Design of the heat recovery systems at the reconstructed pulp mill Östrand

Master's Thesis within the Sustainable Energy Systems programme

JOHAN AHLSTRÖM & MARCUS BENZON

Department of Energy and Environment
Division of Heat and Power Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2015

MASTER’S THESIS

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Cover:
View of Östrand pulp mill

Chalmers Reproservice
Göteborg, Sweden 2015

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ABSTRACT

The aim with this master thesis project was to provide a reference for the reconstruction of the heat recovery systems for the future possible reconstructed pulp mill Östrand, owned by SCA and located in Timrå, Sweden. The principle was to design a heat exchanger network and a secondary heating system that are more efficient than those already proposed by consultants. To achieve this Pinch Analysis was used. The required data for this work were gathered during a one-month visit to Östrand. For the majority of the new process equipment, quotations from different equipment producers were used. However, in some cases, current factory data were used and scaled up to the future production levels.

With the data gathered, the heat exchanger network proposed by Östrand was analysed first to provide a reference case that was later retrofitted to more energy efficient designs. More specifically, two new designs of the heat exchanger network were proposed. The first retrofit design was performed with the goal of using energy as efficiently as possible, but still creating a network that is possible to implement from a practical point of view. The second retrofit design was obtained by including more detailed practical constraints, according to inputs from plant engineers at SCA Östrand, which could have more chances to be implemented at the reconstructed mill.

As a consequence of increased heat recovery, less steam is required for process heating. Since the minimum amount of steam produced is coupled to the amount of black liquor that has to be recovered, increased heat recovery translates into larger steam mass flow rate available for electricity production. This represents a first economic advantage, which should pay back the investment in extra heat exchangers required in the proposed designs compared to the reference prospected design.

Additionally, a modified heat exchanger network requires a modified secondary heating system. This is based on a hot/warm water loop and is a common way in pulp mill to collect and deliver heat where direct heat transfer is not possible, e.g. due to large distance between equipment units, or due to different operation times which also requires water tanks to be used. After the two retrofit suggestions for the heat exchanger network were completed, the design of the secondary heating system was therefore investigated. Depending on the heat available at different temperature levels, different amount of hot water can be produced and the mass flow rates of the different segment of the water loop can be optimized. This translates in reality in optimizing the starting and ending temperatures of these segments, which are separated by a tank where water is stored to accommodate process operational flexibility. While such analysis should follow an economic principle, in this work this was conducted following the objective of recovering as much as excess heat as possible and a procedure called the "tank method" was followed, which was previously developed at the div. of Industrial Energy Systems and Technologies. In this thesis three suggestions regarding what to do with the excess heat are discussed: increased production of district heating, increased steam production for electricity production, and heat pumping. The economic result of excess heat utilization provides a second way to pay back the investment in extra heat exchangers required in the proposed designs compared to the reference prospected design.

While a profitability analysis should be ultimately conducted to identify the best design solutions for the heat exchanger network and for the secondary heating systems, in this work only a discussion of the economic aspects is provided based on the results of the thermodynamic analysis.

These results show that for the ambitious retrofit the electricity production is increased with 24.2 MW and 32.8 MW of excess heat is liberated. For the realistic retrofit, the electricity production is increased with 13.9 MW and 65.7 MW of excess heat is produced.

Compared to the relatively small changes to the original design of the heat recovery systems which was the starting point of this work, the results are considered rather promising and show that there is room for Östrand to improve the design of the future plant.

Key words: Pinch analysis, Pulp production, Process integration, Secondary heating system, the tank method

Design av värmeåtervinningssystemen för den ombyggda massa fabriken Östrand
Examensarbete inom mastersprogrammet *Sustainable Energy Systems*
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SAMMANFATTNING

Syftet med detta examensarbete var att ge en referens för ombyggnaden av värmeåtervinningssystemen för den framtida möjliga ombyggda massafabriken Östrand, som ägs av SCA och ligger i Timrå, Sverige. Principen var att utforma ett värmeväxlarnätverk och ett sekundärt värmesystem som är mer effektiva än de förslag som redan föreslagits av konsulter. För att uppnå detta användes Pinch Analys. Den nödvändiga data som behövdes för detta arbete samlades in under en månads besök i Östrand . För majoriteten av den nya process-utrustningen användes offerter från olika tillverkare, men i vissa fall användes nuvarande data och skalades upp till framtida produktions nivåer.

När data hade sammanställts, analyserades nätverket som föreslagits av Östrand för att tillhandahålla ett referensfall som senare byggdes om för att konstruera mer energieffektiva designer. Mer specifikt, två nya designer av värmeväxlarnätverket har föreslagits. Den första ombyggnaden genomfördes med målet att använda energi så effektivt som möjligt i processen, men fortfarande genom att skapa en design som är möjlig att implementera också ifrån ett tekniskt perspektiv. Den andra ombyggnationen åstadkoms genom att inkludera fler detaljerade praktiska begränsningar, enligt förslag från processingenjörer på SCA Östrand, vilket gör att lösningen har större möjligheter att implementeras i den ombyggda fabriken.

Som en konsekvens av den ökade värmeåtervinningen behövs mindre ånga för värmning av processen. Eftersom den minimala ångförbrukningen är kopplad till mängden svartlut som återvinns, leder ökad värmeåtervinning till högre ångflöden som kan användas till elproduktion. Det representerar en ekonomisk fördel, som leder till att investeringen för de extra värmeväxlare som är nödvändiga i de föreslagna designerna får en snabbare ”pay back”, jämfört med den prospekterade referensdesignen.

Ett värmeväxlarnätverk som är modifierat kräver dessutom ett modifierat sekundärvärmesystem. Detta är baserat på en het/varm-vattenslinga och är ett vanligt sätt för ett massabruk att samla och leverera värme där direkt värmeöverföring inte är möjlig, till exempel på grund av stora avstånd mellan process-enheter, eller på grund av olika drifttider som också kräver vattentankar som behöver användas. Efter att de två föreslagna omgjorda designerna för värmeväxlarnätet var färdiga, utformades och undersöktes sekundärvärmesystemet. Beroende på värmen som finns vid olika temperaturnivåer, kan olika mängd varmvatten produceras och massflödeshastigheterna för de olika segmenten av vattenslingan kan optimeras. Detta innebär i själva verket att optimera start- och sluttemperaturer på dessa segment, som skiljs åt av en tank där vatten lagras, för att rymma flexibilitet för processen. Även om en sådan analys ska följas av en ekonomisk princip, så utfördes detta arbetet med målet att utvinna så mycket överskottsvärme som möjligt och en metod som kallas ”tank metoden” användes, denna metod har utvecklats på divisionen för Industriella Energi

System och Tekniker. I detta arbete har tre förslag angående vad som ska göras med överskottsvärmen diskuterats: ökad produktion av fjärrvärme, ökad produktion av ånga för elproduktion och värmepumpning. Det ekonomiska resultatet av användningen av överskottsvärme ger en andra väg att betala tillbaka på investeringen i extra värmeväxlare som behövs i den föreslagna designen jämfört med referensfallet med den ursprungliga designen.

En lönsamhetsanalys borde ultimat genomföras för att identifiera de bästa designlösningarna för värmeväxlarnätverket och sekundärvärmesystemet, i det här arbetet har dock endast en diskussion angående de ekonomiska aspekterna baserat på resultaten från den termodynamiska analysen presenterats.

Resultaten visar att för den ambitiösa designen ökar elproduktionen med 24,2 MW och 32,8 MW överskottsvärme frigörs. För den realistiska designen ökar elproduktionen med 13,9 MW och 65,7 MW överskottsvärme produceras.

Jämfört de relativt små förändringarna i originaldesignen av värmeåtervinningssystemen som var utgångspunkten i det här arbetet, kan resultaten anses relativt lovande och visar att det finns utrymme för Östrand at förbättra designen av den framtida fabriken

Nyckelord: Pinch analys, pappersmassa, Process-integration, Sekundärvärmesystem, Tankmetoden

Contents

Preface

Throughout this thesis, the primary and secondary heating systems of the future, reconstructed, Östrand pulp mill were evaluated from a thermodynamic point of view. This evaluation was used as a basis for two heat exchanger network designs, aiming at utilising energy in a more efficient way at the future plant. This thesis work was performed as a part of SCAs project for designing the future plant Östrand; where efficient use of energy is regarded of primary importance. The thesis is a cooperation between SCA Östrand and the division of Industrial Energy Systems and Technologies, at the department of Energy and Environment, at Chalmers University of Technology, Sweden. The work has been performed between the 19th of January and the 12th of June.

The main part of the work was done at Chalmers University of Technology, but one month of the work was spent at Östrand mill, Timrå, with the scope of getting familiar with the process and collecting all the necessary data for this study. Daniel Solberg is the on-site supervisor for this thesis work, and has also provided useful input during the entire work.

We would like to express our gratitude towards Daniel, Elin and Matteo for all the help they have provided. Special thanks also to everyone at Östrand - who, during a very busy period, always did their best to answer our questions, to Roger Nordman - who provided some very needed help and to every one at the department of Industrial Energy Systems and Technologies - who have received us in the best way possible and made this past spring a pleasure.

Gothenburg, June 2015

Johan Ahlström & Marcus Benzon,

Notations

Abbreviations

CC	Composite curve
CTMP	Chemi-thermo mechanical pulp
GCC	Grand composite curve
ECF	Elementary chlorine free bleaching
HEN	Heat exchanger network
HWWS	Hot and warm water system (also referred to as “secondary heating system”)
LP	Low-pressure (for steam)
MER	Maximum energy recovery
MP	Medium pressure (for steam)
TCF	Totally chlorine free bleaching
TM	Torkmaskin (drying machine)
TTL	Tank temperature level

Symbols

ADt/y	Air dried metric ton of pulp per year
Q_{XS}	Useable excess heat (kW)
ΔT_{min}	Minimum temperature difference (K)
η_{is}	isentropic efficiency
η_{m+g}	Turbine efficiency after mechanical and generator losses

1 Introduction

1.1 Background

Increased rivalry on the pulp market, especially from modern pulp mills in developing countries has amplified the competition in the pulp industry during later years. Combined with stricter regulations regarding carbon dioxide emissions and increased costs for fossil fuels, this has put pressure on pulp mills to become more energy efficient.

Pulp production is energy demanding and energy efficiency solutions often prove to be a strong basis for cost reductions. Modern Kraft pulp mills with efficient equipment and well-integrated heat recovering solutions can reduce heat use to such a degree that steam can be produced in excess from the black liquor chemical recovery. The excess steam can be utilized either to produce electricity or to deliver district heating to nearly located communities. There are evidences that mills that are able to work as both pulp and power producers have more chances to achieve higher annual profits [Lundberg. V, et al., 2013a], [Lundberg V, et al., 2013b], [Nordman. R et al. 2004].

Östrand currently has an annual production of total 510 000 ADt/y, where 425 000 ADt/y is Kraft pulp and 95 000 ADt/y is CTMP [SCA 2015]. Östrand has applied for a possible increase of the annual production capacity to 1 100 000 ADt/y of pulp per year, where a maximum of 120 000 is chemithermomechanical pulp (CTMP). To be able to accomplish this, large reconstructions of the existing production processes will have to be attained. The CTMP facilities will not be reconstructed but they might be integrated with the rest of the plant. The reconstruction is mainly performed to increase the profitability of the plant. Operating costs in comparison to the amount of produced pulp decreases with an increased production.

The objective of this thesis is to help the company to find solutions that can reduce the plants future energy demand, in relationship to the amount of pulp they are producing.

Since a new recovery boiler with potential for increased production was constructed in 2006, this new reconstruction stage will focus on a larger and more efficient evaporation plant, a new digester plant and a new bleaching process. Since the amount of produced bark will increase with the new process and the total heat demand of the process is expected to drop compared to the amount of produced pulp due to new more energy efficient process equipment, more steam is expected to be available for electricity generation. The reconstruction project also includes the installation of a condensing turbine. Maximizing power production is a typical goal in designing the energy systems integrated with a pulp mill, as electricity is the bi-product with the largest value.

The plant will also change from producing a pulp that is totally chlorine free (TCF) to producing both TCF pulp and elementary chlorine free (ECF) pulp, since the market for TCF is smaller compared to ECF [SCA ÖSTRAND, 2014].

1.2 Aim

The aim of this master thesis project is to suggest heat saving measures that will improve heat recovery at the reconstructed SCA Östrand Kraft pulp mill. More precisely, the thesis will examine the possibilities of improving the heat integration between the different parts of the pulping process, such as the bleaching, digester and evaporators, in order to reduce the heating and cooling demands of the overall process compared to a reference design provided by consultants. Process integration solutions via direct heat exchanging between process hot and cold streams and indirect heat exchanging via the plants secondary heating system are considered in this work.

To accomplish this, an energy balance over the reconstructed plant has been established and a pinch analysis conducted. By using the results from the pinch analysis a heat exchanger network with realistic limitations was designed. Data from the heat exchanger network was used to optimize the secondary heating system of the plant, to maximize the available excess heat. This has then again been used to determine a final design and establish the resulting energy balances over the primary and secondary heat system.

1.3 Scope

The scope of this thesis is to investigate the energy situation at the future plant. The starting point of this work is a reference design regarding of the heat exchanger network and secondary heating system, which was provided by consultants. However, there are several evidences that such proposed design is made out from consolidated practices regarding pulp mill design and that there might be room for further improving such a design. In order to evaluate the reference design and suggest improvements this thesis will try to answer the following general research questions:

- What is the potential for energy recovery in the future plant?
- What is the maximum amount of electricity that can be produced in the process, provided that the suggested design is possible to implement?
- Which energy efficiency solutions can be implemented from a practical point of view and what energy savings would they achieve?

Pinch Analysis is the primary tool for conducting such analysis. This, together with other tools is further descripted in chapter 3.1.

1.4 Conditions for data extractions

Process data were extracted at Östrand in a period that extended from the 3^{d} of February to the 27th of February. This is representative for a winter season and hence a summer case was not considered for this work.

Throughout the work no economical calculations have been performed. Because of this it has not been possible to distinguish between suggested HEN solutions through the achieved energy savings.

No technical specifications regarding the suggested implementations of heat exchangers have been specified. That is, no suggestions on how to realise the design has been given, for instance regarding what type of heat exchangers to use.

The environmental aspects of the suggested HEN designs were not estimated, since there was no interest from Östrand look at that aspect.

2 Process and system description

In the following chapters the pulp producing methods that are used at Östrand, are generally described.

2.1 Pulp production

There are several processes that can be employed in order to produce pulp, for instance the mechanical pulp process, the sulphite process and the most common one, the Kraft process. What divides the processes from each other is mainly the way the cellulose fibres are separated from the rest of the wood components. As the plant studied in this thesis is both a Kraft mill and a chemithermomechanical pulp mill, both these processes will be described in more detail in the following sections.

2.1.1 The Kraft process

In the Kraft process the cellulose fibres are separated from the lignin in the wood by boiling woodchips with white liquor in what is known as the coking unit or digester. The pulp produced in the Kraft process is strong and of high quality, with the drawback of a lower lignin yield compared to the sulphite and mechanical pulping processes.

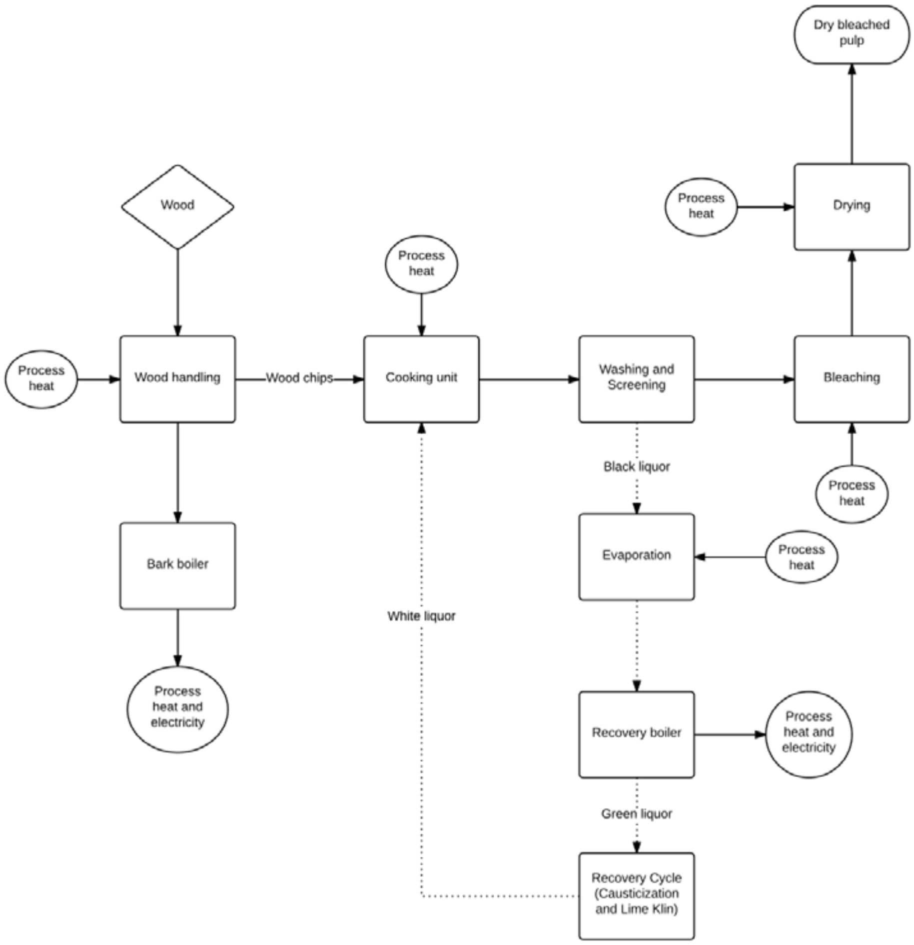


Figure 1: A schematic presentation of the Kraft pulp process. The filled line represents the fibre line and the dotted line represents the chemical recovery.

