Analysing the potential for steam savings in TMP mills using the HLMPP tool

Analysis done for four different TMP mills owned by Holmen and Norske Skog

Master's Thesis within the Sustainable Energy Systems program

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MASTER’S THESIS

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Cover:
In the top left-hand corner, picture of Holmen Braviken mill (Photographer: Västgöten, Source: own work); in the bottom left-hand corner, picture of Norske Skog Skogn mill (Photographer: Eaglestein, Source: own work); in the top right-hand corner, picture of Norske Skog Follum (Photographer: Hau-maggus, Source: own work); in the bottom right-hand corner, picture of Norske Skog Saugbrugs mill (Photographer: Knut E. Haug, Source: own work)

Chalmers Reproservice
Göteborg, Sweden 2010

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ABSTRACT

Thermo mechanical pulp (TMP) mills are large consumers of both steam and electricity. Large energy savings can be achieved through investments in thermal process integration or more energy efficient process equipments. Thermal process integration can help to reduce the hot and cold utility consumptions in a mill. A well known thermal process integration method is pinch analysis.

This master thesis studies the potential for hot utility savings in four different TMP mills in Norway and Sweden. A detailed pinch analysis requires too much time, mainly for data gathering and especially for four mills so instead, a model named the Heat Load Model for Pulp and Paper (HLMPP) is used. The HLMPP can be considered as a simplified pinch analysis which needs a limited amount of input data and, thus, saves time compared to a detailed pinch analysis. Even though HLMPP gives accurate enough estimations, it does not have the precision of a detailed pinch analysis and does not explain how to upgrade the Heat Exchanger Network (HEN) in order to match the potential of steam savings and warm water available.

The results for the four mills studied show promising potentials for steam savings, between 2.1% and 20.3% in total for the four reference cases. Moreover, the results show that large amounts of warm water (excess heat) should be available. However, this excess heat has a fairly low temperature, 65-72°C (for three mills; for the fourth mill, it was even lower). Apart from the reference cases, different sensitivity analyses were studied e.g. a decrease of the fresh water consumption in the Paper Machines (PMs), removal of the internal district heating network, further cooling of waste water, installation of modern dryers with an higher exhaust air moisture content. The results from these sensitivity analyses show that even further steam savings could be possible, between 2.8% and 29.7% in total for the different mills as well as further amount of warm water available.

Applications for excess steam and warm water are numerous. With steam savings giving excess steam, the mills can decide to sell it (export to a close mill or a town for district heating), use it on-site for biomass drying or driving a condensing turbine to produce electricity. Steam savings also enable fuel savings in the boilers or the replacement of old refiners by more efficient refiners (which consume less electricity) without having to burn more fuel in the boilers. Excess warm water can, in spite of being at quite low temperature, be either recovered by a heat pump, utilized in an Organic Rankine cycle (ORC) or used for preheating of other (external or new) process streams. According to the results for each mill, one can see the interest of carrying out a complete pinch analysis for all the mills in order to find the most profitable solution between the applications previously mentioned.

Key words: Thermo-mechanical pulp, process integration, pinch analysis, steam saving, Heat Load Model for Pulp and Paper (HLMPP)

Contents

Preface

This master thesis report is the achievement of a Nordic cooperation involving the division of Heat and Power Technology at Chalmers University of Technology, the department of Energy Technology at Aalto University School of Science and Technology (former Helsinki University of Technology), the Paper and Fibre Research Institute (PFI) and four TMP mills: Holmen Braviken, Norske Skog Follum, Norske Skog Saugbrugs and Norske Skog Skogn.

This study uses the HLMPP tool developed by VTT and Aalto University School of Science and Technology and aims at finding theoretical potential for steam savings for the four mills mentioned above.

I would like to express my gratitude to my examiner, Thore Berntsson and my two supervisors, Johanna Jönsson from Chalmers and Pekka Ruohonen from Aalto. They were always available to assist and guide me during the whole project.

Lastly, I would like to thank Mårten Jarl and Lars Sundström from Holmen Braviken, Jan Brill and Lasse Blom from Norske Skog Follum, Kjetil Bjørlo from Norske Skog Saugbrugs, Øivind Opdal, Tormod Røstad from Norske Skog Skogn and Kai Toven from PFI for their help to provide the data required in this thesis and their precious explanations.

