from drying machine step 2	C44-C48, C51	66.4	64.5	6.4	7.0	Paper room	1, 4, 6
H32c	Moist air from drying machine (step 3)	-	64.5	*soft*	-	7.0	Paper room	1, 4, 6
H33a	Moist air from drying machine split to cyclone dryer	C53	97.3	66.4	0.1	7.0	Paper room	1, 6 **
H33b	Moist air from drying machine, split to cyclone dryer	C53	66.4	20.0	0.7	7.0	Paper room	6 **

H34a	Flash steam from drying machine and cyclone dryer	C48	133.7	133.6	1.8	0.5	Paper room	1
H34b	Flash steam condensate from drying machine and cyclone dryer	C48	133.6	117.1	1.3	2.5	Paper room	1
H35	Bark boiler feed water	C40, C41	139.8	113.9	1.5	2.5	Bark boiler	1
Number	**Cold streams**	**HX with**	**Tstart [°C]**	**Ttarget [°C]**	**Q [MW]**	**$\Delta T_{min, contribution}$ [°C]**	**Process section**	**Data info**
C1	White liquor to digester and impbin	H2	95	120	10.0	3.5	Cooking	2
C2	White liquor to digester	H1	120	140	4.0	3.5	Cooking	2
C3	Liquor mix to digester	MP	145	150	1.0	3.5	Cooking	2
C4	Weak black liquor 2 from digester to impbin	LP, H6	130	140	10.0	3.0	Cooking	2
C5	Digester MP process steam demand	-	178.1	178.2	17.0	0.5	Cooking	2
C6	Impbin LP process steam demand	-	145.1	145.2	9.0	0.5	Cooking	2
C7	KLB from tank to stripper column	H7a	67.2	108.3	14.0	1.9	Evaporation	1
C8	KLS from tank to stripper column	H7b	70.8	103.3	4.7	3.5	Evaporation	1
C9	MeOH column LP process steam demand	-	145.1	145.2	0.6	0.5	Evaporation	1
C10	Evaporator plant LP process steam demand	-	145.1	145.2	89.6	0.5	Evaporation	1
C11	Super concentrator MP process steam demand	-	185.0	185.1	19.2	0.5	Evaporation	1
C12	Feed water from BB filter 1-3 to HX	H15	32.9	93.3	34.7	0.15	Condensate	1
C13	Feed water from VKT-tank to mixing point (mix)	H16	25.1	77.5	12.4	0	Condensate	1
C14	Feed water to feed water tank	H18	77.5	123	34.6	2.5	Condensate	1
C15	Feed water tank LP process steam demand	-	145.1	145.2	11.3	0.5	Condensate	1
C16	FoU facility heating	HW	47.4	64.5	0.0	2.5	Local heating	1

C17	Office and workshop heating	HW	64.1	80.7	0.4	2.5	Local heating	1
C18	Feed water from feed water tank to economizer 1	MP	139.8	144.1	3.0	2.5	Recovery boiler	1
C19	Feed water heating between economizer 1 and 2	HP	221.3	221.4	5.7	0.5	Recovery boiler	1
C20	Weak gas to GA-cyclone	LP, MP	49.9	132.2	0.5	7.0	Recovery boiler	1
C21	Outdoor air to recovery boiler	LP	6.2	43.1	2.4	8.0	Recovery boiler	3
C22	Primary air to recovery boiler	LP, MP, HP	44.7	190.0	5.5	8.0	Recovery boiler	1
C23	Secondary air to recovery boiler	LP, MP, HP	44.7	168.1	3.8	8.0	Recovery boiler	1
C24	Quaternary air to recovery boiler	LP, MP, HP	31.0	179.9	4.4	8.0	Recovery boiler	1
C25	Strong black liquor to nozzles	MP	128.7	136.2	1.5	3.5	Recovery boiler	1
C26	Production of warm water, recovery boiler house	HW	5.9	51.6	10.9	2.5	Recovery boiler	1 ***
C27	Air to bark dryer	HW, LP	6.2	111.3	10.5	8.0	Wood handling	1
C28	Deicing/wood handling water	-	44.2	50.4	0.2	2.5	Wood handling	1
C29	Heat demand timber kilns	LP	94.2	110.7	18.2	0	Saw mill	1
C30	Heat demand sawdust dryer	HW, H13, H14	77.4	95.0	8.7	0	Saw mill	1
C31	Heat demand tomato farm	HW	46.5	65.0	0.7	2.5	Tomato farm	1
C32	Bleaching step 2 MP process steam demand	-	185.0	185.1	2.6	0.5	Bleaching	1
C33	Bleaching step 4 MP process steam demand	-	185.0	185.1	5.7	0.5	Bleaching	1
C34	Warm water production for filter 4	-	5.9	67.1	17.2	2.5	Bleaching	1