The first stage in the Kraft pulp process is the removing of the bark, which takes place in a debarking drum. After that the remaining wood, now containing less than one per cent bark, is chopped up to chips that continues to the digester. The first part of the digesting process is steaming of the wood chips in the “chip bin”. Low-pressure steam or flash steam (steam that is produced when the pressure is lowered later in the process) is used to pre-treat the chips, thereby removing the non-condensable gases inside the porous wood. This part is important in order to achieve an evenly distributed dissolving of the lignin in the later digesting stages. After the steaming the now heated wood chips continues to the impregnation stage where the boiling chemicals, mainly hydroxide and sulphide ions, are added to the process.

From the impregnation the soaked wood chips continues to the delignification step. The remaining white liquor is added to the mix of boiling chemicals and wood chips and the temperature is increased to 160-175°C along with a pressure increase. The target with this stage of the process is to dissolve the lignin; however the boiling chemicals will react with some of the cellulose and hemicellulose as well. This is not desirable and it is therefore important that the reaction takes place at the right conditions, thus minimizing the amount of reacted cellulose. Used boiling chemicals, known as black liquor, are removed from the delignification step and go via a flash tank to chemical recovery. Black liquor is basically a mixture of the un-organic components that comes from the boiling chemicals, dissolved organic components and water.

The last stage of the boiling process is the blowing. In this stage the pressure is lowered fast, which makes the water within the wood chips evaporate. As the transportation of the chemicals out from the chips is much slower than the evaporation process, it creates an over-pressure within the chips, thereby destroying them. A lot of desirable cellulose molecules get damaged in this part of the process; hence it is important that the blowing does not take place under to violent conditions.

After the boiling process a mixture of the exposed cellulose fibres, undissolved wood chips and black liquor remains. This mix continues to the washing process to separate the fibres from the remaining black liquor. To wash the mixture several different stages are used, depending on the type of process and what kind of pulp that is produced.

Normally the pulp continues to the bleaching step after it has been washed. In many plants the pulp is pre-bleached using oxygen before it enters the main bleaching steps. There are several different chemicals that can be used to bleach the pulp depending on the required level of bleaching, the required pulp quality and environmental considerations. Some common bleaching chemicals are: hydrogen peroxide, sodium dioxide, oxygen and chlorine dioxide. It is common that the bleaching takes place in several steps using different process conditions in each step. One common way to distinguish between different bleaching processes is whether they utilise chlorine or not in the process. Chlorine was the most common bleaching chemical some years ago, but due to its large negative impact on the environment it has been gradually phased out and today no pulp mills in Sweden utilize pure chlorine. Instead two main alternative bleaching processes are employed: totally chlorine free bleaching (TCF) and elementary chlorine free bleaching (ECF).

The produced black liquor contains valuable chemicals that can be reused, together with a lot of energy from the dissolved organic compounds that is unnecessary to waste. To be able to use the energy and reuse the chemicals, the black liquor is burned in a combined furnace and chemical reactor known as the recovery boiler. However, to burn the black liquor, the water level in the mixture has to be reduced; this is achieved in a multi-effect evaporator. The evaporation occurs in a cascade of stages, called effects, at progressively lower pressures where the steam from one stage (evaporated water and organic compounds) is used as heating medium in the next stage at immediate low pressure. The first stage of the evaporation train operates using steam produced in the recovery boiler. Theoretically, the more effects that are used in the more heat can be recovered. However losses occur between the stages and more investment is required for more evaporator effects so that an optimum number of evaporator effects can be found. The evaporation process is nevertheless energy demanding and often a large part of the steam produced at the mill is utilized for evaporation.

In the recovery boiler the black liquor is sprayed in as droplets from above the hearth of the furnace and in that way the water in the droplets are evaporated and most of the organic compounds combusted before the inorganic chemicals ends up in the melt bed at the bottom of the furnace, from where they eventually are removed. The walls of the furnace are covered with tubes where water is vaporized, in that way most of the energy from the dissolved organic compounds is recovered. The melt with the inorganic substances is removed from the bottom of the recovery boiler and mixed with re-circulated weak liquor, creating what is known as green liquor.

In order to reuse the boiling chemicals the green liquor has to be transformed back to white liquor, this is attained through the slaking and caustification process. First the green liquor is mixed with lime, which reacts with the water in the mixture creating calcium hydroxide. In the next step the calcium hydroxide reacts with the calcium carbonate ions, creating white liquor and hydrated lime. After this stage the white liquor and the hydrated lime are separated, the liquor goes back to the digester to be used in the boiling process again, and the hydrated lime is sent to a reactor where it is burnt, creating lime that can be reused in the green liquor process. The hydrated lime is reacted back to lime in an endothermic process that takes place in the limekiln. The limekiln is basically a rotating furnace where the reaction takes place at temperatures above 1000°C.

Cleaned pulp from the bleaching steps still consists, to a large degree, of water. Normally the finished pulp product that is shipped to customers contains about ten per cent moisture and therefore the pulp from the bleaching process has to be dried. The drying process can be designed in a number of ways. However, two separate methods distinguish themselves from the others. By drying the pulp through a drying machine, the pulp is first run through several wire presses where water is pressed out of the pulp. The last water is drawn out of the pulp through convection. Large fans blow air through heating batteries and the heated air then forces the water out of the pulp. When the pulp is dried using a drying machine the finished product comes out as large sheets that can be easily transported.

The other common drying method is to dry the pulp with a flash dryer. This means that the pulp is injected to a large tube that blows the pulp upwards with the use of large fans that blows heated air through the pulp. When using this process the dried pulp becomes very fluffy and cotton like.

2.1.2 The chemithermomechanical pulp process

The CTMP process utilizes a combination of mechanical work and chemicals in order to produce pulp. Similar to the Kraft process the wood is first debarked and chopped up to chips. The chips are then washed and steamed before it is impregnated with sodium sulphite and sodium hydroxide under high temperature and pressure. The chemicals are added in order to reduce the energy demand for the fibre separation during refining later in the process. After the impregnation stage the impregnated wood chips are brought to the refiner, where the chips are processed between two refining discs creating a fibre laying [Theliander, H et al 2000]. The pulp is then cleaned from the added chemicals and dissolved lignin hemicellulose, before it is sent to the bleaching process and finally to the customer.

The CTMP process produces a pulp that is weaker compared to the pulp produced in the Kraft process. It is often used for products that require thick material, which gives flexural rigidity such as cardboard [Theliander, H et al. 2000].

2.2 The studied mill Östrand

Renowned Swedish financier Ivar Kruger formed SCA in 1929 and in connection with that Östrand pulp mill was constructed. Since then the mill has been reconstructed several times, where the last large reconstruction took place in 2006 when a new recovery boiler was installed. In order to evaluate a possible expansion of the production facilities at Östrand a project was started during 2014. The project shall, by the summer of 2015, have come up with solutions for rebuilding the mill in order to increase the production of Kraft pulp.

Kraft pulp is the main product manufactured at Östrand today, with a production of 425 000 ADt/y, this production will increase to 900 000 ADt/y after the reconstruction. The Kraft pulp from Östrand is sold under the brand “Celeste”.

The CTMP factory is not included in the reconstruction plans for the mill, meaning that Östrand will produce roughly the same amount of CTMP also after the reconstruction. However, the project is looking at changing parts of the heat exchanging network within the CTMP factory, thus process integration in this part of the factory might be possible. The CTMP factory produces roughly 95 000 ADt/y.

2.3 The Kraft pulp production at Östrand

2.3.1 The fibre line

At Östrand pulp mill the raw material used for the pulp production is both round wood and sawmill chips. The round wood is transported to the mill via roads, rail or by ship and the delivery of sawmill chips comes either via roads or by ships. The handling of the round wood is similar both for the CTMP production and the Kraft pulp production. First the wood is debarked and then chopped up to chips and sent to storing in a large tank before it is sent to either the CTMP process or the Kraft process.

For the digester a concept based on the chip bin and impregnation vessel is considered in this work. This suggestion is comparable to the digester used at Östrand today. The wood chips are steamed in the chip bin using flash steam. White liquor is added both in the impregnation vessel and in the digester. Deduction liquor is flashed in one flash tank, the flash steam goes through a steam converter, the dirty condensate goes to a stripper column and the generated steam is used to preheat the wood chips in the chip bin. The weak liquor stream from the bottom of the flash tank is sent via a heat exchanger to the evaporators for recycling of the boiling chemicals.

After the digester, the pulp is washed, first through screening and then with cleaning chemicals according to a counterblow scheme, meaning that the cleaning chemicals are added at the end of the cleaning stage. By treating the cleaned pulp with oxygen, it is pre bleached before it enters the bleaching process. The oxygen treating takes place in two reactors that are connected in series. Besides oxygen, the pulp is also treated with complexing-agent to bind the metal ions that can cause problems in the later bleaching steps, and with sulphuric acid to adjust the pH value in order to optimize the process. Water used in the oxygen threatening steps mainly consists of condensate from the evaporation plant, in order to reduce water consumption at the site. Water from the oxygen steps is cooled before it is utilized in the digester, the water is cooled to such a degree that the stream from the blow tank does not have to be cooled before it enters the oxygen treating process.

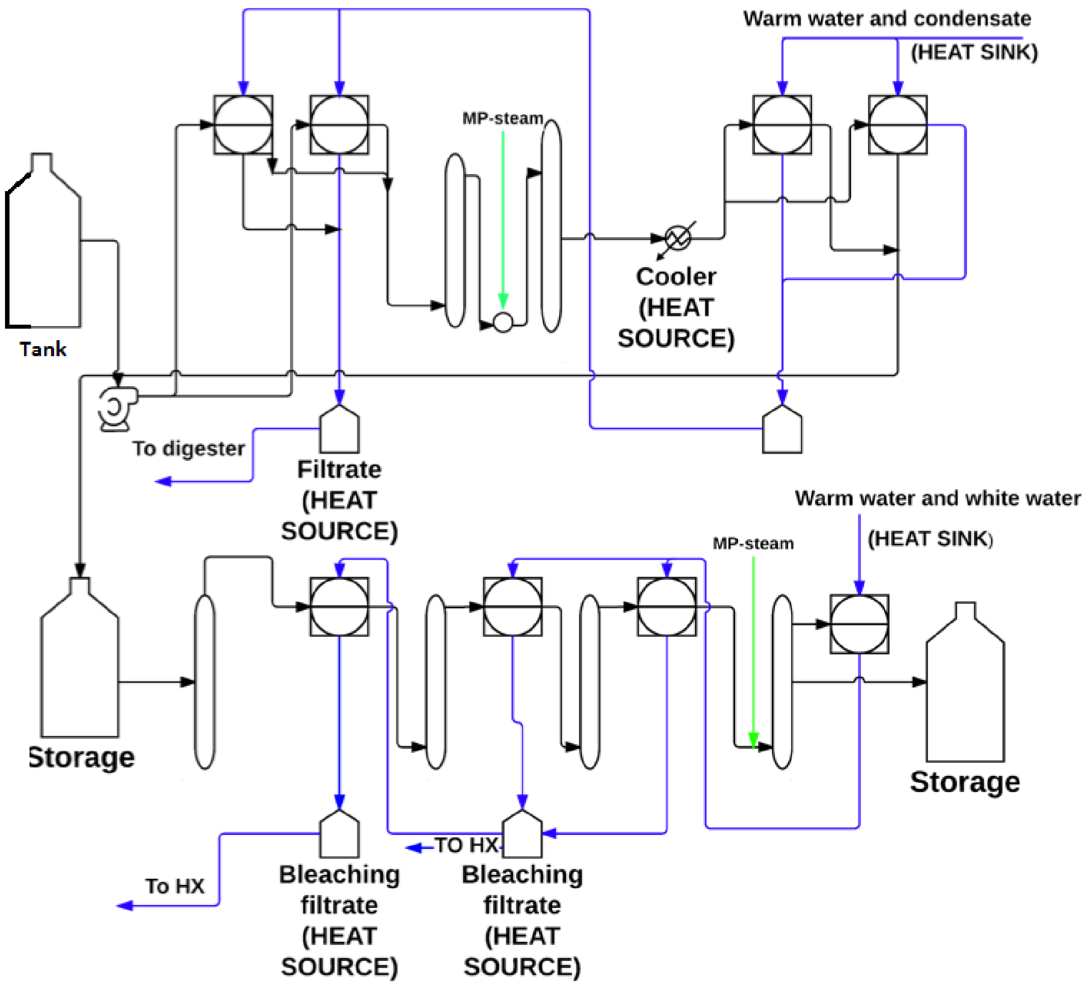


Figure 2: The prospective oxygen steps and bleaching steps in the project

The reconstructed plant will be able to produce both totally chlorine free pulp, as Östrand does today and elementary chlorine free pulp. For this thesis a bleaching process where the entire production is bleached using ECF bleaching was assumed.

The water requirements for the bleaching process are mainly filled by using recycled white water from the causticising department and by using warm water from the mills secondary heating system. The water that is used in the bleaching process becomes contaminated and is sent to water cleaning system before it is emitted into the Baltic. In order for the bacterial flora in the water cleaning system to work properly the temperature of the incoming water has to be cooled to 37°C.

2.3.2 Chemical recovery

Black liquor from the digester and pulp washing is transferred to the evaporators in order to increase the dryness of the liquor so that it can be burned in the recovery boiler. The new evaporation plant will consist of 7.5 effects where the last step is a super thickener; the black liquor from the evaporation will have a solid content of 80-82%. At the reconstructed plant the stripper column that cleans the dirtiest condensates from the mill is built into the evaporation process. Methanol is separated from the dirty gases from the stripper column before they are sent to a gas furnace where all strong gases and odorous gases will be burned. Three condensates will be extracted from the evaporation plant. The cleanest condensate exits at 117°C and is sent straight to the condensate tank, the stripper condensate is clean enough to be utilized in the bleaching process as earlier mentioned, and the last condensate is used in the causticising department. This means that no wastewater is produced from the new evaporation process.

At Östrand the caustification plant and attached limekiln is large enough to handle the increased production that comes with the reconstruction of the rest of the plant. The limekiln will be fuelled with milled bio pellets and if required with extra oil.

The market demand for bark is low, which means that it is hard to sell the bark produced in the debarking drum. Therefore it often proves more profitable to combust the bark at the site and produce stream. At Östrand it is planned to combust all bark after the reconstruction.

The recovery boiler that was constructed in 2006 was designed in such a way that an extension is possible. That means that the present recovery boiler will be used also in the future.

2.3.3 Drying process

Today the Kraft pulp produced at Östrand is dried using a drying machine and a flash-drying machine. In order to handle the extra production after the reconstruction a new drying machine, similar but larger than the one the plant has today will be constructed. The idea is that the new drying machine will both handle the increased production and replace the old flash-drying machine. At the reconstructed plant, both the drying machines will be using low-pressure steam. The CTMP process will be using the same blow-drying machine as it uses today also after the reconstruction.

2.4 Heat recovery and utility systems at the mill

2.4.1 The steam system

The recovery boiler produces superheated steam at 106 bar and 515°C which is used directly in two backpressure steam turbines. The first back pressure turbine has one steam draw-off at 12.1 bar that feeds the medium pressure steam header, steam is finally released at a back pressure of 4.7 bar to feed the low pressure steam header. The turbine also has small draw offs at 27, 16 and 7 bar, which are used to pre-heat water and combustion air to the recovery boiler. The other backpressure turbine has no draw off and only feed the 4.7 bar header.

In the bio boiler where bark is combusted, superheated steam at 64 bar and 410°C is produced. The reconstructed plant will be more energy efficient than the former one. This means that the steam consumption of the plant will decrease in comparison to the amount of pulp produced.

Since Östrand has decided that all bark will be combusted in the bio boiler, an excess production of steam will arise. Hence a condensing turbine will be constructed and the excess steam can be used to produce electricity. The condensing turbine will decrease the pressure of the steam to 0.02 bar and 17°C where a condenser is used to condense the steam into water which is then sent back to the boiler system. Figure 3 visualises the steam system at the reconstructed mill.

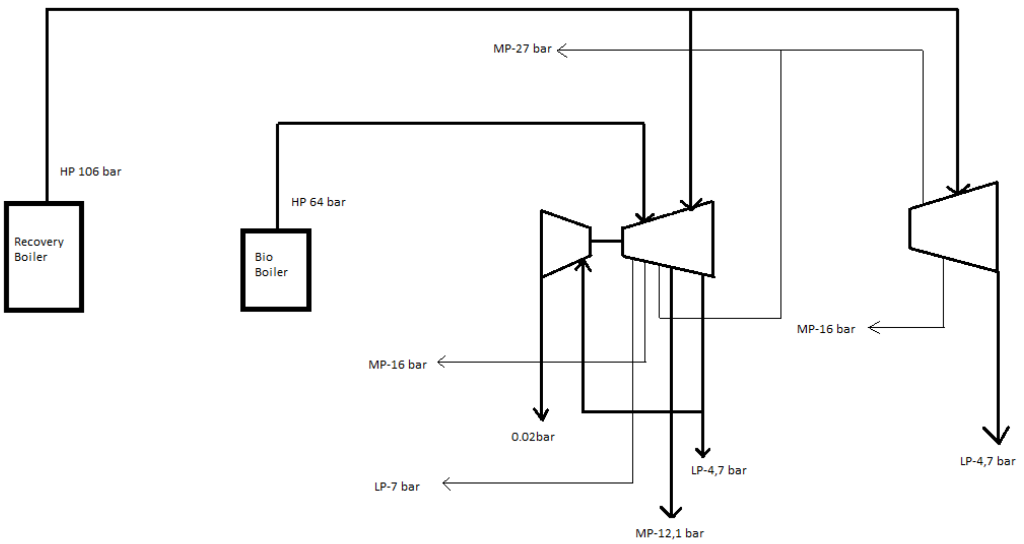


Figure 3 The steam system at the future pulp mill

2.4.2 The secondary heating system

At most pulp mills the largest part of the heat recovery takes place indirectly through a secondary heating system which collects the heat from different process heat sources and deliver the heat to process heat sinks. This is done for several reasons. The site of a pulp mill is often rather large and direct heat exchange is therefore limited to those streams that are located close to each other to avoid transporting large streams of process fluid, such as for instance white or black liquor. Additionally it often happens that different technology providers build the different process parts, which therefore leads to separate heat exchanger networks that are then “plugged in” into the steam and water heating system when such process parts are assembled at the mill site.