Göteborg April 2010

Grégory Michel

Notations

°C	Centigrade degree
ΔTmin	Minimum temperature difference
AD	Air-dried (90 % dryness)
BD	Bone-dried (100% dryness)
CC	Composite curves
DH	District Heating
DIP	Deinked pulp
GCC	Grand composite curve
GW	Ground Wood
HC	High Consistency
HEN	Heat Exchanger Network
HLMPP	Heat Load Model for Pulp and Paper
HP	Heat Pump
HX	Heat Exchanger
h	Hour
J	Joule
kg	Kilogram
kW	Kilowatt
LC	Low Consistency
m	Meter
m^3	Cubic meter
MER	Maximum Energy Recovery
MFC	Machine Finished Coated
MW	Megawatt
ORC	Organic Rankine Cycle
PFI	Paper and Fibre Research Institute

(P)GW	(Pressurized) Ground Wood
PI	Process Integration
PM	Paper Machine
RCF	Recycled Fibre
s	Second
SC	Super Calender
SEC	Specific Energy Consumption
TMP	Thermo Mechanical Pulp

1 Introduction

The dependence on fossil fuels can be reduced e.g. by increasing the share of biomass in the global energy usage. Increasing the use of biomass implies to convert it into a wide range of products and applications such as power generation, ethanol production, etc. in e.g. a biorefinery[1] plant. The pulp and paper industry used to focus on the production of pulp and paper but, nowadays, the concept of biorefinery is growing up among pulp and paper companies and is boosted by public subsidies. In this industrial sector, the biorefinery concept is characterized by generating different biomass based products in addition to the pulp and/or paper produced. However, the biorefinery concept has mainly been investigated for the chemical pulp and paper industry since in the chemical pulping process the main wood components (lignin, hemicelluloses and celluloses) are broken down and only the cellulose is used for the paper. Thus, the other components can be extracted in different ways and used as raw materials for new products. If efficiently thermally integrated, the Kraft pulp mills can also have a true steam surplus which can be used in the biorefinery processes.

For mechanical pulp and paper mills, including Thermo mechanical pulp (TMP) and paper mills, the wood is not broken down chemically, instead it is ground or, also named, refined without any extraction wood components (giving a higher yield compared to the chemical pulp). Hence, not all biorefinery concepts studied for chemical mills can be applied to the mechanical pulp and paper industry. Some biorefinery concepts which are applicable to the mechanical pulp and paper industry are drying of biomass, export of heat to a district heating grid, decrease in bark consumption in order to sell it, etc.

All of these biorefinery ideas can be efficiently integrated to the mills if excess hot utility or excess heat at suitable temperature is found in the existing processes. To identify hot utility savings and temperature levels of excess heat Process Integration (PI) can be used. One PI tool commonly used is the pinch analysis. Even though a pinch analysis requires a time consuming data gathering, it has proven its effectiveness for the last 20 years (Gundersen, 2002).

However, the biorefinery concept is not the TMP mills only interest. TMP mills are enormous electricity consumers and thus they are also looking at ways to reduce their electricity consumption. The paper market is a very competitive market, therefore being the most energy efficient mill is a main advantage. Within the industry, more efficient refiners which consume less electricity have been implemented such as low consistency (LC) and double disc. To a certain extent, PI can also facilitate such a reduction of the electricity consumption in the refiners since a decreased steam demand gives the opportunity to reduce the electricity used in the refiners without burning more fuel in the boilers (the electricity used in the refiners can partly be recovered as steam).

Regarding previous PI studies on TMP mills, a pinch analysis including one TMP line and one Paper Machine (PM) line has been done for the Norske Skog Skogn TMP mill (Festin & Mora, 2009). The study showed good savings potential for the parts of the mill studied. Besides this study, a scientist publication about a model mill, using

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[1] A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. The biorefinery concept is analogous to today's petroleum refinery, which produces multiple fuels and products from petroleum.

the best available technology, also showed that hot utility and cold utility could be saved if the mill was further process integrated (Axelsson & Berntsson, 2005).

In this report, four TMP mills will be analyzed using the Heat Load Model for Pulp and Paper (HLMPP) in order to estimate their respective theoretical potential for steam savings and warm water available and see to what extent biorefinery concept as well as decreased electricity consumption can be applied to the mills. The HLMPP is a simplified pinch analysis tool which with good accuracy and less data identifies the potential for steam savings (Hakala, Manninen, & Ruohonen, 2008). As the data gathering is simplified, the study of one TMP requires less time than a detailed pinch analysis. The HLMPP concept will be further explained together with the pinch analysis method in Chapter 2.