C35	BB2 filtrate from filtrate tank 2 to screw feeder	LP	87.0	90.9	2.1	3.5	Bleaching	1
C36	BB4 filtrate from filtrate tank 4 to screw feeder	LP	86.8	90.7	2.1	3.5	Bleaching	1
C37	Lukewarm water production for polymer preparation	HW	5.9	25.0	0.1	2.5	Causticizing	1
C38	Hot water production for lime filter	H23	5.9	69.5	22.0	2.5	Causticizing	1
C39	O2 reactor MP process steam demand	-	185.0	185.1	0.2	0.5	Oxygen bleaching	1
C40	Air to bark boiler	H35	6.2	84.7	0.8	8.0	Bark boiler	1
C41	Air to kablitz in bark boiler	H35	6.2	121.5	0.7	8.0	Bark boiler	1
C42	Chemical plant LP process steam demand	-	145.1	145.2	1.0	0.5	Chemical plant	1
C43	VKT production	WW, (LP)	5.9	24.9	6.1	2.5	Chemical plant	1
C44	NaOH dilution water	WW	5.9	55	0.4	2.5	Chemical plant	1 ***
C45	Air to paper room 1	H32a-b	6.1	30	1.2	8.0	Paper room	1, 3, 4
C46	Air to paper room 2	H32a-b	6.1	23	1.6	8.0	Paper room	1, 3, 4
C47	Air to pulp cooling	H32a-b	6.1	25.0	2.4	8.0	Paper room	1, 3, 4
C48	Air feed to drying machine	H32a-b, H34a-b	23	98.9	5.1	8.0	Paper room	1, 3, 4
C49	Drying machine LP process steam demand	-	145.1	145.2	48.5	0.5	Paper room	3
C50	Water 1 for paper room	-	5.9	49.9	19.9	2.5	Paper room	1
C51	Water 2 for paper room	H32a-b	49.9	61.7	3.6	2.5	Paper room	1, 3, 4
C52	Paper room LP (MP) process steam demand	-	145.1	145.2	3.0	0.5	Paper room	1
C53	Air feed to cyclone dryer	H33a-b, LP, MP	6.1	155.6	14.9	6.3	Paper room	1, 5
C54	District heating Varberg	H20/HW, H3, LP	40.9	95.8	16.2	2.5	District heating	1

Explanation to the numbers and notations in the table column “Data info”.

1. Data collected from process in operation (logged data from plant operator program)
2. Approximated values based upon discussion with process engineers at Värö mill
3. Design data
4. Flow calculated using fan/pump design data
5. Flow calculated from mass and heat balances
6. Estimated data using Mollier diagram

* Leakage steam from TB21 is assumed to have same heat load as leakage steam from TB31
** Target temperature/flow rate measured by staff at Södra Cell Värö 2017-04-07
*** Measured volumetric flow rate 2017-03-29
**** Start temperature extracted from 2017-03-04

Note that for streams having a ΔT_{min} contribution of 0 °C, that is either due to mixing of two streams, or because the temperature of the stream in question is not represented at the temperatures where the true process demand is. For example, the true process demand for the stream “Turbine cooling TB31” is to cool hydraulic oil and the turbine generator. However, due to missing data, the temperatures have instead been extracted for the water used to perform this cooling (represented as a hot stream) with a ΔT_{min} contribution of 0 °C. Furthermore, for steams having a ΔT_{min} that deviates from Table 2, that is due to that the corresponding heat exchangers operates at a lower ΔT_{min} than what is stated in Table 2.