There are in addition often requirements for using hot and warm water directly in the process. For instance there is a need for warm water in the bleaching sequences and for the lime filters. These requirements are also fulfilled through the secondary heating system. By utilizing tanks to store water, the secondary heating system can also be used as a heat buffer, when the process demands and supplies varies within the process. The hot and warm water also acts as cold utilities in the process.

A prospective secondary heating system of the plant has been suggested by the design engineers and consultants at Östrand. This design is not definite and may be further optimized, as is partly the aim of this thesis. A sketch of this secondary heating system is showed in figure 4.

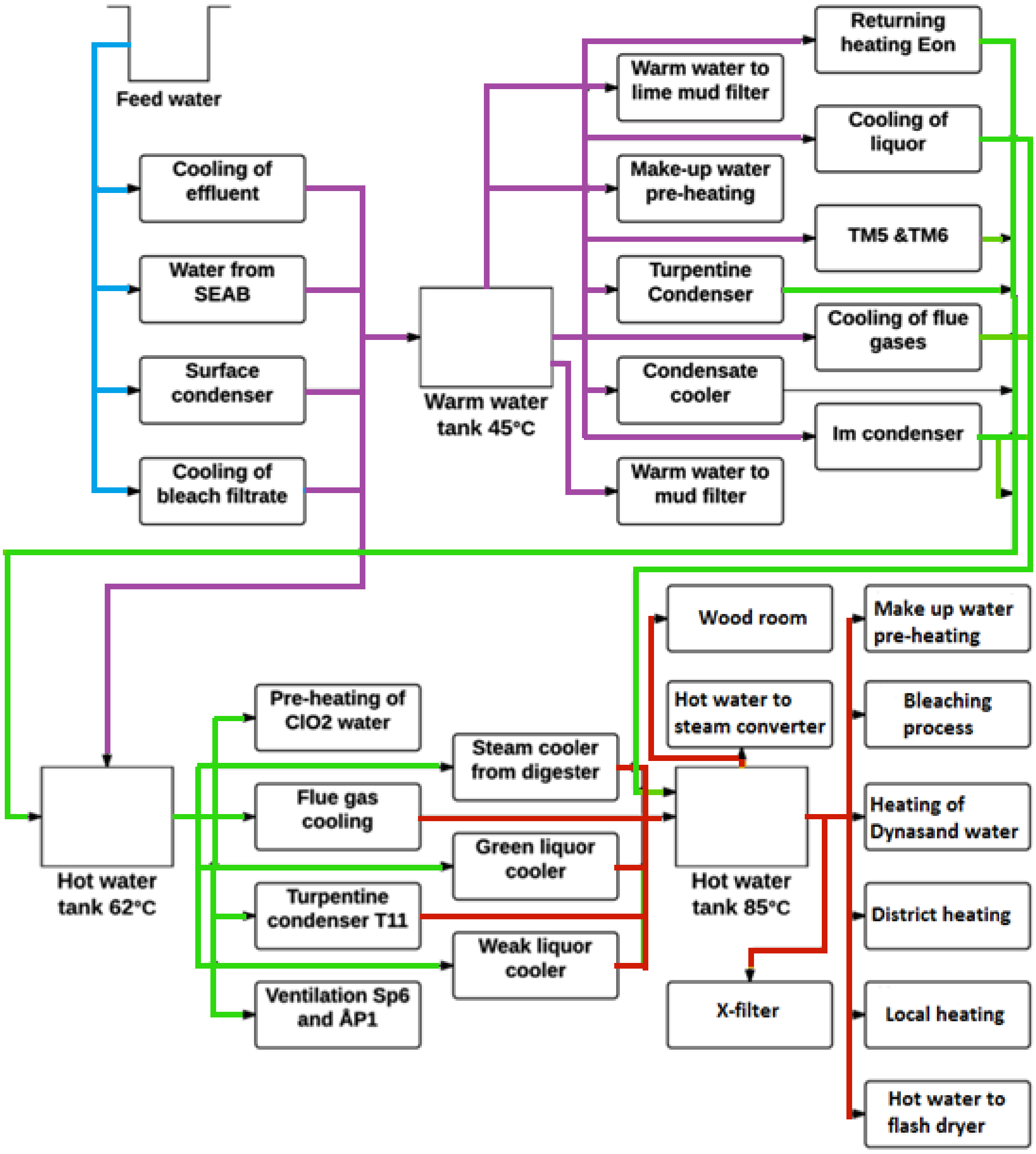


Figure 4 The prospective secondary heating system of the project, the blue arrows represents fresh water, purple arrows represent 45°C water, green arrow represent 62°C water and red arrows represent 85°C water.

2.4.3 The district heating systems

Östrand mill currently delivers the entire demand of district heating to Timrå County through the E.ON district-heating network. Since the entire demand is fulfilled there is no room for increasing this production after the implementation of the project.

District heating is also delivered to Sundsvall County via the SEAB district-heating network. Unlike the Timrå network, Östrand does not deliver the entire district-heating requirement to the SEAB district-heating network. As of today, parts of the remaining heating requirements to Sundsvall are fulfilled using boilers. This means that there are room for Östrand to increase the delivery of district heating to the SEAB network, as the district heating that is produced from Östrand is made out from waste heat and it is better to utilize this heat rather than to fire boilers. Details regarding heat delivery and price agreements between SCA Östrand and the energy service companies are confidential. However, the room for increased delivery of district heating to SEAB is large and should not be a limiting factor.

3 Methodology

A literature study was performed to investigate if other studies have been done.

A visit to the mill in Östrand was conducted between the 3^{d} and 27th of February in order to gather information about the reconstruction process and data about the prospected plant.

A considerable amount of work in this project has been devoted to find data regarding temperature levels and heat loads of the different relevant heat sinks and heat sources of the reconstructed mill. Since the mill has not yet been reconstructed during the execution of this master thesis, it became in some cases necessary to assume values of certain data based on indication of plant engineers. After a preliminary understanding of the existing mill was obtained from the controller screens, relevant data were gathered from the site, together with quotations from suppliers.

By identifying heat sinks and heat sources for the process, as it will be after the planned production increase, a pinch analysis was performed and theoretical heating and cooling requirements identified. The result from the pinch analysis provides the theoretical level of heat recovery, the basis for identifying the pinch violations in the prospected heat exchanger network and for proposing new design options.

3.1 Pinch analysis

The main tool utilized in this work is Pinch Analysis which is a common process integration tool especially used for conceptual design of energy intensive processes where energy targets are often used as design reference.

3.1.1 Basic theory

Industrial processes such as pulp industry, which involve different chemical processes, are complex and to perform an energy-balance over the entire system might be difficult. However a method known as Pinch Analysis provides a methodology to systematically carry out energy analysis for a defined process. This method can be used both for new designs, also called grass root design, and for existing designs that need retrofitting. Pinch analysis provides a set of tools for analysis and design of heat recovery systems, which have the advantage of being based on a simple set of ideas that can be represented into graphs where the net heat and cooling demand of a system can be clearly seen.

The first step in a pinch analysis is to extract process thermal stream data. These are the starting temperature, target temperature, and heat load of all the heat sinks and sources, conventionally referred to as cold and hot streams. With this data it is possible to establish the hot and cold composite curves (CC). The hot CC is constructed by calculating the total heat content of all hot streams identified. The cold CC is constructed likewise. Both the curves can then be displayed in a graph, which is shown as an example in figure 5. From this graph important information is received, such as the maximum possible heat recovery and the minimum amount of external cooling and heating required for the process.

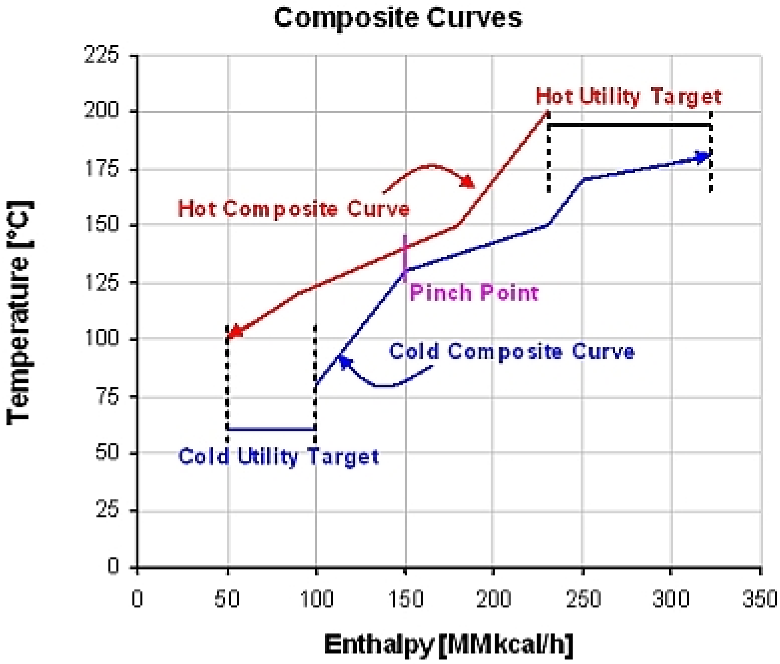


Figure 5 Example of Grand Composite Curves [Clearwater bay technology, Inc. 2003-2012].

A minimum allowed temperature difference between a hot and cold stream that is being heat exchanged, known as ΔT_{min}, is defined. To determine a reasonable ΔT_{min}, different aspects have to be considered. For a high ΔT_{min}, the driving forces for heat transfer are large and a smaller heat exchange area is required. The opposite is true for low ΔT_{min} values, where the driving forces are small and a larger heat exchanging area is required. A larger driving force means that less heat is utilized, which increases costs for utilities. A trade-off between running costs and investment costs thereby has to be attained. Typical values for ΔT_{min} range between 10-20 K.

Another way to represent the system thermal cascade is to construct the grand composite curve (GCC). The temperatures used in the GCC are shifted, meaning that temperatures for hot streams are lowered with $\Delta T_{min}/2$ and the temperatures for the cold streams are increased with $\Delta T_{min}/2$. By constructing the GCC vital information is established, such as at which temperature levels the process exhibit a net heat deficit or surplus, thus giving important information on the temperature at which cooling and heating from an utility system should or can be placed. Above the pinch point there is a heat deficit and below the pinch there is a heat surplus. By finding the so-called pockets, i.e. where the curves overlap each other, in the GCC it can also be found out at which temperature intervals there are room for heat recovery. An example of a grand composite curve is visualised in figure 6.

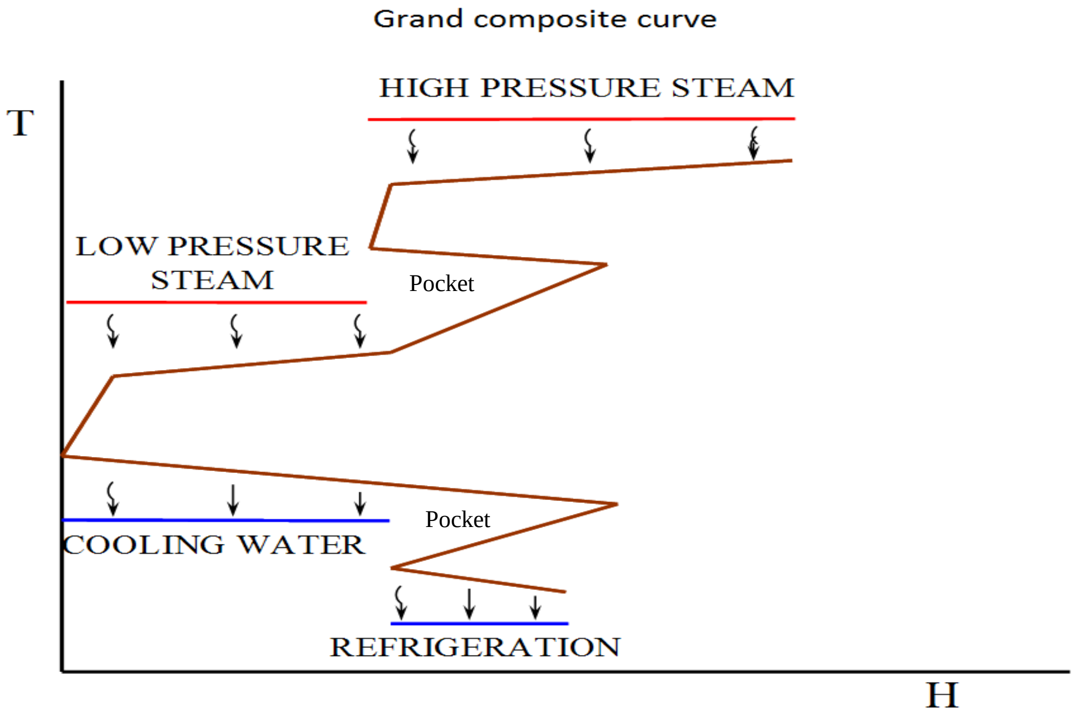


Figure 6: GCC [HRC consultants Ltd. 2014]

3.1.2 Heat exchanger network design

In order to create a maximum energy recovery (MER) network, i.e. a network where a minimum hot and cold utility demand is fulfilled, three important rules has to be followed.

- Do not transfer heat across the pinch (from a hot stream above the pinch to a cool stream below the pinch)
- Do not use external cooling above the pinch
- Do not use external heating below the pinch

Breaking one of these rules will result in an increase in utility demand. By cooling above the pinch the heating demand will increase and heating below the pinch will result in an increase in cooling demand. By transferring heat across the pinch both hot and cold utility will increase.

When designing a network for a specified process, the network is split into two separate parts in order to avoid one of the pinch rule violations, one network above the pinch and one network below the pinch. Above the pinch a match between a hot and cold stream where the hot stream is “ticked off”, meaning that a stream is completely cooled or heated to the pinch temperature, is desired. Below the pinch a match between a cold and hot stream where the cold stream is “ticked off” is desired. By “ticking off” streams above and below the pinch it ensures that no external cooling is provided above the pinch (where the system behaves as a heat sink and therefore only heating is theoretically required) and no external heating is provided below the pinch (where the system behaves as a heat source and therefore only cooling is theoretically required) and hence a MER network is designed.

When retrofitting an existing process it can be difficult, or not economically feasible to create a MER network. Below some general retrofit principles are presented. These principles need to be considered in order to ensure a feasible and economical heat exchanging solution for the process. [Kemp I 1982]

- Retain existing heat exchangers in original positions as much as possible
- Install as few new heat exchangers as possible
- Re-pipe no more than needed

When performing a pinch analysis you specify your own boundary conditions by stating the allowed minimum temperature difference between a hot and a cold stream. By evaluating the possible heat recovery for that specified temperature difference the study proceeds to reach the optimum heat recovery by designing the HEN. This means that the system as a whole is not optimized, as it is not possible to distinguish between the performed design and other designs using other minimum temperature difference. In order to find the optimum design an extra criterion has to be applied to the analysis. In most cases this is achieved by trying to optimize the design from an economic perspective.

3.1.3 Tank curves

A specific tool within pinch analysis, used to optimize secondary heating systems of process industries, was developed by Roger Nordman and presented in the paper "Design of Kraft pulp mill hot and warm water systems – A new method that maximizes excess heat" in 2005. The paper introduces the tank curve, which is used to decide the number of tanks and the temperature levels of those tanks, in order to maximize excess heat at a high temperature level.

The following steps describes in detail how the tank curve of a certain system is designed.

1. Identify the hot streams of the secondary heating system and construct the hot CC.
2. Identify the cold streams in the secondary heating system.
3. Identify the process demands and the cooling demands from the cold streams.
4. Construct the cold CC from the cold streams for process demand.
5. Calculate the theoretical target of excess heat at a given $\Delta T_{min.}$
6. Replace the cold composite curve with the "tank curve", the tank curve is explained below.
7. Vary the number of tanks and the temperature levels in the tanks in order to maximize excess heat.

Step 1. Construct the CC from all hot streams in the HWWS

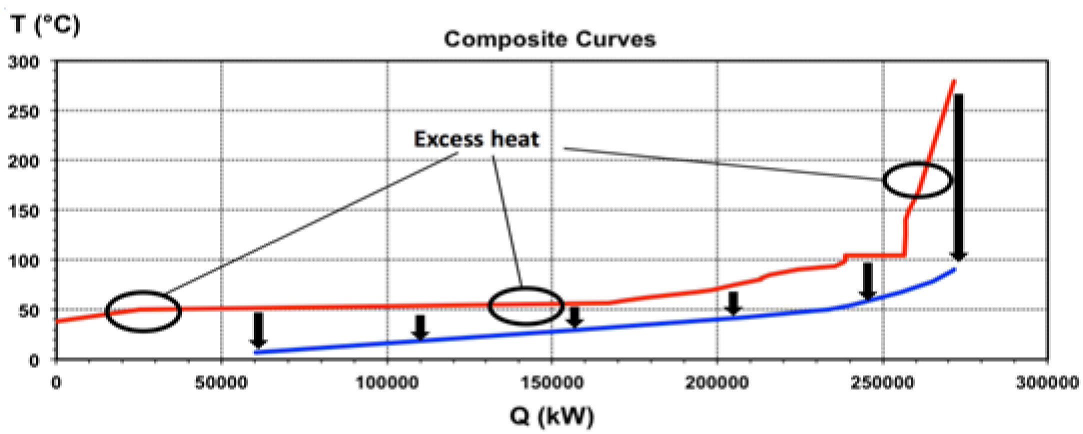
Step 2. In this method the CC only represents the net process demands of hot or warm fresh water. All cold streams' start temperature is set to the inlet temperature of the fresh water. The target temperature is set to the process demand temperature. Defining the cold CC like this, the slope will continuously increase, as the slope is equal to 1/F*Cp.