1.1 Objective

This thesis aims at analyzing the potential for hot utility savings at four different Scandinavian TMP mills. The potential to export warm water is also discussed. Three of the mills, Follum, Saugbrugs and Skogn, are located in Norway and owned by Norske Skog. The fourth one, Braviken, belongs to the Holmen group and is situated in Sweden. With four mills in the sample, a good representation of the main kinds of TMP mills is achieved.

Studying the potential for process integration based on pinch analysis is a time consuming work, especially the data gathering phase. Hence in this work a generic tool for screening of potential is used; the HLMPP which gives accurate enough results compared to a complete pinch analysis but needs less input data (Hakala, Manninen, & Ruohonen, 2008). However, the HLMPP cannot be used to explain how to achieve these potentials. Thus, the HLMPP should be used as a reference study in order to decide whether or not, a detailed pinch analysis is advised to be carried out.

Finally, a discussion is carried out which interprets the results according to mills characteristics such as technical age, TMP share in paper recipe, fresh water usage etc. The discussion will introduce some biorefinery concepts and ideas to decrease electricity consumption according to the potential for steam savings and warm water available at the different mills.

1.2 Scope

Four pulp mills were investigated during the work presented in this thesis. This large scope was possible due to the time savings achieved while using the HLMPP compared to a normal pinch analysis data gathering and also since no retrofit analysis was made (a retrofit analysis cannot be done using HLMPP since the stream data is simulated and not the real streams).

The system boundaries depend on the mill characteristics and also the model limitations. In the HLMPP, the mill can have up to three TMP pulp lines, one (un)Pressurized Ground Wood (GW/PGW) and up to three paper machines (PM). Debarking, Re-Cycled Fibers line (RCF) and, if existing, district heating is also included in the model. This implies that extra units, apart from the previous mentioned, are not included in the model.

Only the theoretical possibility to improve the energy efficiency is covered in this thesis since this is the scope of the HLMPP. Thus economic and environmental impacts are not considered here. Sensitivity analyses are carried out for all the mills which investigate the influence of different changes such as replacing old dryers with modern dryers, a reduction of the fresh water used in the processes, removal of the internal district heating network, etc.

1.3 Methods used

This thesis started with a four week literature study. The TMP process, pinch analysis and the HLMPP tool needed to be understood in order for the work to be efficient, especially during the mill visits.

The working method for the four mills was mainly the same even if there were some small differences. The main steps in the working method are summarized below:

1. Data gathering by the help of mill employees' and mill visit(s). The input data is compiled in a predefined Excel file
2. Steady state simulation of the TMP plant with the Balas software to find missing values required by the model (if any)
3. Stream tables creations (done by the HLMPP tool) followed by the Composite Curve and Grand Composite Curve construction (done in Propi)
4. Interpretation of the results (analysis of the Composite Curve and Grand Composite Curve) in addition with a sensitivity analysis of relevant parameters
5. Communication of results to mill personnel to check accuracy

For a further explanation regarding HLMPP, the reader is advised to go to Section 2.2.

One must notice that the data gathering process for an HLMPP analysis is faster and easier than for a pinch analysis. As a consequence, mill visits were done only at Braviken while the three Norske Skog mills provided all their data through email communication.

2 Pinch analysis and the HLMPP tool

This thesis applies the pinch analysis concept and uses the HLMPP tool. In the subsequent text both concepts are explained.

2.1 Pinch analysis

The Heat Recovery Pinch concept was invented in the late 70's and was made suitable for industrial processes in the 80's. Pinch analysis aims at finding process integration opportunities and, this way, minimizes the hot and cold utility demands through maximizing internal heat recovery.

Pinch analysis can be used for new designs (often called grass root or green field) but also for existing plants or processes (retrofits). For both cases, the same four phases should be respected:

1. Data gathering, which involves collecting stream data for the process and the utility system
2. Targeting, which establishes figures (CC and GCC curves) for best performance in various respects, determining the theoretical minimum hot and cold utility demand
3. Original network design, where the initial Heat Exchanger Network, is established
4. Retrofit, where the initial design is improved in order to get closer to the targets identified in 2

This thesis includes the two first phases of a full pinch analysis. These two phases are described in the subsequent text. For the two last phases, the reader is advised to consult (Gundersen, 2002) or (Linnehoff, Townsend, & Boland, 1982).