Appendix 2: Pinch Temperature Interval

See Table 17 for the entire pinch temperature interval, including the corresponding load, cold/hot pinch temperature and ΔT_{min} for each pinch temperature.

Table 17. Calculated pinch temperature interval.

Q [MW]	Tcold [°C]	Thot [°C]	ΔT_{min} [°C]	Tshifted [°C]
247.7	77.4	83.4	6.0	80.4
248.0	77.5	83.5	6.0	80.5
251.5	78.8	84.8	6.0	81.8
252.3	79.1	85.0	5.9	82.1
253.7	79.6	85.4	5.8	82.5
256.6	80.7	86.2	5.5	83.5
259.2	81.7	87.0	5.3	84.3
267.5	84.7	89.9	5.2	87.3
267.6	84.8	90.0	5.2	87.3
272.7	86.7	92.0	5.3	89.3
273.1	86.8	92.1	5.3	89.5
273.6	87.0	92.2	5.2	89.6
275.8	87.6	92.8	5.2	90.2
277.4	88.0	92.9	4.9	90.5
278.9	88.4	93.3	4.9	90.8
287.5	90.7	96.3	5.6	93.5
288.2	90.9	96.5	5.6	93.7
290.4	91.7	97.3	5.6	94.5
294.8	93.3	98.8	5.5	96.0
295.0	93.4	98.9	5.5	96.2
295.7	93.8	99.0	5.2	96.4
296.7	94.2	99.4	5.2	96.8
299.2	95.0	100.2	5.2	97.6
299.3	95,1	100.3	5.2	97.7
300.1	95.3	100.6	5.3	97.9
303.4	96.3	101.9	5.6	99.1
305.5	97.0	102.0	5.0	99.5
311.4	98.9	104.5	5.6	101.7
314.8	100.0	105.9	5.9	102.9
320.7	101.9	106.0	4.1	104.0

Appendix 3: Complete list of pinch violations

See Table 18 for a complete list of all pinch violations determined by analyzing the existing HEN for the true pinch point.

Table 18. List of all individual pinch violations identified in the existing HEN.

Name	Process part	Pinch violation [MW]	Pinch violation type
RB Flue gas cooling/feed water heating	Recovery boiler	18.2	Heat transferred through the pinch
Heat demand saw mill	Saw mill	10.8	Heating below pinch
Heat demand air feed to cyclone dryer	Paper room	8.3	Heating below pinch
Condensate HX with feed water	Condensate	3.6	Heat is transferred through the pinch
Heating of air to bark dryer	Wood handling	2.7	Heating below pinch
Combustion air to RB (outdoor air) [6]	Recovery boiler	2.4	Heating below pinch
White liquor heated with black liquor	Cooking	2.3	Heat transferred through the pinch
BB2 heater	Bleaching	2.1	Heating below pinch
BB4 heater	Bleaching	2.1	Heating below pinch
Combustion air to RB (primary air)	Recovery boiler	1.9	Heating below pinch
Combustion air to RB (quaternary air)	Recovery boiler	1.9	Heating below pinch
Flash steam heats air to drying machine	Paper room	1.8	Heat transferred through the pinch
Combustion air to RB (secondary air)	Recovery boiler	1.6	Heating below pinch
Evaporation vapor 1 C provides heat to saw mill	Saw mill	1.3	Heat transferred through the pinch
Flash steam condensate heats air to drying machine	Paper room	1.1	Heat transferred through the pinch
KLB is heated with KLR	Evaporation plant	1.1	Heat transferred through the pinch
Heating of air to bark boiler with feed water	Wood handling	0.8	Heat transferred through the pinch
Blowdown steam from steam drum	Recovery boiler	0.6	Cooling above pinch