Step 3. Shift the cold CC leftwards until a user-defined ΔT_{min} is reached. The part of the hot CC that overshoots on the right of the cold CC is the theoretical maximum of Q_{excess}.

Step 4. Heating of fresh water to the different tank temperature levels (TTL's) in the system composes the tank curve. All fresh water s heated from the fresh water inlet temperature to the temperature levels where tanks are placed in the system. The number of stream intervals in the tank curve is therefor equal to the number of tanks in the HWWS. The tank curve has the same heat demand as the original cold CC. The curves coincide at the TTL's, as well as the start point.

Step 5. Maximize the amount of excess heat by varying the number of tanks and their temperature levels, as well as the ΔT_{min}.

Below a schematic picture describing the purpose of the tank method is displayed.



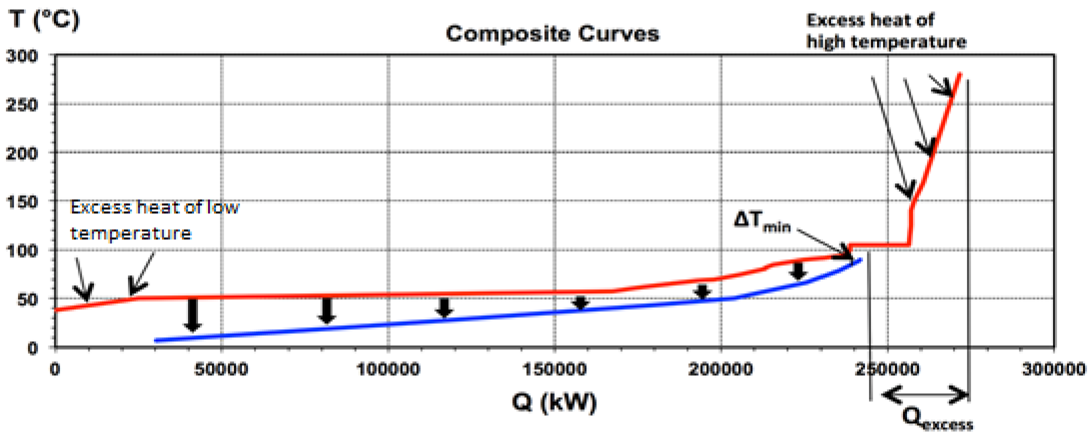


Figure 7a) curves that show how the temperature of the cooling demands, which could be used for Q_{exces}, varies.

Figure 7b): Shifting the tank curve left until reaching the defined ΔT_{min} yields the maximum usable Q_{exces}

The tank curve is applied after the design of the internal heat-exchanging system is finished and it provides a forecast of how to much excess heat that can be released if the secondary heating system is optimized. There might be several suggestions regarding how to utilize this excess heat from the process. These will be discussed later in this report. [Nordman et al. 2004-12-28]

3.2 Extraction of data

As all parts of the new process were not designed when data were collected, certain parts of the new site had to be estimated by scaling up streams at the current mill. This was achieved by calculating the heating or cooling demand for specific streams, which was then multiplied by 2.11, which is the production scale-up factor (increase from 425000 to 900000 ADt/y).

It was decided that all data should be gathered for a winter case. This case was defined between 30th of October 2014 to 12th of February 2015. This means that not all months of the year are represented in the analysis, but rather the one seasonal extreme. From the start of the project the idea was to cover both a winter and a summer case, but to start with the winter case, when the energy consumption of the plant is at its maximum. Though, when the work proceeded it was soon realised that there would not be enough time to evaluate a summer case as well.

When data was gathered for a specific stream, an averaged value was taken for the specific period. From the process factory data it could be seen when there was a production stop or disturbance. The data from these days or hours were omitted when averaged values were calculated. After the averaged values for the existing process were calculated they were scaled up to meet the higher demands for the reconstructed plant.

The major part of the data for the reconstructed plant has been gathered from different suppliers. Flow sheets, performance balances and predicted performances for the new bleaching unit, new digester, new evaporation unit and new drying machine have been used to calculate the necessary data for the pinch analysis. The data that was not presented from the quotations had to be taken from the process factory data and to be scaled up to meet the higher production capacity. Among these latter streams, the most important were the green liquor cooler and both the turpentine condensers.

Data for the secondary heating system, such as temperatures of the feed water tanks and hot water tanks, has been gathered based on estimations on the existing plant made by consultants.

3.3 Extra data reconciliation

For many parts of the new process the stream data was not complete when data was gathered. Quotations from the different equipment producing companies were still evaluated and all equipment descriptions were not yet specified.

In order to acquire the specific data, energy and mass balances had to be performed with the information specified and in some cases assumptions had to be made in order to be able to specify certain data. Description of assumptions and calculations performed in different parts of the process are presented below.

3.3.1 The digester

From the quotations regarding the cooking unit some assumptions had to be made. The total white liquor flow into the cooking unit was specified, but assumptions regarding how the flow was divided between the impregnation-vessel and cooking unit had to be made. It has been assumed that 50 % of the total flow goes to the impregnation vessel and 50% to the cooking unit. From the flow to the cooking unit, assumptions were made so that 60% goes to the top of the unit and 40% to the economizer heat exchanger, before entering the middle of the cooking unit.

When calculating the amount of flash steam from the flash-tank to the chip bin it was assumed that the pressure in the flash-tank would be lowered to such a degree that the extracted steam would cover the energy demand in the chip bin. Since a winter case is investigated it was assumed that the chips contains 55% frozen moisture, a value estimated by a senior process engineer at Östrand. From the calculations it was noticed that the flash steam from the flash could cover the entire steam demand, hence no LP-steam is needed in the chip bin.

3.3.2 The bleaching process

From the quotations regarding the bleaching unit, some assumptions had to be made. The amount of MP-steam needed in the oxygen-step and the Q/D1-step was assumed to be 0.1 tonne steam/tonne pulp for a temperature increase of 5°C. When determining the amount of pulp leaving together with the wash water, in between the bleaching steps, it was assumed that 3.5% of the pulp mass is washed away.

3.3.3 Evaporation plant

Concerning the new evaporation plant, the proposal presented in “the project” has been used as a calculation basis. In this suggestion the stripper column is integrated into the evaporation plant. Since the new evaporation plant will be constructed according to the latest technology, there are no opportunities for re designing that part of the process. It has therefore been decided that the steam demand for this process will be viewed as irreplaceable. What this really means is that the evaporation plant is viewed as a “black box” that cannot be further integrated to the rest of the process. Also all condensate from the evaporation unit is recycled and the “clean” condensate is lead to the bleaching unit and the “dirty” condensate is lead to the green liquor caustification plant. The steam requirements for the evaporation process are treated in the same manor as the steam that is injected directly into the process but with a temperature difference, since the steam is not directly injected to the process.

3.3.4 TM5, TM6 and CTMP dryer

The old drying machine TM5 will be used with low-pressure steam instead of medium-pressure steam, as it is today. In that way the plant will save energy. The performance for both TM5 and TM6 are assumed to be similar in the calculations. In order to find the required mass flow of air, a balance with the amount of removed water was used. The temperature of the leaving air is a soft target that was specified to a temperature just above the dew point (60°C at atmospheric pressure) for the humid air with the given absolute moisture content of the air, so that there will be no condensate within the process. To calculate the energy content of the air from the dryers the enthalpy at the inlet and outlet temperatures were used.

3.3.5 District heating

Today Östrand supplies Timrå and Sundsvall with district heating and will continue to do so also after the reconstruction. Östrand is committed to supply E.ON in Timrå with a certain amount of district heating and they also have a commitment to deliver a confidential amount of district heating to SEAB in Sundsvall. These streams are included in the pinch analysis as cold streams. After the reconstruction of the mill the plant is likely to be able to increase its production of district heating. This increase is however not included in the basic plant data set, rather it is treated as a variable that can be maximized.

3.4 Stream representation

From the gathered information, stream data was extracted and can be found in Appendix I as hot and cold streams. Some separate streams that can be lumped together are represented as one, in order to reduce the number of streams and make the analysis easier. One example of that is the demand of process water at different temperatures.

Start and end temperatures for streams can be organized as either hard or soft target, where hard means that a temperature is targeted and cannot be changed and a soft target is a temperature, that can be decided in order to optimize the certain process from an energy perspective. One example of a hard target is the temperature into the bleaching process and one example of soft target is the moist air out from the drying machines.

Another important factor is to distinguish between the streams that need steam directly into the process, i.e. in the chip bin and feed water tanks, where steam is injected directly into the process and cannot be replaced by other sources of heating, and streams that use steam as heating medium. When steam is used directly in the process and cannot be replaced by other sources of heating, the stream is represented as a cold stream at the steam condensing temperature. However, when steam is used for heating purpose only i.e. could be replaced with another source of heating; the heat demand is represented as a cold stream at its start and end temperature. The temperatures for these streams are simply given as the start and end temperature of the heated stream.

Different values for minimum temperature difference for heat transfer are assigned depending on of the type of fluid to reflect different heat transfer coefficient (i.e. the lower the heat transfer coefficient, the greater the minimum temperature difference constraint). The values used in this thesis are taken from E.Axelsson (2008) and represented in Table 1. In the cases where steam is injected directly into the process, the temperature difference between the steam and the cold stream is set to zero in the used program. [E. Axelsson 2008]

Table 1 Minimum temperature difference for different mediums, when heat exchanged.

Fluid	$\Delta T_{min}/2$ [K]
Live steam	0.5
Contaminated steam	2
Clean water	2.5
Contaminated water	3.5
Steam with non-condensable gases	4
Air	8
Flue gases	7
Glycol	3
Moist air	7

3.5 Design method

There were two angles from which the design process could be initiated. Either the streams could be specified and a grass root design could be performed, or the prospective heat-exchanging network could be used as a base for a retrofit. The second procedure was followed here since the prospected design already included the numerous heat exchange limitations introduced by practical process constraints. By first constructing the prospected heat exchanger network, the magnitude of the pinch violations could also be identified. This information was later used in the process to apprehend the potential for reduction of energy usage. This means that no MER network was constructed during this thesis. This was simply because it would not be possible to construct a MER without violating the technical limitations at in the production. Rather the tool of pinch analysis has been used to magnify the possible improvements of the HEN through quantification of the pinch rule violations within the system. In figure 8 the design approach and methodology of this thesis is visualised.

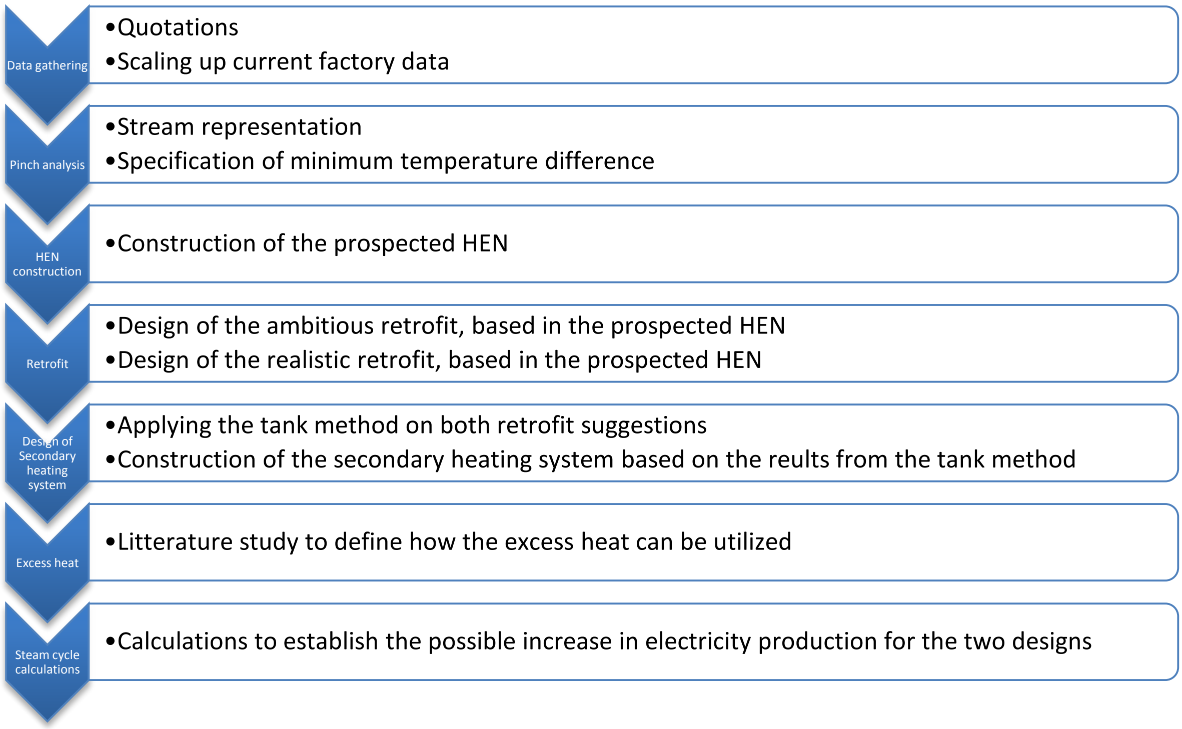


Figure 8 The design approach used for this thesis work

The cooling demand remaining, after the heating demand for cold streams is fulfilled, is cooled away with cold utility streams at same temperatures as the secondary heating that cools them in reality. In that way the abundance of warm water at different temperature levels is represented.

As hot utilities, steam at the specified temperatures and pressure-levels were used. In this way the heat balance over the future plant could be performed. It is important to remember to set the minimum temperature difference, for the streams where steam is injected direct to the process, to zero. Required amount of steam at different pressure levels was calculated and the excess warm and hot water in the different tanks could be calculated. To be able to categorize the "pinch rule violations" in the prospective heat-exchanging network, a built-in function in "Energy Analyser" was used. These violations were, as mentioned, used as a base for new heat exchanging solutions.

When performing the process integration via direct heat exchanging, considerations regarding practical limitations had to be considered. Therefore decisions to present two alternative solutions were taken.

- The first solution is more ambitious, from an energy recovery point of view, and focus has been put into reducing energy consumption as much as possible, without violating any technical restraints. All heat-exchanging solutions are realistic and viable, but they may be expensive or un-practical to implement.
- For the second design presented focus has been put into finding process integrations that are simpler and more likely to be implemented. For instance there are several improvements that could be applied to the recovery boiler that will not be considered in the project, since the recovery boiler only will be re-constructed, meaning that large changes will be very expensive. In the end

this means that the second design will save less energy compared to the first design.

When the ambitious and realistic retrofits had been defined, the secondary heating system, in the two re-designs was optimized using the “tank method”. As described in chapter 3.1.2, the tank method provides a forecast, regarding possibilities for extraction of high quality excess heat. In order to actually exploit this heat, it is therefore necessary to modify the suggested HEN designs again, after the system has been evaluated with the tank method. When using the tank method it is discovered at which temperatures the maximum excess heat is emitted; thereby a study regarding ways to utilize the heat can be performed, instead of using the heat directly for district heating.

In the paper by Nordman, mentioned in chapter 3.1.2, he discusses the fact that maximizing the excess heat does not have to be the best solution. If a small minimum temperature difference is applied to the secondary heating system, the available excess heat will be large with the drawback of large heat exchangers, which mean large investment costs. Hence, there is a trade-off between heat exchanging area and excess heat and thus an economic evaluation has to be performed in order to draw any definite conclusions regarding optimum designs. Another aspect that becomes important to consider, especially when applying the tank method to a retrofit case, is the number of tanks. If there already exists a certain number of tanks at the production site, it might be beneficial to use them when optimizing the secondary heating system. An evaluation regarding the temperature levels of the tanks should also be performed. There are clear perks of placing tanks at temperature levels where there is a process demand, even if it is not optimal to maximize the excess heat. In that way the problem of having to mix hot secondary water with cold feed water is avoided. Something that is preferable both for controllability and investment reasons. [Nordman et al. 2004-12-28]

The Visual basic code that has been used to perform all calculations related to the tank method could hypothetically be used for a design involving four, or more, tanks. However, the calculation time would be extremely long. For this study no solutions involving more than three tanks have been evaluated. Partly because the limitations of the code regarding time, but mainly since the early results clearly showed that there would be no reason to implement a solution containing more than three tanks, for any of the designs, using a realistic minimum temperature difference.

When the two designs were completed, the energy savings were evaluated for both cases. The amount of excess steam at different pressure levels and the excess heat was quantified. Since the production of black liquor and bark was known beforehand, the total mass flow of steam was specified. This information together with calculations for a steam cycle was used to apprehend the magnitude of the possible increase of electricity production in the two cases. In this thesis it has been assumed that electricity is the energy carrier with the highest values for Östrand, thereby the electricity production should be maximized.

Finally opportunities regarding the best way to exploit the excess heat below the pinch were evaluated. The first priority is to make steam of the excess heat and then to make district heating with the remaining excess heat.

3.6 Software's

Below you can find general descriptions of the computer software's that have ben utilized in the thesis.

3.6.1 Pro PI

For this thesis Microsoft Excel add in program "Pro PI", developed by Chalmers Industriteknik AB, has been used. By adding data of the start and target temperatures and energy content for the different streams, Pro PI can create the composite and grand composite curves for the studied process. The program also provides the pinch temperature and the minimum hot and cold utility demand for the process. The program also produces an image of the streams in the process that can be used to design heat exchanger networks and visualise pinch rule violations.

3.6.2 Aspen Energy Analyser

The software Energy Analyser was developed by "Aspentech" and is used to minimize energy consumption in processes. Similarly to "Pro PI", the software constructs the composite curves and the grand composite curves when provided with the necessary stream data. The program can also be used to design heat exchanger networks between the specified streams. Unlike Pro PI, previously specified streams can be changed during the design process, without having to redo the heat-exchanging network. It is also possible to split streams in Energy Analyser, without redoing the network. These properties makes Energy Analyser easier to use compared to Pro PI and therefore the main part of the work has been performed using this software.