2.1.1 Data gathering (Phase 1)

Any industrial process is a combination of streams that need to respect specific temperature ranges due to process restrictions. The desired temperatures are achieved either by internal heat exchange with other process streams (heat recovery) or with heat exchangers using external hot and cold streams (hot and cold utilities). The data gathering aims at identifying these streams.

Two kinds of streams are defined: cold and hot streams. A hot stream is a stream that must be cooled (regardless of temperature range). On the opposite side, a cold stream needs to be heated (regardless of temperature range).

The minimum temperature approach, ΔTmin, is the lowest temperature difference between the hot stream and the cold stream that can be accepted in a heat exchanger. Its value is determined by the maximum size of heat exchangers (HX) that can be accepted due to economical considerations. Indeed, the bigger the HX is, the more expensive it is. An individual ΔTmin is set for all the HX in this thesis and it depends on the kind of streams that are exchanged. A summary of the different ΔTmin used in this thesis can be seen in Table 2.1.

Table 2.1: Minimum temperature differences used for the pinch analysis in this study (Axelsson & Berntsson, 2005)

Type of stream	ΔTmin/2 [°C]
Clean Water	2.5
Dirty Water	3.5
Steam from refiner	2
Clean Steam	1
Air	8
Steam with gases	4

At the end of the data gathering, a stream data table is built. An example of such table can be found in Table 2.2.

Table 2.2: Example of a stream and utility data table

Stream name	Hot/Cold stream	Start temperature [°C]	Target temperature [°C]	Flow rate [kg/s]	Heat load [kW]
Water to process	Cold	2	60	61	14 801
TMP filtrate	Hot	75	67	64.9	2148
Chips warming	Cold	10	75	12.7	2465

2.1.2 Targeting (Phase 2)

From the stream data the Composite Curve (example given in Figure 2.1) and the Grand Composite Curve (example given in Figure 2.2) can be drawn. The Composite Curve and the Grand Composite Curve are labelled CC and GCC throughout this thesis.

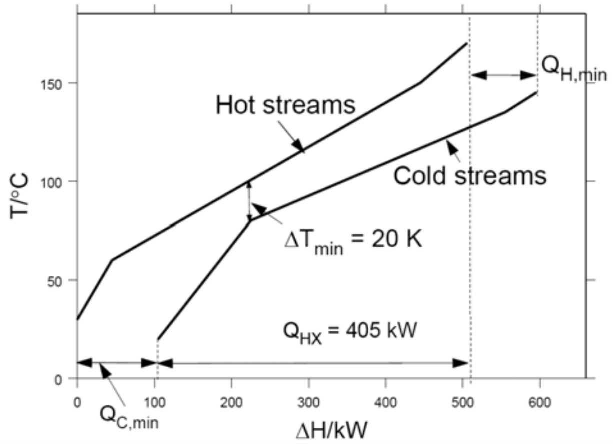

Figure 2.1: Composite curve, ΔTmin=20 K (Industrial Energy Systems course material)

The CC and GCC provide valuable information such as maximum internal heat recovery Q_{HX}, minimum hot utility demand $Q_{H,min}$ and minimum cold utility demand $Q_{C,min}$ which can be achieved for an ideal process integration case.

The pinch temperature is easily readable in both the CC and the GCC. Above the pinch temperature there is a deficit of heat and below there is an excess of heat.

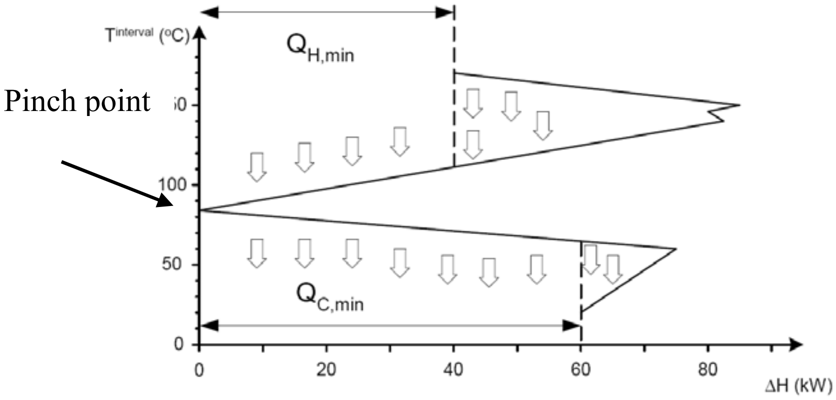

Figure 2.2: Grand Composite Curve (Industrial Energy Systems course material)