[6] This is a HTR using LP steam to heat a feed stream of combustion air to the recovery boiler. However, it supposed to be running only during times when the ambient air temperature is below 15 °C. The total heat load for this HTR is a pinch violation. However, the load is from design data and therefore the actual pinch violation for this HTR may not necessarily be this high. It is likely so that the load for this HTR has been overestimated.

Heating of kablitz air to bark boiler with feed water	Wood handling	0.5	Heat transferred through the pinch
Evaporation vapor 1 C produces hot water	Evaporation plant	0.5	Heat transferred through the pinch
TB31 leakage steam condensation	Turbine hall	0.4	Cooling above pinch
KLS is heated with KLR	Evaporation plant	0.4	Heat transferred through the pinch
Heating of weak gas	Recovery boiler	0.3	Heating below pinch
	Total	**66.7**	

See Table 19 for comments regarding pinch violations for which retrofit suggestions have not been proposed in the investigation.

Table 19. Comments for identified pinch violations not solved/mitigated.

Name	**Pinch violation [MW]**	**Comments**
Combustion air to RB (outdoor air)	2.4	Only supposed to be running during the colder months of the year. Used for frost protection. The HX has already been evaluated previously with the conclusion that it is more safe to use steam compared to heated water here. What can be done is to optimize when to run it.
White liquor heated with black liquor	2.3	The white liquor entering the digester is heat exchanged with black liquor leaving the digester. To heat the 95 °C white liquor prior to this HX to reduce the violation is deemed unfeasible.
BB2 heater	2.1	This HX result in a pinch violation because LP steam is utilized to heat a cold stream below the pinch. According to the hot CC, there are hot streams available for improved heat recovery within the relevant temperature region. However, these streams are not very closely located to the bleaching section and are also used for other heating purposes. However, it might be interesting to investigate the possibility of heat exchanging this cold stream with some hot black liquor of the cooking section.
BB4 heater	2.1	See comment for BB2 heater.
Flash steam heats air to drying machine	1.8	Flash steam performs top heating of the air to the drying machine (target temperature of 99°C). From a practical perspective, this is a good usage of the flash steam because it is closely located to the drying machine.
Evaporation vapor 1 C provides heat to saw mill	1.3	A heat exchanger which decreases the steam demand for the saw mill water to some extent compared to using live steam. The evaporation vapor has a temperature of 116 °C meaning that it is entirely above the process pinch.

Flash steam condensate heats air to drying machine	1.1	Heats one of feed of air to the drying machine. As for the flash steam, the flash condensate performs top heating of air to the drying machines. In a similar manner, as for the flash steam, this is deemed as a practical solution.
KLB is heated with KLR	1.1	Clean liquor condensate leaving the stripper column is heat exchanged with mixed liquor condensate entering the stripper column.
Heating of air to bark boiler with feed water	0.8	Combustion air entering the bark boiler is heated by its own feed water. By preheating the incoming air by other means, there would be high temperature heat available in terms of the feed water. The preheating could potentially be performed with some heated water within the SHS.
Blowdown steam from steam drum	0.6	The heat here could possibly be used to partly heat weak gas (see below). Both streams are present in the recovery boiler section of the plant. Heat would be transferred though the pinch by implementing this suggestion, however the total amount of pinch violations would decrease. By doing so, there would be savings in LP steam.
Heating of kablitz air to bark boiler with feed water	0.5	See comment for heating of air to bark boiler above.
Evaporation vapor 1 C produces hot water	0.5	Could theoretically be used to heat the saw mill water (and thereby replace LP steam). However, that can instead result in a deficit of HW.
TB31 leakage steam condensation	0.4	Condensation of leakage steam from the turbine with condensate from the condenser. There is not much that can be done about this because it is related to the operation of the turbine.
KLS is heated with KLR	0.4	Clean liquor condensate leaving the stripper column is heat exchanged with contaminated condensate leaving the stripper column.
Heating of weak gas	0.3	See comment for blowdown steam drum.