3.6.3 Visual basic code for tank method

To simplify the necessary calculations for the tank method, a visual basic 6.0 code, developed by Markus Lindahl in 2003, has ben used. The visual basic file works as a macro in Microsoft Excel that can be used together with Pro PI. The code is developed as an algorithm with the objective of finding the theoretical excess heat and the real excess heat than can be released for a certain process. By specifying the minimum temperature difference for the process the code calculates the theoretical maximum excess heat. By then specifying the number of tanks, and knowing that the temperature of the last tank must be the same as the temperature of the process demand with the highest temperature, the temperature of the other tanks are altered, striving at fitting the tank curve so that 100% of the excess heat can be used. If it is not possible to release all of the theoretically calculated excess heat, the code finds the temperature of the other tanks that leads to the case were most of the theoretical excess heat is released. Figure 9 displays a scheme that describes the algorithm used in the code.

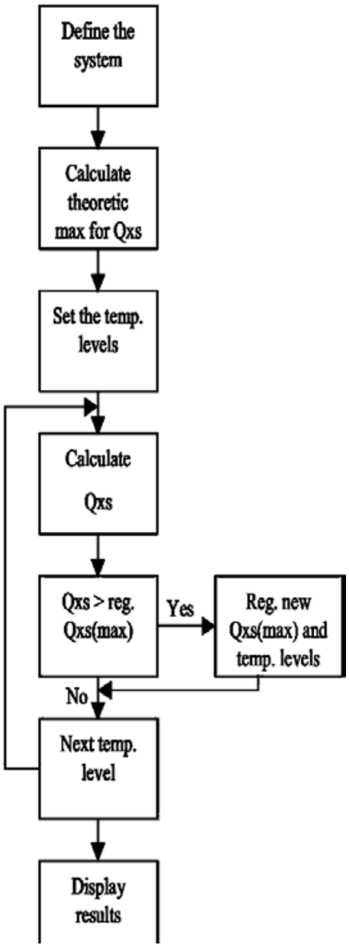


Figure 9 The algorithm that the Visual Basic code is based on. [Lindahl 2003]

4 Results

This chapter starts by providing key data and Pinch Analysis curves for the reconstructed pulp process at Östrand. After this, the results for the prospected design are presented and the main pinch violations are discussed. The latter provide the base for the retrofits that are presented after the base case design. A careful review of the solutions in both the retrofits are then presented, describing the reasons behind all decisions. After this, an evaluation of the results for the tank method are presented, describing how the decisions regarding the number of temperature levels and the choice of minimum temperature difference within the secondary heating system were taken. The final HEN designs are then presented, together with the results regarding excess heat production and the possible increase in electricity production for the different designs.

4.1 Key data

Key data for the process is presented in table 2.

Table 2 Key Data for the old and for the reconstructed pulp mill Östrand

Data	Old plant	New plant
Kraft pulp production	425 000 ADt/y	900 000 ADt/y
CTMP production	95 000 ADt/y	95 000 ADt/y
Power generation capacity	75 MW	200 MW
District heating SEAB	~ 16 MW	16-60 MW
1District heating Eon	16 MW	16 MW
Wood consumption (approximate)	2600 000 fm^3	4975 000 fm^3

These are the values presented by SCA Östrand, used when seeking permission for expanding their production. As can be seen the electricity production is expected to substantially increase with the enlarged pulp production and the expected number for increased electricity production for the prospected design is 158.7 MW. The electricity production of the plant increases more than linearly, compared to the increase of pulp production. This is due to the fact that the process equipment at the new site will be more efficient than for the old plant, thus increasing the excess steam production, and thereby the electricity production, even more

Regarding production of district heating, the maximum district heating demand for the E.ON network is already provided by Östrand, hence no increase is planned for this network. However, for the SEAB network, there is room to increase the district heating delivery from the mill, the actual numbers are however confidential.

4.2 Heat recovery targets for the reconstructed mill

The CCs and GCC of the reconstructed plant are presented in figure 10 respectively 11. The minimum hot utility for the prospective design is 223.2 MW and the minimum cold utility is 30.5MW, the pinch temperature is 113.8°C.

From the composite curves in figure 10, it is possible to discern the levels of the low and medium pressure steam demands, as well as the final condenser.

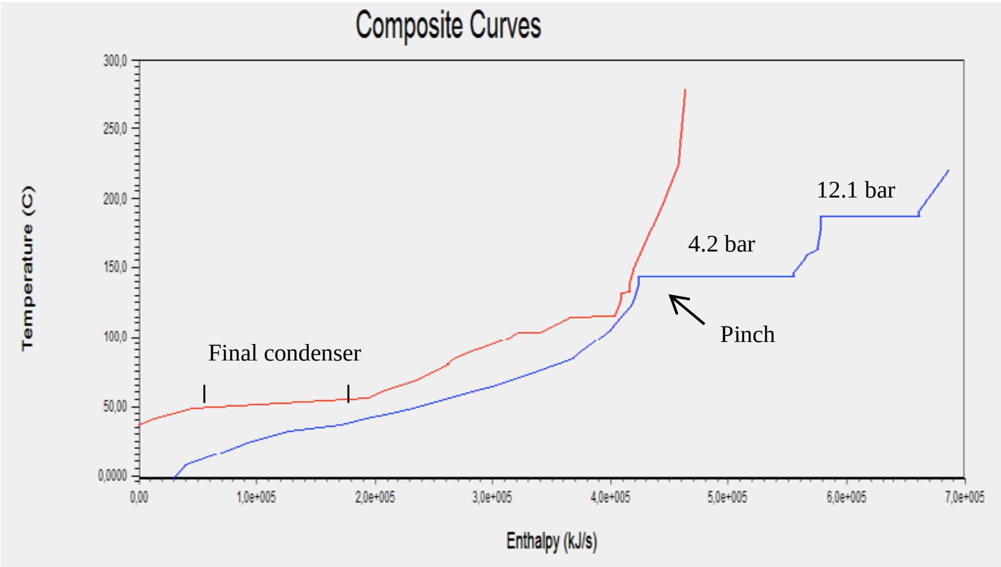


Figure 10: The Composite Curve for the reconstructed plant Östrand

In the grand composite curve displayed in Figure 11, the temperatures are shifted and the composite curves are merged together. The pinch temperature is located at zero enthalpy, i.e. where heat balance occurs, as marked in figure 11. Where “pocket” is marked out in figure 11, there is room for heat recovery between two or more temperature intervals and therefore such heat recovery shall occur at temperature differences larger than the minimum. This means in principle that the heat recovery occurs at the expenses of large exergy losses, which can be on the other hand recovered into work if an appropriate utility system such as a steam network that includes the option of power recovery by steam expansion is appropriately designed to exploit such pocket. The final condenser provides around 130 MW and is thereby a large heat source, as is illustrated in figure 10 and 11. The steam levels for medium- and low-pressure steam that is required as a process demand are marked out in the graph.

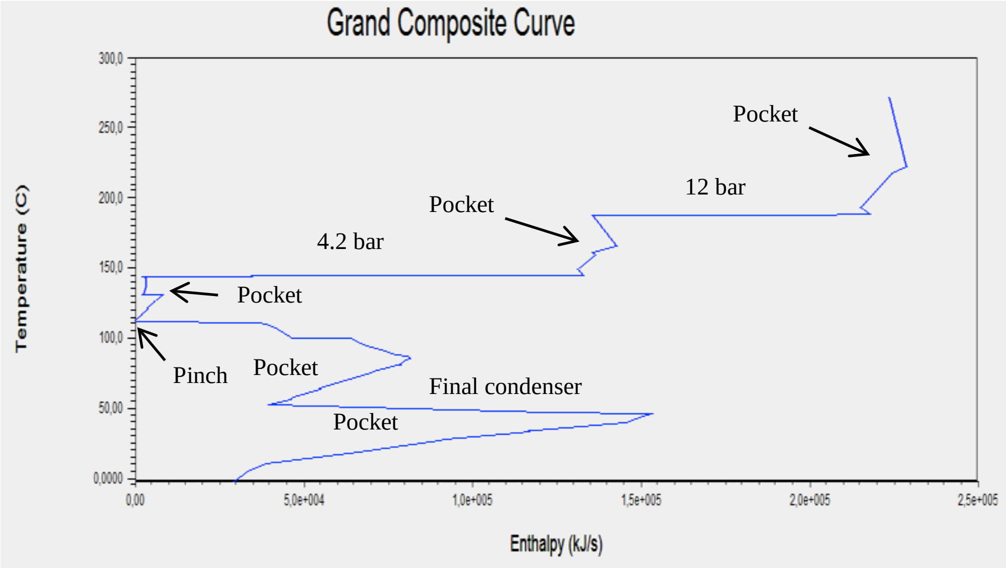


Figure 11: The Grand Composite Curves for the reconstructed plant Östrand.

4.3 The prospective HEN at the reconstructed plant

The prospected HEN was constructed for the plant. From this network valuable information were obtained. Figure 12 displays the prospected HEN.

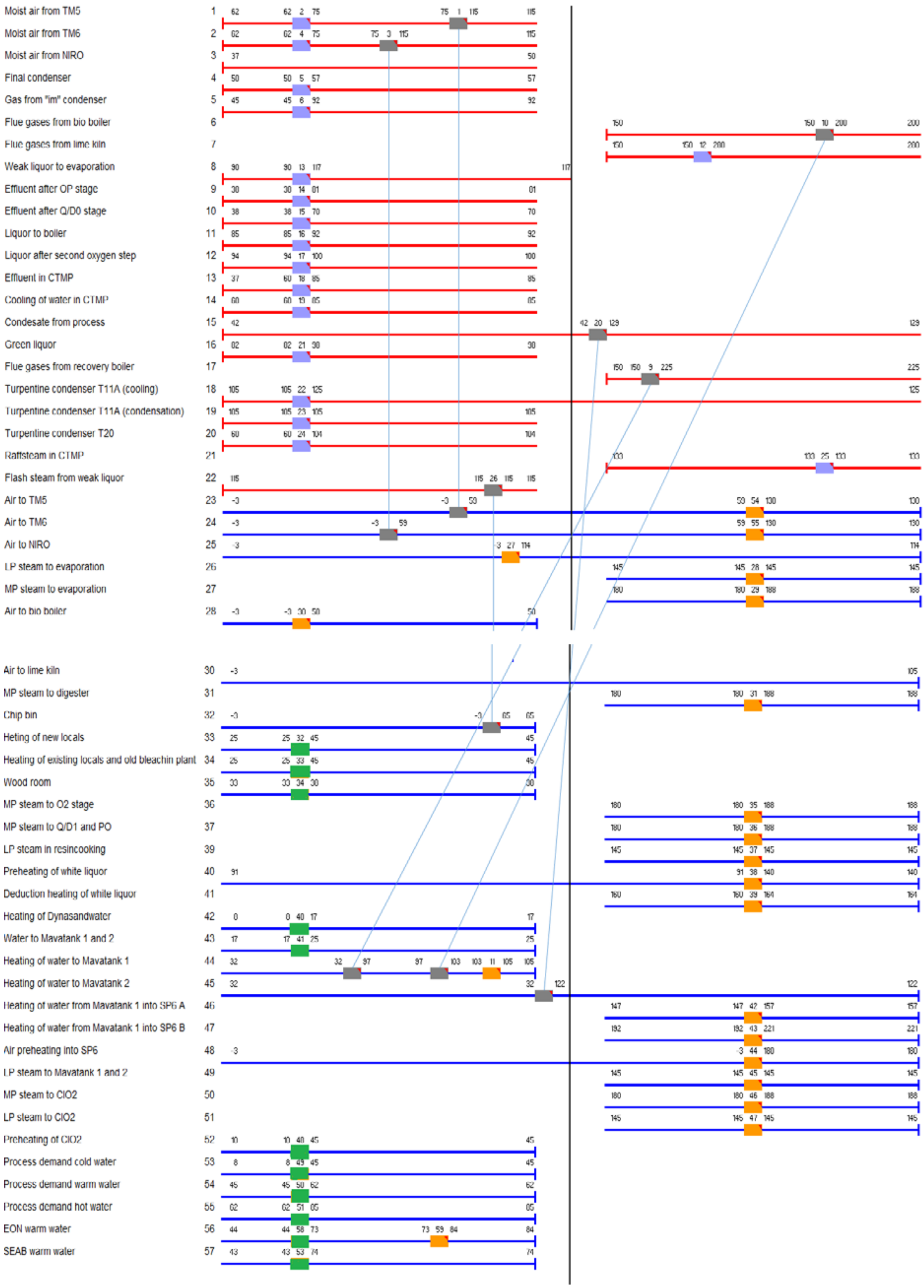


Figure 12 The prospected HEN design. The orange heat exchangers are using steam, the green heat exchangers are heated by water from the secondary heating system and the purple heat exchangers are heating water in the secondary heating system. The thick dividing the system into two parts represents the pinch temperature

In table 3, the largest pinch violations for the prospective heat exchanger-network are displayed. A complete list of pinch violations for this design can be found in Appendix II. The sum of the pinch violations was calculated to 100.1 MW. By comparing the minimum utility usage with the actual utility usage for the prospective design, it is possible to apprehend the design. The number for the actual utility usage decided with the minimum utility usage is 0.23 for cold utilities and 0.7 for hot utilities.

Table 3 The largest pinch violations in the prospective heat-exchanger design for the project

Function	Q [MW]	Type of violation
Feed water heated with flue gases from recovery boiler	30.2	Heat exchanging across the pinch
Pre-heating of combustion air to SP6 with LP-steam	20.8	Heating below pinch
Heating of cooling water with flue gases from limekiln	9.7	Cooling above pinch

4.4 Retrofit suggestions

In this chapter two retrofit design suggestions are presented. Later in the process these two designs are used as bases for an improved design of the plants secondary heating system by the use of the "tank method".

4.4.1 Ambitious retrofit

After the reconstruction, the production facilities at Östrand will consist mainly of new equipment, however some parts of the current factory will be used also after the reconstruction, for instance the Recovery Boiler. This means that the opportunities regarding heat exchanging are somewhat limited by technical constraints. The area on which the plant is located is limited and already contains the current production facilities and some remaining old production buildings, a fact that affects the possible spatial arrangement of the HEN.

In this chapter a HEN design aiming at minimizing the energy consumption, but still following the technical limitations, is presented. With this ambitious retrofit applied, pinch violations are reduced from 100 MW to 40.4 MW, corresponding to a reduction of the heat demand with 59 MW or 59%.

4.4.1.1 Recovery boiler

The main "pinch violation" in the reconstructed plant is due to the fact that the high quality heat in the flue gases from the recovery boiler is used to pre-heat low temperature feed water. Since the boiler feed water-preheating starts below the pinch temperature, this heat transfer match translates into heat transferred through the pinch.

To remove this violation in the proposed ambitious design, these flue gases are used to heat the feed water to the recovery boiler at a higher temperature, i.e. only above the pinch temperature. The heating demand for the feed water to the recovery boiler below the pinch, which previously was fulfilled with the hot flue gases, are covered using 85°C hot water and low-pressure steam in this design. This solution leads to an increased demand of low-pressure steam. However, this is still beneficial for Östrand, as the medium pressure steam is of higher value than the low-pressure steam since it can be used to produce more electricity.

The remaining heat in the flue gases is used to heat the combustion air above the pinch via direct heat exchanging (which in the prospected design is instead achieved by steam heating). In this way the consumption of medium pressure steam, at the site, is reduced.

The remaining heating requirements for the combustion air to the recovery boiler is covered by direct heat exchanging with the “im-condenser”, the flue gases from the bio boiler and with low-pressure steam. The heat in the flue gases from the bio boiler that is not utilized to heat the combustion air to the recovery boiler is used to heat combustion air to the bio boiler through direct heat exchange. The remaining heating demand for the combustion air to the bio boiler is covered by heat exchanging with 85°C hot water from the secondary heating system.

4.4.1.2 Limekiln

Another large pinch violation in the prospected design is associated with the high temperature heat from the limekiln flue gases which is used to produce 85°C hot water, i.e. cooling above the pinch.

It is difficult to understand why this heat must be cooled away with secondary heating unless technical limitations regarding what can be done with this stream are taken into account. In fact, the flue gas from the limekiln contains a lot of impurities and it is therefore not recommended for direct heat exchange with other sensitive process streams. Hence, this pinch violation cannot be avoided through direct heat exchanging to heat a process demand.

An investigation of possible uses of the heat in the flue gases from the limekiln has been performed as a part of the project. The study shows that it is possible to use the heat either to produce hot water, or to raise low-pressure steam [Anita Markusson et al. 2014]. During this evaluation, it has been assumed that the heat in the limekiln flue gases is used to produce hot water, mainly because this has been the main indication at Östrand. However, since the flue gases from the limekiln is the stream with the highest temperature that is cooled through the secondary heating system, this stream is the one that could be mainly used for other purposes than production of warm water provided that there is excess heat available in the process. It could then be discussed if it is beneficial to produce low-pressure steam instead of hot water from these flue gases.

4.4.1.3 CTMP

In the prospected HEN design, refiner steam from the CTMP plant is used to produce warm water, which leads to a large pinch violation. For the ambitious retrofit we used this steam mainly to heat white liquor to the digester and secondarily to use in the drying machines above the pinch temperature. However, in doing so, some heat is transferred through the pinch when heating the white liquor. This is a pinch violation that is hard to avoid as the refiner steam is of a temperature that is not needed within the process.

Another option would be to utilize all the refiner steam in the steam batteries for TM5 and TM6. However, this would lead to an even larger heat transfer through the pinch and more heat exchangers. To cover the heating needs for the air to the CTMP dryer, the exhausted air is heat exchanged with the incoming air, before the steam batteries.

4.4.1.4 Make up water

In the ambitious design the feed water from the Dynasand filters is heated with 45°C water from the secondary heating system instead of 85°C hot water. The remaining heating demand for the make-up water is separated between the make-up water tank to the recovery boiler and the tank to the bio-boiler. Make-up water to the bio-boiler is heated by direct heat exchange with the condensate stream from the bleaching process, in the same way as it is envisioned in the prospective design.