The CC and the GCC give the minimum theoretical energy consumption. For an existing plant, this target is usually never achieved due to a non optimal design of the heat exchanger network (HEN). There can be three reasons to why the existing energy consumption is larger than the identified target, these reasons are usually called pinch violations and are described below:

- Cooling of streams above the pinch temperature. Doing that adds a heating demand since there is a deficit of heat above the pinch.
- Heating of streams below the pinch. Doing that adds a cooling demand since there is an excess of heat below the pinch.
- Transfer of heat through the pinch. Doing that violates both of the above mentioned rules and adds both a heating and a cooling demand

2.1.3 ProPi

The ProPi add-on for Excel is a tool for Pinch analysis, created by CIT Industriell Energianalys, which enables to draw the CC and the GCC with less effort. The ProPi tool was used throughout work presented in this master thesis.

2.2 Description of the HLMPP

The Heat Load Model for Pulp and Paper (HLMPP) aims at giving the theoretical potential for energy savings of a process with less input data compared to a traditional Pinch analysis. It has been developed by Hakala and Manninen from VTT and Ruohonen from Aalto University School of Science and Technology, Department of Energy Technology, Industrial Energy Engineering. Studies performed with this tool have been compared with real pinch analyses and the accuracy level has been found sufficient (Hakala, Manninen, & Ruohonen, 2008). However, since the tool is new, further validation, based on results from more studies, should be performed in the forthcoming years. Section 4.1 presents how reliable HLMPP is to estimate the potential for hot utility saving and extra warm water available.

The boundary of the studied system is limited to the mill. All the production lines are included as long as they respect the size of the HLMPP mill model. Currently the mill model in the HLMPP includes:

- One debarking line
- One Ground wood (GW) line
- Up to three Thermo mechanical pulp (TMP) lines
- One Recycled Fiber (RCF) line
- Up to three Paper Machines (PM)
- One stock preparation unit (From pulp lines to paper machines)
- One steam generation unit (LP steam)
- One district heating

The four studied mills in this study all fit into this system. A general overview of the HLMPP mill model is presented in Figure 2.3. All the mills do not have all these lines. If, for instance, there is no RCF line then this part is disabled in the HLMPP.

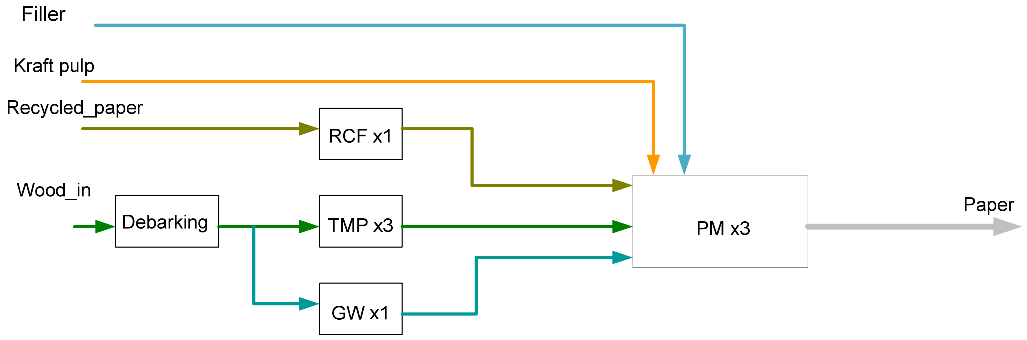

Figure 2.3: Overview of the HLMPP TMP mill model

As displayed above, the mill may also use some Kraft pulp (imported) but no energy analysis is included for this part, it is only for mass balance purpose. Each line is detailed in the Section 3.1.