Appendix 4: Warm water excess heat evaluation

Table 20 lists the warm water producers at the mill and their corresponding mass flows.

Table 20. Warm water production at Värö mill.

Warm water production		
Name	**Mass flow [kg/s]**	**Comments**
Acid bleaching effluent	-	Currently not operating
Alkaline bleaching effluent	145.9	-
Turpentine cooler	9.3	Cooking section
Filtrate cooler COP & AWP	-	Not included (rarely used)
Cooling to dissolving tank scrubber	115.5	-
Blowdown steam	2.3	-
Return water saw mill & pellets	74.0	-
Return ClO_2 production	-	Only for ECF bleaching
Return water weak gas fiber line	16.3	-
Total	363.4	

See Table 21 for a summary of the warm water users at the mill.

Table 21. Warm water users at Värö mill.

Warm water usage		
Name	**Mass flow [kg/s]**	**Comments**
Turpentine condensation	90.7	Cooking section
Weak black liquor cooling to evaporation	133.6	Cooking section
Hot water production evaporation vapor	0.1	Cooking section
VVK to BTM tank	66.5	Not included (rarely used)
Bleaching KLR70-tank	-	0 according to balances
VKT production	30.9	-
NaOH dilution	1.8	-
Dumping condenser	-	0 according to balances
Total	323.6	