This solution entails a pinch violation as heat is transferred through the pinch but due to the small entity of this violation it was concluded that there are no real advantages in resolving such violation. The make-up water to the recovery boiler is heated by direct heat exchange with the weak liquor from the digester. This solution reduces the pinch violations substantially. The remaining heat in the weak liquor is used to produce 85°C hot water.

Effluent from the bleaching stages is not used for any direct heat exchange. The effluent is dirty and it is undesirably to carry it through the plant. Therefore all the effluent is used to produce hot and warm water instead. Figure 13 shows the re-designed heat-exchanger design for the ambitious case, direct heat exchanging is visualised as a line between a hot and a cold stream.

Figure 13 The total HEN for the ambitious retrofit. The orange heat exchangers are using steam, the green heat exchangers are heated by water from the secondary heating system and the purple heat exchangers are heating water in the secondary heating system. The thick dividing the system into two parts represents the pinch temperature.

The remaining pinch violations in this design are those, which, for various technical reasons, cannot be resolved. A complete list of these violations is presented in Appendix II.

4.4.2 Realistic retrofit

For the “realistic” retrofit no changes concerning the feed water to the recovery boiler were considered. The current Recovery Boiler will be reconstructed and hence a new Recovery Boiler will not be installed, a fact that limits the possibilities regarding process integration.

4.4.2.1.1 Recovery boiler

What can be done in terms of improved heat recovery is to use the hot flue gases to pre-heat the incoming combustion air to the recovery boiler. If the recovery boiler were constructed from the beginning, this would be achieved through a direct heat exchanging solution. However, in realistic retrofit, there is no room for a solution of this type and the heat exchanging has to be solved with a closed water heating and cooling system. The rest of the changes that are applied to the recovery boiler in the ambitious retrofit are possible to implement, but the cost would be most probably rather high. In a similar way as in the recovery boiler, the flue gases from the bio-boiler are used to pre-heat the combustion air.

4.4.2.2 Make up water

Similarly to the ambitious case, secondary heating water at 45°C is used to heat the water from the Dynasand filters. Also, instead of using steam to pre-heat the combustion air to the bio boiler, 85°C hot water is used in order to reduce steam consumption. The pipeline required to transport the makeup water to the recovery boiler, in order to heat exchange it with the weak liquor might be quite expensive, therefore this solution was not considered in this realistic HEN design. Instead of using direct heat exchanging, 62°C and 85°C hot water is used to heat the feed water as much as possible, the remaining heating is covered using LP steam.

4.4.2.3 CTMP

The refiner steam is used to pre-heat white liquor as it is in the ambitious re-design. This is a realistic usage of the steam, previously investigated by Östrand. Unlike the ambitious case, the remaining refiner steam is used to preheat air to the CTMP dryer instead of using it above the pinch in TM5. This is a solution more desired from Östrand, mainly due to controllability reasons such as to keep the CTMP and Kraft processes separated if possible. A reduction of the steam consumption in the CTMP dryer is also achieved by heat exchanging the incoming air with the outgoing air.

If the “realistic retrofit” is implemented, pinch violations can be reduced to 65.6 MW or with 34.4%. A schematic figure representing the heat exchanger network design for the realistic case is displayed in figure 14.

Figure 14 The total HEN for the realistic retrofit. The orange heat exchangers are using steam, the green heat exchangers are heated by secondary heating and the purple heat exchangers are heating the secondary heating system.

The remaining pinch violations are those who, for various technical and practical reasons, cannot be solved. A complete list of these violations is presented in Appendix II.

4.5 Design of the secondary heating systems

The suggested designs are improved through the use of the tank method. As described in chapter 3.1.3 this method provides targets regarding how much excess heat that theoretically can be liberated at high temperatures, with a specified number of tanks and specified minimum temperature difference. However, to be able to utilize this heat, the HEN for the secondary heating systems has to be modified.

The final designs for the arrangements of the secondary heating systems for the ambitious and realistic retrofits are presented below. These designs are modified from the previously presented designs in order to produce as much of the forecasted excess heat, calculated with the tank method, as possible.

In this project, no economic aspects have been included in actual calculations and therefore it is impossible to validate the decisions regarding the optimal design of the HEN and of the secondary heating systems. Nevertheless, the design of the secondary heating systems has been performed for several values of temperature difference and number of tanks but due to lack of time only one suggestion for each design has been further evaluated.

4.5.1 Ambitious retrofit

The visual basic code described in chapter 3.6.3 was used to perform calculations with different values for ΔT_{min} and varying the number of tanks from 1 to 3 for each ΔT_{min} value. The results are presented in the tables 4 to 7.

Table 4 Results for the tank method simulations using a minimum temperature difference of 1°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	54	28756	53249	85	105
2	100	53249	53249	85, 68	86
3	100	53249	53249	85, 69, 8	90

Table 5 Results for the tank method simulations using a minimum temperature difference of 5°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	40	18458	46186	85	105
2	100	46186	46186	85, 66	90
3	100	46186	46186	85, 66, 5	90

Table 6 Results for the tank method simulations using a minimum temperature difference of 10°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	16	5562	34534	85	223
2	100	34534	34534	85, 62	95
3	100	34534	34534	85, 63, 7	95

Table 7 Results for the tank method simulations using a minimum temperature difference of 15°C. x means that there is no existing solution.

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	X*	X	X	X	X
2	96	30272	31395	85, 55	105
3	100	31314	31314	85, 81, 54	105

Q_{XS} is the available excess heat and $Q_{XS, Max}$ is the maximum available excess heat at that specified minimum temperature difference. T_{Min} is the lowest temperature of the available excess heat and T_{Tank} is the temperature in the specified tanks.

As can be seen from the tables, it is possible to extract 100% of the available excess heat, for a case with a minimum temperature difference of 10°C, using two tanks. Doing so, it is also possible to place the second tank at a temperature of 62°C, which is a temperature that is needed within the process. Following to the same reasoning as described in chapter 23.5 this means that less mixing of streams with different temperatures is needed, which is beneficial for Östrand, since investments in an extra mixing tank should be avoided if possible.

For a case where the temperature difference is 15°C instead of 10°C, it would be possible to liberate 100% of the theoretical excess heat at high temperature by increasing the number of tanks to 3. This would result in a case where less heat transfer area is required, which would mean less investment costs but it would also substantially reduce the amount of excess heat that can be utilized.

It should be noticed that it would also be possible to lower the minimum temperature difference to 5°C or 1°C, and thereby be able to extract even more heat, but with the drawback of a larger investment required in heat exchanger.

In this work, two tanks and a minimum temperature difference of 10°C was retained for further analysis. The shifting of the tank curve for the ambitious retrofit is displayed in figure 15.

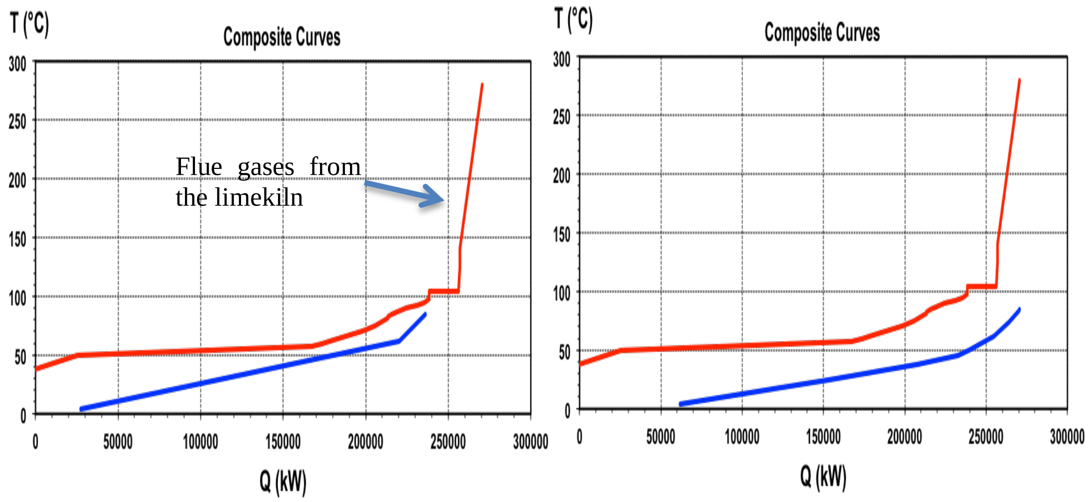


Figure 15 The un-shifted CC and the shifted tank curve for the secondary heating system of the ambitious retrofit

As can be seen from figure 12 large parts of the available excess heat is made up of the hot flue gases from the limekiln, which theoretically can be used for steam production. The lowest temperature of the available excess heat is 95°C, which is clearly enough for production of district heating.

Note that the "tank method" followed in this work follows the objective of maximizing the excess heat available at high temperatures and therefore does not take into account the actual temperature level at which this excess heat is used.

To liberate the excess heat at high temperatures, the HEN for the ambitious design had to be modified for a final design. The design was performed with the goal of releasing the calculated possible excess heat, with as few heat exchangers as possible. The result is displayed in figure 16. Only the secondary heating of the total heat exchanger network is included in figure 16, in order to get a good overview of what is changed when the design of the secondary heating system is also taken into account.

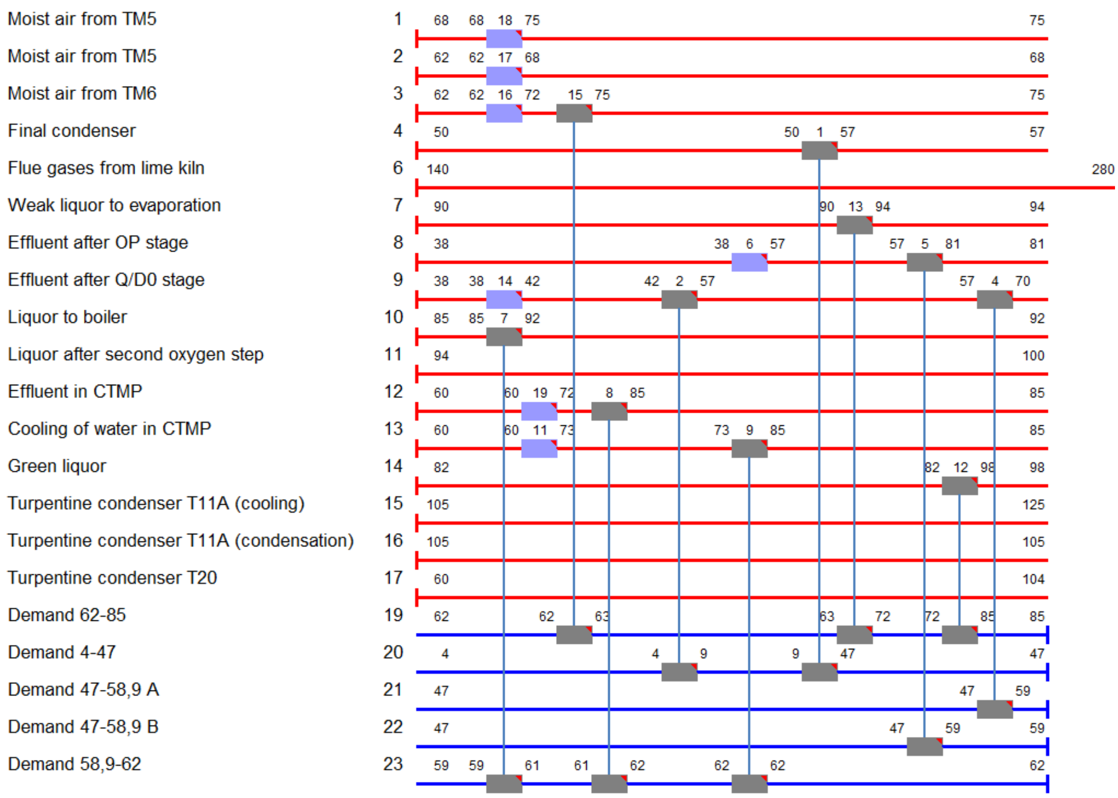


Figure 16 The final design for the secondary heating system of the "ambitious retrofit". The reason that there are five demands is that the stream from 4-62°C has been split between 47 °C to 58.9°C. There is no better alternative to represent a stream split in “Pro PI”.

For this design 95% of the theoretical excess heat from the secondary heating system is utilized, even though 100% could be utilized theoretically. The reason why not all the excess heat utilized is due to practical limitations when the HEN is designed. As mentioned, for the design with two temperature levels and a minimum temperature difference of 10°C the excess heat is available from 95°C. As some streams is in a range up to just a few degrees above 95°C, or contains proportionally small amounts of energy above 95°C, it would probably not be beneficial to invest in a heat exchanger to recover such a small amount of energy.

For this design, the unutilized excess heat is the green liquor cooler, which is in a temperature interval between 98-82°C, hence only 3°C could be utilized as excess heat. Depending on in what way Östrand decides to utilize the excess heat, it is not sure that an extra heat exchanger would have to be utilized. If, for instance, Östrand would prefer to produce district heating from all the excess heat, all the excess heat streams would be used to produce 85°C hot water and no extra heat exchanger would be required in this case. Conversely, this study has chosen to leave the question, regarding how the excess heat should be utilized, open.

The streams that are cooled with the cold utilities in figure 16 represents the waste heat of the process. The waste heat can be described as heat that are deemed to be of too low temperature to be used for any purpose within or outside the process and hence has to be cooled away. The cold streams used to cool away this heat can be characterized as the cold utility needed for the process.

4.5.2 Realistic retrofit

The visual basic code described in chapter 3.6.3 was used to perform calculations with different values for ΔT_{min} and varying the number of tanks from 1 to 3 for each ΔT_{min} value. The results are presented in the tables 8 to 11.

Table 8 Results for the tank method simulations using a minimum temperature difference of 1°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	72	55127	76100	85	101
2	100	76100	76100	85, 37	91
3	100	76100	76100	85, 37, 5	91

Table 9 Results for the tank method simulations using a minimum temperature difference of 5°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	58	43788	75491	85	105
2	100	75491	75491	85, 40	91
3	100	75491	75491	85, 40, 5	91

Table 10 Results for the tank method simulations using a minimum temperature difference of 10°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	44	29633	67013	85	106
2	100	67013	67013	85, 45	95
3	100	67013	67013	85, 39, 5	90

Table 11 Results for the tank method simulations using a minimum temperature difference of 15°C

Number of tanks	% of Q_{XS}	Q_{XS}	$Q_{XS, Max}$	T_{Tank}	T_{Min}
1	27	15463	57090	85	116
2	100	57090	57090	85, 38	100
3	100	57090	57090	85, 38, 5	100

As can be seen from the tables, similarly as for the ambitious retrofit, it is possible to extract 100% of the theoretically available excess heat, for a case with a minimum temperature difference of 10°C, using two tanks. According to the same reasoning as in the previous case, a design using two tanks and a minimum temperature difference of 10°C is applied.

Since there is a desire to have the tank temperature at a level where there is a process demand, it was decided to try to specify the secondary tank level to 45°C, as there is a process demand of hot water at that temperature. Calculations also showed that this was possible. We also tried to change the temperature of the second tank to 62°C where the second process demand is, but no feasible solutions were obtained.

The minimum temperature of the available excess heat is 95°C also for this case. The hot and cold CC, together with the shifted tank curve, for the realistic retrofit is displayed in figure 17.

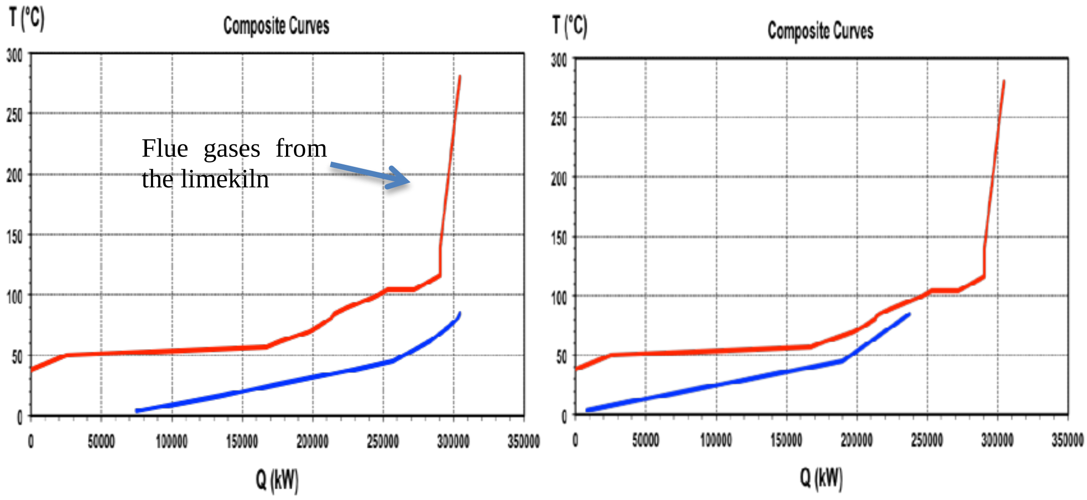


Figure 17 The un-shifted CC and the shifted tank curve for the secondary heating system of the realistic design. The arrow points out the stream that represents the hot flue gases from the limekiln.

The result for the design is displayed in figure 18, similar as for the ambitious case; it is only the secondary heating system that is displayed, as it is only the secondary heating system that is modified in this part of the thesis. The design has been performed with the goal of liberating all the excess heat at high temperatures with as few heat exchangers as possible.

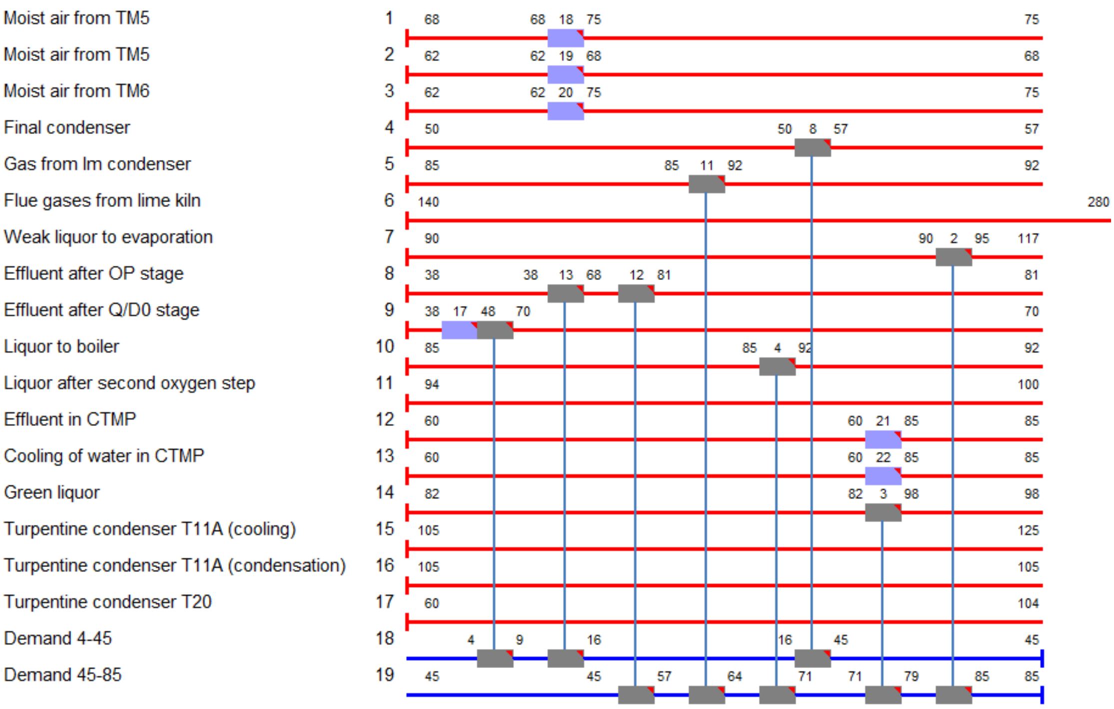


Figure 18 The redesigned secondary heating system for the "realistic retrofit"

For this design suggestion, 97.5% of the possible excess heat off 67 MW can be utilized, meaning that 65.7 MW of excess heat at high temperature is obtained. The reason why not the all excess-heat is used is that the heat in the green liquor stream that is above 95°C is used to heat the 85°C water.

It might appear strange that two of the streams that goes from 85°C is cooled away with cold utilities, when they could be used to produce heat that technically could be used for district heating. A consequence that comes from the fact that all excess heat is not liberated, due to the arguments mentioned in chapter 4.5.1. This has created a system with two streams that, according to theory, should be used for production of hot water, but now are unnecessary, i.e. they are to cold to be used to produce excess heat. Since it was not known beforehand that the two streams would not be used, it was impossible to heat exchange them in another way when the design was performed. In reality, these two stream should be used to produce 85°C that can be used to increase the possible production of district heating.

4.6 Final results

To quantify the possible increased production of electricity, steam cycle calculations has been performed. For these calculations a turbine efficiency of 0.4 has been used, provided by engineers at Östrand. Table 11 below presents the final results for reduction of pinch violations, reduction of steam usage, released excess heat and increased electricity productions, for the two designs suggested in this thesis.

Table 12 Summary of the results presented in the thesis

	Prospected design	Ambitious retrofit	Realistic retrofit
Total pinch violations [MW]	100.1	40.4	65.6
4.2 bar steam [kg/s]	67.7	56.6	59.3
7 bar steam [kg/s]	3	0	3
12.1 bar steam [kg/s]	33.2	31.4	31.3
16 bar steam [kg/s]	4.2	0	2.3
27 bar steam [kg/s]	6	4.5	6
Increase in electricity production [MW]	-	24.2	13.9
Excess heat [MW]	-	32.8	65.7

What can also be seen from the results is that the electricity production is substantially larger for the ambitious retrofit where as the excess heat production is larger form the realistic retrofit, both results comparatively expected.

Since the steam consumption is reduced further within the process for the ambitious retrofit, compared to the realistic retrofit, there is a larger excess steam production in the ambitious retrofit case. This excess steam is used to increase the electricity production, which explains why the ambitious retrofit produces more electricity. However, since the ambitious retrofit uses less hot utilities there is also less excess heat production. This is natural and can be explained with the pinch rules. If you heat below the pinch, where there is a heat surplus, the heat will have to be cooled away. In this case that heat is partly utilized as excess heat.

5 Discussion

In this part of the report a discussion regarding the methodology and results of this thesis is presented, followed by a discussion regarding possible ways to exploit the excess heat.

5.1 Validity of study

One problem regarding the validity of the study is that it is not representative for the entire production year. The production year can be divided into two seasonal extremes regarding the heating requirements for the plant, the summer and the winter case, and the heating requirements between these two cases might differ considerably. Therefore, if this thesis were to be used for further purposes, the recommendation would be to perform the similar accountings also for a summer case.

As mentioned in chapter 3.2, the data has been gathered from quotations regarding the new process equipment. This means that there is a risk that large parts of the data will be unrepresentative when the final decisions have been made regarding what equipment to use. Therefore, this study should be viewed as advisory regarding heat exchanging possibilities for the plant, rather than definite.

Another possible drawback regarding the validity of the study is the fact that certain assumptions had to be made due to the lack of some data. The new process equipment will, most likely, be more efficient than today's equipment, used to scale up the values. It is hard to determine the margin of error regarding these assumptions. What probably is safe to assume regarding the reliability of all assumptions in this thesis is that the used values regarding energy needs are rather high.

What can be pointed out, though, is that the part where the largest heat saving measures can be implemented is the parts regarding the recovery boiler. As the recovery boiler is one of the process parts that will not be replaced, the data was specified. This suggests that all calculations regarding the recovery boiler can be considered rather definite. Hence, the overall uncertainty of the study is reduced.

5.2 Evaluation of the final results

In the two chapters bellow the results of the study are reflected upon. Both the results of the used minimum temperature difference and the final outcome of the study are discussed.

5.2.1 Impact of the minimum temperature difference assumption

Since the pinch temperature affects which heat exchanging solutions that can be implemented in order to create a more energy efficient system, if the pinch rules are followed when performing the design. For some systems there might be desired heat exchanging solutions that cannot be applied at a certain pinch temperature. However, the only measure that can be applied in order to change the pinch temperature of the studied process would be to utilize another minimum temperature differences for the process.

For this thesis the minimum temperature difference was specified individually for every different kind of stream within the system. The values used were taken from a similar study performed at a pulp mill a few years ago. They were specified to create a system that recovers as much heat as possible, without requiring too large heat exchangers, which of course, as described before, always is a trade off between large capital costs and efficiency.

To evaluate the effect the used minimum temperature difference had on the outcome of the study, a sensitivity analysis evaluating the effects on the composite curves for the system when changing the minimum temperature difference was also performed. The results for this analysis are displayed in figure 19. Two cases were evaluated, using a universal minimum temperature difference of 20°C respectively 30°C.

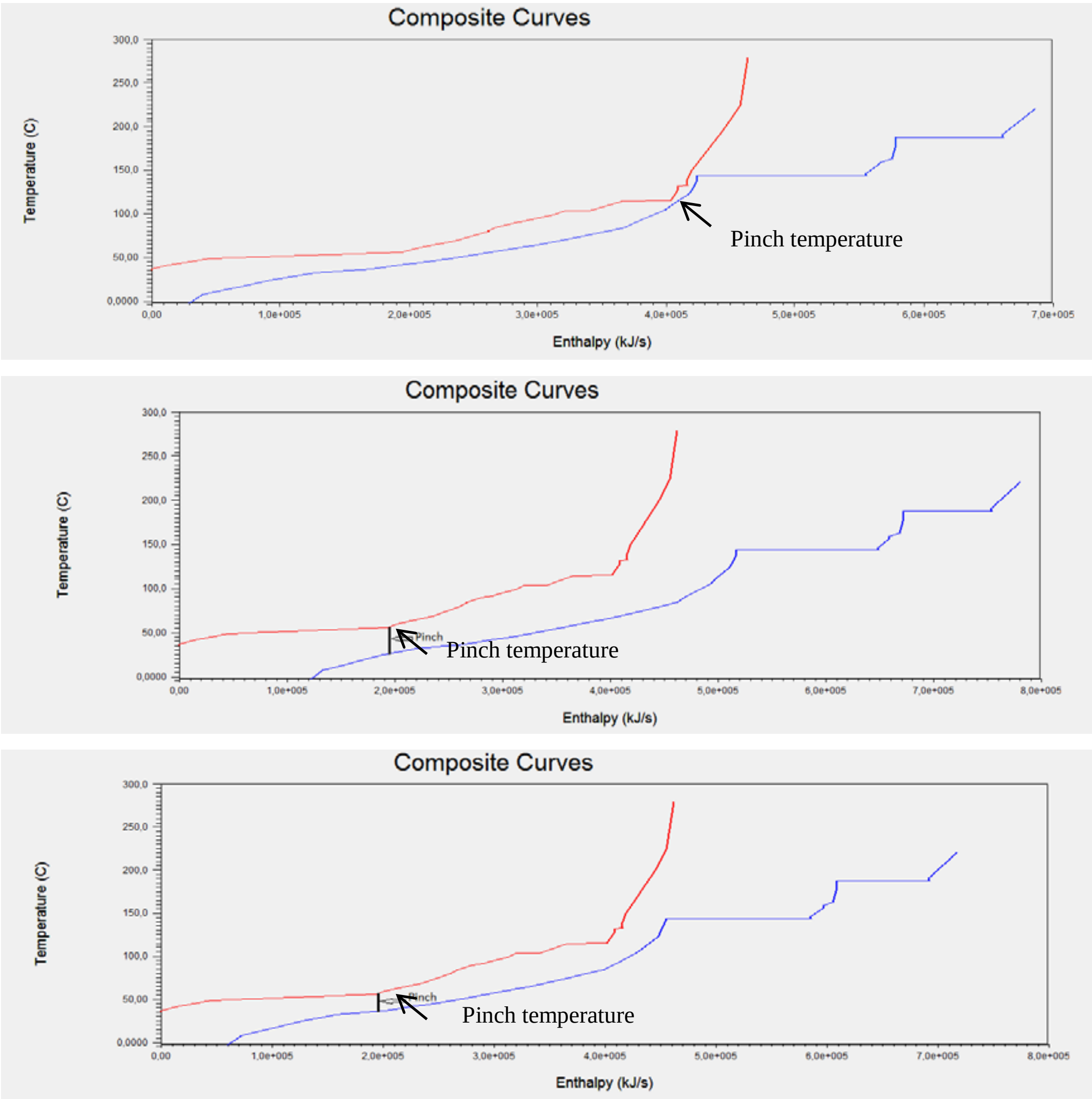


Figure 19 The grand composite curve for the original case, a case using a ΔT_{min} of 30°C respectively a case using ΔT_{min} of 20 °C

As can be seen from figure 19, the pinch temperature of the system is changed severely, from 113.4°C to 47°C, when the minimum temperature difference is specified to a universal 20°C instead of using the individual values for each stream. For a case using a minimum temperature difference of 30°C instead, the pinch temperature becomes 42°C, which confirms the trend, i.e. the pinch temperature for the system is lowered when the minimum temperature difference between the streams

To clarify that there are no large changes in the pinch temperature by just adjusting the minimum temperature difference to a small degree, two cases using minimum temperature differences of 10°C and 15°C were also investigated. These results showed that the pinch temperature for these two cases only changed to 111.6°C and 109.1°C, thus resulting in new systems that would not be possible to design very different from what has been done. Figures for these results are displayed in appendix III.

It should also be pointed out that one of the first steps in performing a pinch analysis is to specify the allowed minimum temperature difference for the process, which in turn provides the utility targets. Based on that the heat exchanger network is then designed, which means that you specify your own restrictions from the beginning. It is also obvious for this case that it is not the minimum temperature difference the limits the results for the study, but rather the practical heat exchanging restrictions within the process

5.2.2 Outcomes of the study

Both the results regarding the possible increase of electricity production and excess heat, for the two designs are expected. A reduction of pinch violations leads to a reduction of utility usage. The reason that the increased electricity production is not as large as the decrease of the pinch rule violations is due to the Carnot factor and the losses in the turbine, meaning that there are losses when converting heat to electricity and that there are both mechanical and isentropic losses in the turbine. Since the pinch rule violations are lower for the ambitious retrofit, compared to the realistic retrofit, it is logical that the electricity production is larger for the ambitious retrofit.

The results for the excess heat, liberated in the tank method procedure, might seem strange. In the realistic retrofit a larger part of the heat exchanging takes place through the secondary heating system compared to the ambitious retrofit. One example of this is the different ways that the weak liquor, from the flash tank to the evaporation plant, is used in the two different designs. In the ambitious retrofit this stream is heat exchanged directly with feed water to the feed water tanks for the boilers, and the remaining heat is cooled away to produce 62°C secondary heating. In the realistic retrofit, this stream is used entirely for production of secondary heating.

The reduction of heat exchanging that takes place through the secondary heating system has affected the shape of the hot composite curve for the secondary heating system. With a steeper hot CC, which is the case for the ambitious retrofit compared to the realistic retrofit, it is not possible to shift the cold CC as far, resulting in a system where less excess heat is available at the same number of tanks and using the same minimum temperature difference.

Basically, when the heating system of the plant is improved, the usage of steam in the process is reduced. That means that less heat is “bleed” through the process, which can be utilized for excess heat. In the end this means simply that an increased electricity production is coupled to a decreased production off excess heat.

5.3 Possible usage of excess heat

This thesis has shown that there is excess-heat available at high temperatures, which can be utilized for different purposes, in both the suggested designs. In this part of the thesis it is investigated how the excess heat theoretically could be utilized. These proposals are based on previous studies. The suggestions are only proposals on what would be possible to implement at the site, meaning that the actual outcomes, regarding increased electricity production or district heating, have not been valued. Because of this, it is not possible to draw conclusions about the best alternative. In order for Östrand to proceed with any of these proposals, more refined analysis regarding the impact of the implementations should be performed. If viewed from an even larger perspective, it is even harder to determine how to utilize excess heat in the best way. As stated by Inger-Lise Svensson and Johanna Jönsson in 2008, “Using excess heat in the processes decreases the steam demand, thus generating a steam surplus that can be utilised. Used externally, the excess heat could replace fossil fuels that the district heating system would otherwise use”. As this study is performed for SCA, focus is on their interests and it is most likely that solutions that contributes to an increased electricity production within the plant would benefit them the most, from an economical point of view.

Below, three different suggestions regarding how to use excess heat are presented

5.3.1 District heating

The main purpose of this thesis has been to investigate what the possible increase in, mainly electricity, but also district would be, provided that certain energy optimization measures were implemented. As there is room for a possible increase of district heating distribution to Sundsvall via the SEAB district-heating network, this idea is clearly an option. For the ambitious retrofit, the excess heat was 32.8 MW; theoretically all this heat could be used to produce district heating to Sundsvall. In the realistic retrofit the excess heat is 65.7MW and theoretically, all of this heat is of a temperature high enough to produce district heating to Sundsvall.

If it was decided to use the excess heat to increase the district heating delivery to the SEAB network, the numbers would probably increase even more than what the numbers for the excess heat suggest. This points out a limitation with the tank method. If the excess heat was to be used to produce district heating, it is possible that some of the heat that is deemed as low quality or waste heat could be used to heat the returning district heating water at lower temperatures. The high temperature heat could then be used at higher temperatures and in that way increase the total district heating production even further. This is something that is not highlighted when the tank method is applied, as it does not consider at which temperatures the district heating water returns.

5.3.2 Low pressure steam production

The hot flue gases from the limekiln represent a large part of the excess heat made available, for both designs. As mentioned previously, it is possible to use these flue gases to raise low-pressure steam at 4 bars.

Figure 20 below, show the technical solution for low-pressure steam production from the limekiln flue gases.

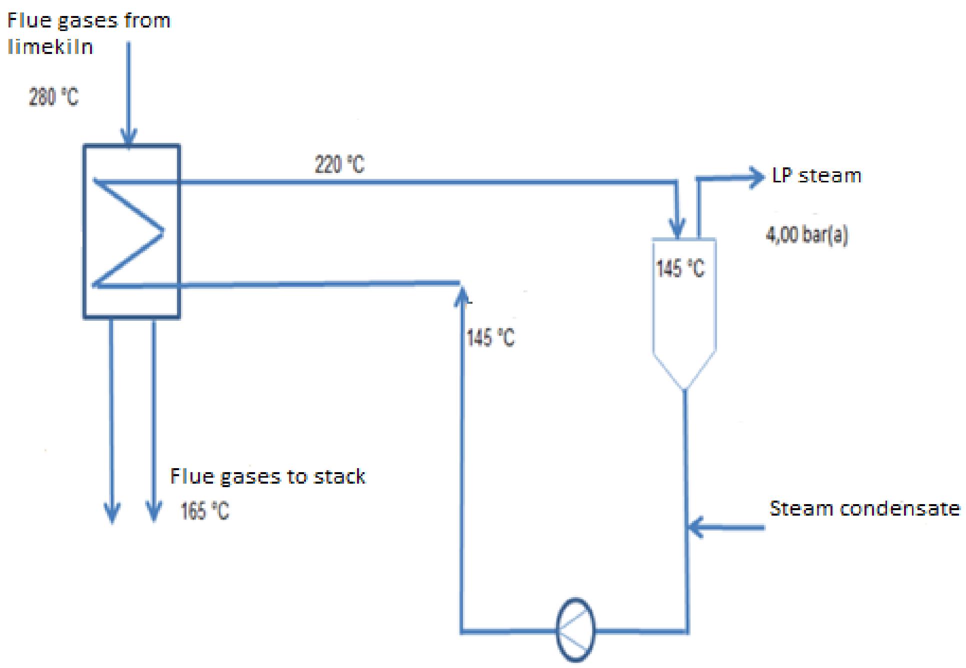


Figure 20: Technical solution for production of LP steam from flue gases. [A. Markusson et al. 2014]

According to the study, performed by "Värmeforsk", which this suggestion is taken from, a steam production of approximately 0.06 t/ADt can be expected from the limekiln flue gas cooler [A. Markusson et al. 2014].