Appendix 5: Secondary heating system TCF Winter

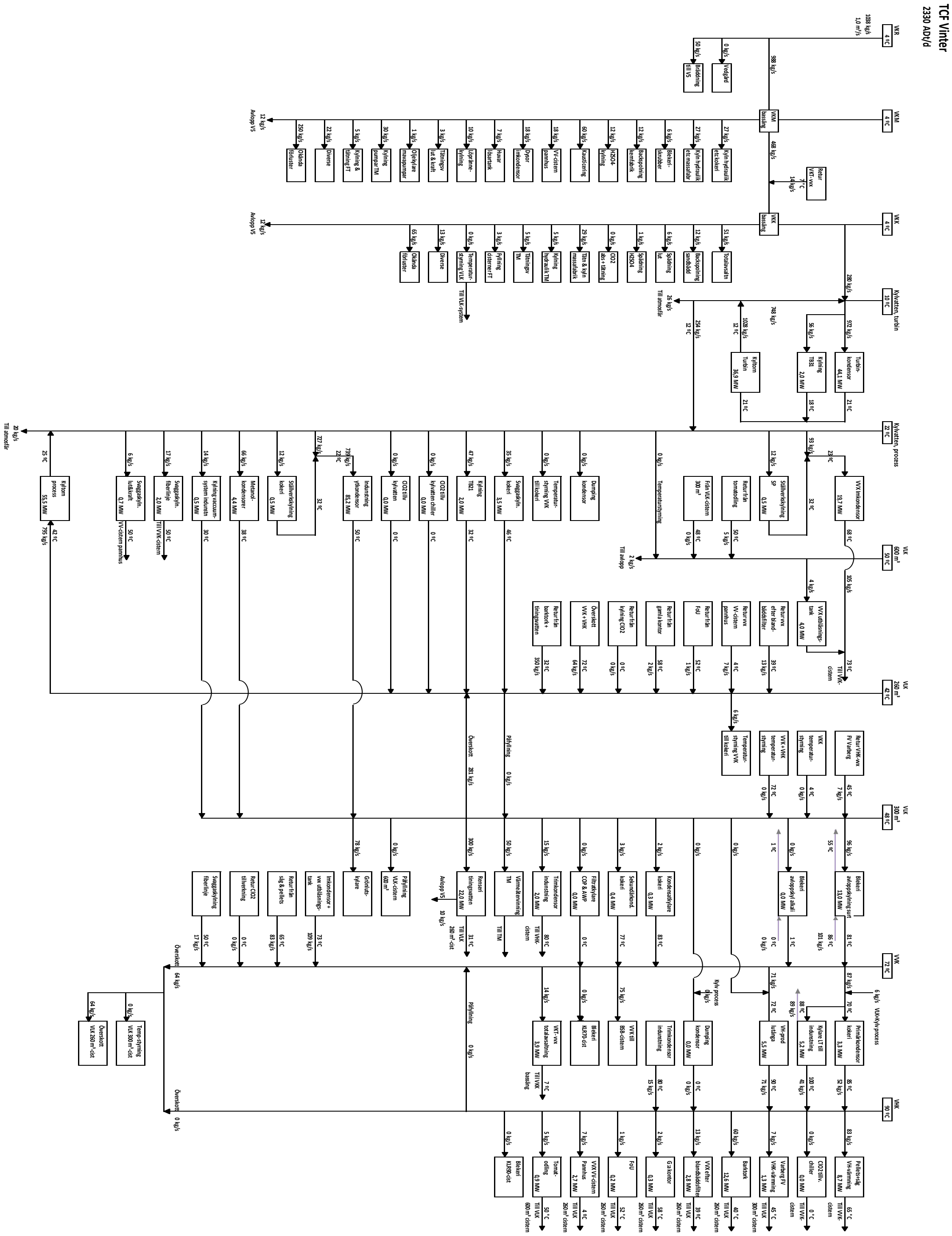

Figure 24. The secondary heating system of Värö mill for a TCF winter case.

Appendix 6: Other suggestions

Today, mechanically purified water of 6 °C is heated with HW to a temperature of 49 °C before it enters a tank in the recovery boiler house. This heating could however perhaps be performed with WW instead. With this suggestion, there would be an excess of HW available for use in retrofits. However, the flow of HW is unknow because there is currently no measuring device connected to the secondary heating side of the heat exchanger.

Furthermore, HW is sent to a nearby tomato farm. The identified demand is water at a temperature of 65 °C. Therefore, it is suggested to evaluate whether it is possible to instead deliver WW to the tomato farm to save HW.

Cooling provided to the dissolving tank scrubber is today performed using CW. However most of the cooling could instead be performed with LWW. By first cooling the vapor from the dissolving tank scrubber with LWW followed by top cooling with CW, it is possible to meet the process requirement. There are two alternative use for these solutions. One could either increase the production of WW compared to today, or produce WW at a higher temperature. Unfortunately, it would not be possible to reach the temperature of HW since the involved hot stream has a start temperature of 85.4 °C. This solution might be good to consider to regain a buffer of warm water.

The evaporation plant section was rebuilt during the expansion project including new heat exchangers enabling additional extractions of evaporation vapor from some of the effects included in the evaporation line. These heat exchangers are used to increase the production of HW when there is a demand for it, and to heat the HW to the saw mill. The heat exchangers have a 20 MW HW production capacity and a 15.7 MW capacity for heating the HW to the saw mill. This way of utilizing the heat in the evaporation vapor enhances the energy efficiency compared to using live steam for the same heating purpose.

During the investigated time period, the utilization of these heat exchangers was not that extensive. However, by optimizing the usage of these additional savings in primary heat can be achieved. An increased production of HW could for instance be utilized in the existing bypass HX within the condensate treatment enabling additional savings in terms of steam. If there is not enough capacity for this bypass HX it could either be rebuilt, but the HW could also be thought of to be used to solve other pinch violations related to for instance the combustion air to the recovery boiler or air heating to the cyclone dryer. Instead of producing HW from the HXs, one could alternatively increase the amount of heating provided with evaporation vapor to the circulating saw mill HW in order to decrease the steam demand for this stream.