The available excess heat in both designs is made up by substantially more heat than what is in the flue gases from the limekiln. Parts of this heat is at temperatures higher than 100°C and should thereby theoretically also be possible to use to raise steam. In this report, no technical solutions regarding how to produce steam with this heat are produced.

There are several parts of the process at Östrand that utilizes low-pressure steam and clearly there is room for an increased production. For instance, previously made studies have shown that it is possible to use steam raised from excess heat in the evaporation stages and in that way reduce the consumption of live steam [R. Nordman et al. 2005], [J. Algehed 2002].

A possible study should focus on if the increased value that comes from producing steam in the limekiln is larger than the value of an increased production of, for instance, district heating.

5.3.3 Heat pumping

For both the realistic and ambitious retrofit, excess heat at temperatures to low to produce steam is released. A way to utilize this heat is to heat pump it up to temperatures where it can be used to produce either steam or to cover heat needs within the process. There is potential to use heat pumping to upgrade heat from for instance flue gases. This heat could in turn be used for many purposes, for instance to raise steam [Perry. S et al. 2008].

It would also be possible to use heat pumping to make use of the low temperature excess heat. In a paper published in "Applied Energy" in January 2012 the author's handles the problems regarding thermal losses of low-grade thermal energy in process industry. Where they define low quality heat as of a temperature lower than what can be used in the process. As a mean to exploit this heat, they conclude that heat pumping in order to produce either district heating or steam is possible. [Ammal, Y et al. 2011]. This study has not looked closer at ways to exploit low temperature heat, but if possible, this should clearly be looked in to.

5.4 Future work

In order for Östrand to implement any of the suggested solutions it is vital that rigours cost calculations are performed. Otherwise it is not possible to deem whether it is beneficial, also from a cost perspective, to implement these solutions. If these calculations are performed it is important not to judge the economical benefits of the designs compared to not implementing any solutions at all, but rather compare them to the costs of the prospected HEN design.

An economical evaluation of the different opportunities regarding number of tanks and minimum temperature difference within the secondary heating system should also be performed. As previously mentioned, the design of the secondary heating system used today might not be the optimal one. An economical criterion is essential to be able to distinguish between the alternatives.

As mentioned earlier, the study should be performed for a case using the data for a summer case.

6 Conclusions

The objective of this thesis has been to assess both the primary and secondary heating system of the future pulp mill Östrand, in order to suggest improvements that will conduct in more efficient energy utilization at the site. To do this a pinch analysis of the suggested HEN design has been performed. The results from that analysis were used as base for two retrofit suggestions; the first suggestion aiming at reducing the pinch violations as much as possible without violating any technical restraints and the second suggestion aiming at creating a HEN solution that both improves the energy utilization and is possible to implement from a practical point of view.

Results showed that both suggested designs would result in increased electricity production if implemented. As expected, the ambitious retrofit design concluded in larger increase of electricity production. The results also show that there are simple process integration suggestions that can be implemented to increase the electricity production substantially at the plant. According to the early prospected numbers, the installed turbine of 200 MW will be enough to handle the increase in electricity production.

What can also be seen from the results is that relatively large amounts of excess heat at high temperature can be produced for both retrofit cases, provided that the secondary heating systems of the designs are improved. This heat can be released for a design case using only two tanks, compared to the prospected design that contains three tanks. The amount of excess heat is larger for the realistic retrofit compared to the ambitious retrofit, meaning that the lesser production of electricity is somewhat offset by larger production of excess heat. There are several ways in which this excess heat can be exploited.

To determine that the suggested designs are optimal, an economic criterion has to apply to the study. However, this study has provided SCA Östrand with several suggestions regarding how the energy system of their future plant can be designed in a way in which energy is used more efficiently compared to what has been suggested in the prospect design.

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Appendix I

Table 13 A summary of all streams included in the thesis

Name	Inlet T	Outlet T	Q	∆T	Comment
Units	C	C	MW	C	
Moist air from TM5	115	37	21.79	10	From quotation
Moist air from TM6	115	37	63.93	10	From quotation
Moist air from CTMP dryer	49.9	37	14.21	10	From quotation
Final condenser	57	50	127.14	8	From quotation
Gas from "im" condenser	92	45	13.48	14	Up scaled
Flue gases from bio boiler	200	150	2.85	14	From quotation
Flue gases from gas boiler	275	65	1.92	14	From quotation
Flue gases from lime kiln	280	150	12.72	14	From quotation
Weak liquor to evaporation	116.6	90	40.14	6	From quotation
Effluent after OP stage	81	38	46.83	7	From quotation
Effluent after Q/D0 stage	70	38	32.64	7	From quotation
Liquor to digester	92	85	8.29	6	From quotation
Liquor after second oxygen step	100	94	0.79	6	From quotation
Effluent in CTMP	85	60	2.32	7	On going project
Cooling of water in CTMP	85	60	2.32	5	From quotation
Condensate from process	129.2	42	44.12	5	From quotation
Green liquor	98	82	9.28	7	Up scaled
Flue gases from recovery boiler	225	140	28.94	14	From quotation
Turpentine condenser T11A (cooling)	125.1	104.56	0.51	7	Up scaled

Turpentine condenser T11A (condensation)	104.56	104.5	17.88	7	Up scaled
Turpentine condenser T20	104	59.95	0.028	8	Up scaled
Flash steam from weak liquor	115.43	115.3	35.62	0	Equal to Q for Chip bin
Air to TM5	-2.5	130	4.79	16	From quotation
Air to TM6	-2.5	130	1406	16	From quotation
Air to CTMP dryer	-2.5	114.2	6.35	16	From quotation
LP steam to evaporation	144.9	145	98.51	0	From quotation
MP steam to evaporation	179.9	188	19.66	0	From quotation
Air to bio boiler	-2.5	50	2.60	16	From quotation
Air to gas boiler	-2.5	50	0.38	16	From quotation
Air to lime kiln	-2.5	105	9.88	16	From quotation
MP steam to digester	179.9	188	32.55	0	From quotation
Chip bin	-2.5	65	35.62	0	Up scaled
Heating of new locals	25	45	27.94	6	From quotation
Heating of existing locals and old bleaching plant	25	45	1.21	6	From quotation
Wood room	33	38	19.0	5	From quotation
MP steam to O2 stage	179.9	188	6.75	0	From quotation
MP steam to Q/D1 and PO	179.9	188	19.72	0	From quotation
MP steam in CTMP	188	188	1.81	0	From process factory data *
Raff steam in CTMP	133.1	133	6.36	0	From process factory data *
LP steam in resin cooking	144.9	145	0.39	0	Up scaled

Preheating of white liquor	91.4	140	7	6	From quotation
Deduction heating of white liquor	159.5	163.5	8.46	6	From quotation
Heating of Dynasandwater	8	17	2.14	5	From quotation
Water to Mavatank 1 and 2	17	25	1.91	5	From quotation
Heating of water to Mavatank 1	32.3	105	65.08	5	From quotation
Heating of water to Mavatank 2	32.3	122	8.37	5	From quotation
Heating of water from Mavatank 1 into SP6 A	147.4	157	8.41	5	From quotation
Heating of water from Mavatank 1 into SP6 B	192	221	25.41	5	From quotation
Air preheating into SP6	-2.5	180	32.82	16	From quotation
LP steam to Mavatank 1 and 2	144.9	145	27.18	0	From quotation
MP steam to ClO2	179.9	188	2.23	0	From quotation
LP steam to ClO2	144.9	145	0.22	0	From quotation
Preheating of ClO2	10	45	5.17	5	From quotation
Process demand cold water	8	45	59.44	5	From quotation *
Process demand warm water	45	62	26.97	5	From quotation **
Process demand hot water	62	85	32.80	5	From quotation *
EON warm water	44	84	16.26	5	From quotation
SEAB warm water	43	73.6	16.00	5	From quotation

*From process factory data: Same demand before and after reconstruction, CTMP is unaffected by reconstruction.

**From quotation: Determined from various streams which contribute to the need of process water, these streams consist of the hot water to bleaching unit, lime mud filter, district heating, ventilation for SP6 and ÅP, hot water to steam converter, warm water to ClO_2 and hot water to Dynasand filter.

Appendix II

Table 14 All pinch rule violations in the prospected heat exchanger network

Name	Size [MW]	Type
Feed water heated with flue gases from recovery boiler	30.17	Heat transfer through the pinch
Pre-heating of combustion air to SP6 with LP-steam	20.79	Heating below pinch
Heating of secondary heating system with flue gases from limekiln	9.66	Cooling above pinch
Heating of secondary heating system with raffsteam	6.36	Cooling above pinch
Air to CTMP dryer heated with LP-steam	6.04	Heating below pinch
Air to TM6 heated with LP-steam	5.26	Heating below pinch
District heating water to EON is heated with LP-steam	4.47	Heating below pinch
Water to MAVA tank is heated with flue gases from bio boiler	2.84	Heat transfer through the pinch
Air to bio boiler is heated with LP-steam	2.6	Heating below pinch
White liquor is preheated with LP-steam	2.48	Heating below pinch
Heating of Dynasand water with secondary heating system (which has been heated with flue gases from lime kiln)	2.14	Heating below pinch
Preheating of MAVA tank 1 & 2 with secondary heating system (which has been heated with flue gases from lime kiln)	1.9	Heating below pinch
Air to TM5 with LP-steam	1.79	Heating below pinch

The turpentine condenser is cooled with water from the secondary heating system.	0.16	Cooling above pinch
Heat-exchanging between the feed water and the reused cooling water from the process.	2.12	Heat transfer through the pinch.

Table 15 Remaining pinch-violations after the ambitious re-design of the heat-exchanging network in the project.

Name	Size [MW]	Type	Reason
Heating of water to district heating and secondary heating system using flue gases from the limekiln.	12.93	Heat transfer through the pinch.	Not possible to cool the flue gases from the limekiln with anything other than water
Heating of air to TM 6 with low-pressure steam.	5.26	Heating below pinch	The “steam batteries” that heats the drying air has to be heated with steam.
Pre-heating of combustion air to SP6 with flue gases from recovery boiler	3.66	Heat transfer through the pinch.	There are no other alternatives due to technical limitations on the available hot streams
Pre-heating of combustion air to SP6 with LP steam.	3.49	Heat transfer through the pinch.	There are no other alternatives due to technical limitations on the available hot streams
Pre-heating of white liquor using raffsteam.	2.48	Heat transfer through pinch	There is no use for the refinery steam above the pinch; therefore it is transferred through the pinch, in order to reduce the requirements of low-pressure steam.
Air to CTMP dryer with raffsteam.	2.1	Heating below pinch	There is no use for the refinery steam above the pinch; therefore it is transferred through the pinch, in order to reduce the requirements of low-pressure steam.

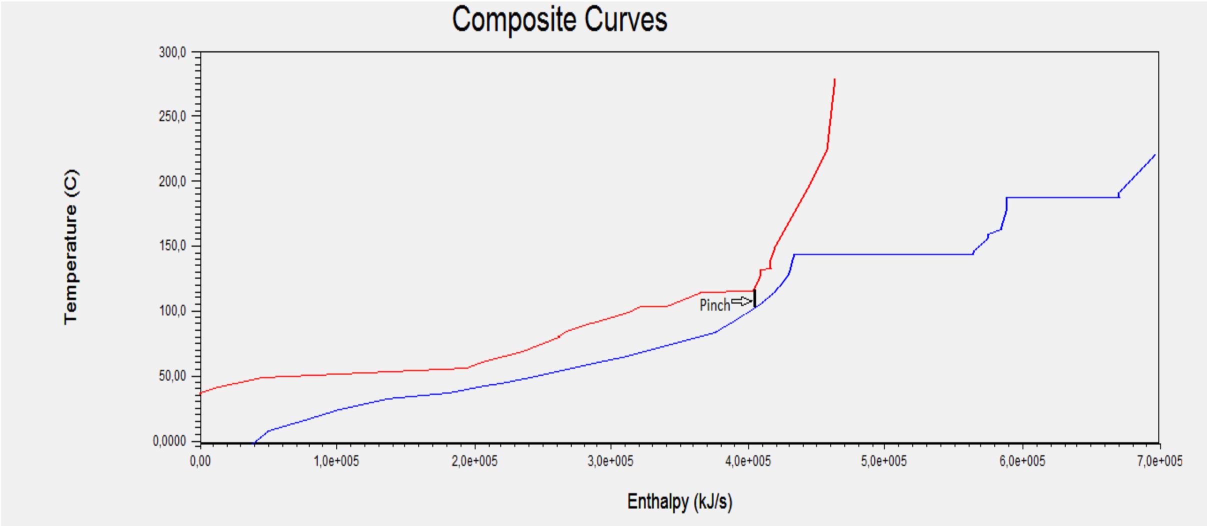
Air to CTMP dryer with LP-steam.	1.9	Heating below pinch	Could have been avoided, but due to technical limitations it is not possible.
Air to bio boiler heated with flue gases from bio boiler	1.82	Heat transfer through pinch	No other alternative.
Air to TM5 heated with LP-steam	1.79	Heating below pinch	The "steam batteries" that heats the drying air has to be heated with steam.
District heating to EON with LP-steam	1.71	Heating below pinch	No other alternative.
The turpentine condenser is cooled with water from the secondary heating system.	0.16	Cooling above the pinch	Not possible to run the condenser with anything other than cooling water.
Heat-exchanging between the feed water and the reused cooling water from the process.	2.12	Heat-exchanging through the pinch.	Would be possible to change. But due to geographical location and the fact that the two streams match each other perfectly, it was decided not to change this solution.

Table 16 Remaining pinch rule violations for the realistic retrofit

Name	Size [MW]	Type	Reason
Combustion air to recovery boiler is heated with flue gases from recovery boiler	16.81	Heat transfer through the pinch.	Best alternative possible due to technical limitations for the recovery boiler.
Secondary heating system warmed with flue gases from limekiln.	14.46	Heat transfer through the pinch.	There are no other alternatives due to technical limitations on the available hot streams
Water to MAVA tank 1 heated with LP-steam.	11.65	Heating below pinch	Could have been avoided, but due to technical limitations it is not possible.
Air to TM6 heated with LP-steam.	5.2	Heating below pinch	No other alternative. The "steam batteries" that heats the drying air has to be heated with steam.

Combustion air to recovery boiler heated with LP-steam	3.97	Heating below pinch	No other alternative.
Air to CTMP dryer heated with Raffsteam	3.2	Heat transfer through the pinch.	There is no use for the refinery steam above the pinch; therefore it is transferred through the pinch, in order to reduce the requirements of low-pressure steam.
Air to bio boiler heated with flue gases from bio boiler (through secondary heating system)	2.6	Heat transfer through the pinch.	No other alternative.
Preheating of white liquor with refinery steam from the CTMP mill	2.48	Heat transfer through the pinch.	There is no use for the refinery steam above the pinch; therefore it is transferred through the pinch, in order to reduce the requirements of low-pressure steam.
Air to TM5 heated with LP-steam	1.8	Heat transfer through the pinch.	No other alternative. The “steam batteries” that heats the drying air has to be heated with steam.
District heating to EON with LP-steam	1.62	Heating below pinch	No other alternative.
Heating of water to MAVA tank 1 with flue gases from bio boiler.	0.25	Heat transfer through the pinch	Not possible to cool the flue gases from the limekiln with anything other than water
The turpentine condenser is cooled with water from the secondary heating system.	0.16	Cooling above pinch	Not possible to run the condenser with anything other than cooling water.
Heat-exchanging between the feed water and the reused cooling water from the process.	2.12	Heat transfer through the pinch.	Would be possible to change. But due to geographical location and the fact that the two streams match each other perfectly, it was decided not to change this solution.

Appendix III



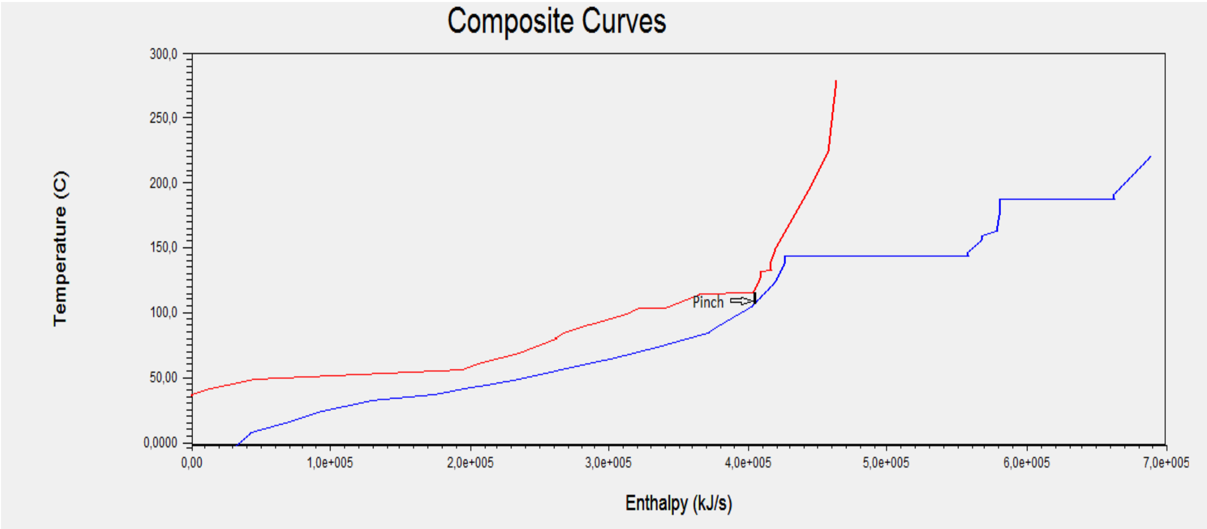


Figure 21 The composite curves for a case using a global ΔT_{min} of 10°C and for a case using a global ΔT_{min} of 15°C.