The work using the HLMPP is made up of four steps:

1. User data input

Like a normal pinch analysis, the data gathering must be performed. However, the data needed for the analysis is not as extensive as for a normal pinch analysis. The mill's specific parameters are fed in a Microsoft Excel worksheet and this might be done by the mill's employees. The input data required is e.g. production rates, furnish mix (raw materials, product description), refiner's specific energy consumption. Moreover, the data is checked and some unclear terms are filled in co-operation with the mills during visits and through email communication. The complete list of required data is showed in Appendix 1 with explanations and comments in Appendix 2.

2. Process calculations

The Balas software runs simulations with the input data collected during the data gathering in order to get the stream data required for the pinch analysis. As soon as a convergent solution is reached, the Excel file is updated and a complete stream and utility data table is constructed in a new sheet in the same Excel file.

3. Stream data

There are at maximum 98 streams considered in the system if the mill has all the production lines used in the model and if all lines are selected. Indeed, one can decide which units to include or exclude in the pinch analysis by simply check or uncheck a cell dedicated to one line in the Excel file. The stream data used in the HLMPP pinch analysis is presented in Appendix 2.

4. Analysis

The last step is comprised of interpretation of the CC and the GCC. The CC and the GCC are drawn according to the units that one decides to include in the analysis (as described above). Thus it is very easy to investigate improvements such as further cooling of some hot streams.

If the mill does not recover all heat in some hot streams then maybe more integration can be achieved. The flexibility of the HLMPP allows to quickly investigate the influence of different parameters such as a new, modern dryer with high exhaust air moisture content ($> 150\ g_{water}/kg_{air}$), better heat recovery of this air, lower water consumption etc. It is not a retrofit analysis but just a quick way to estimate some improvements and their impacts on the cold and hot utility demands.

3 TMP mill process

Two important pulp processes can be distinguished; the chemical pulping process and the mechanical pulping process. The Thermo mechanical pulp (TMP) belongs to the last category. The TMP share of total pulp production is showed in Table 3.1 (Food and Agriculture Organization, 2008) and (Skogs Industrierna).

Table 3.1: TMP and Chemical pulp share for Finland, Norway and Sweden in 2008

Unit: 1000 metric tons air dry	**Finland**	**Norway**	**Sweden**
TMP production	2 753	1 272	2 427
Chemical pulp production	7 159	581	8 338
Total wood pulp production	11 623	1 929	12 171
TMP share [%]	24	66	20

For these three countries, the share of TMP stands for around 25% (60% for chemical pulp).

TMP is mainly used for the production of printing papers which have good opacity and printability at low basis weight. Hence newsprint, uncoated and coated magazine papers are the most important consumers of TMP. TMP pulp is used for both cheap and expensive paper grades. Newsprint is a cheap paper and magazine papers are expensive. Newsprint can contain up to 100% of TMP but the last decades have proved an increasing share of DIP[2] content (Sundholm, 1999).

3.1 TMP mill process description

This section introduces the TMP mill processes and the way the processes are taken into consideration in the HLMPP. The stream data used for building the CC and GCC in HLMPP is detailed in Appendix 2.

3.1.1 Debarking line

In this process wood timbers are debarked and chipped. The removed bark goes to a bark press and is then sent to a boiler where it can be employed to produce heat (and power). Figure 3.1 displays the process.

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[2] DIP stands for deinked pulp, pulp produced from recovered printing paper, e.g. newsprint, through a de-inking process. In this thesis, RCF and DIP are both used.

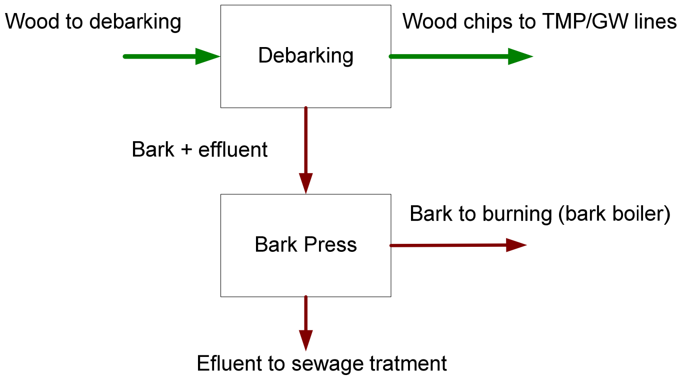

Figure 3.1: The debarking line

3.1.2 TMP lines

The TMP lines in HLMPP can be separated in several main steps: prior to refining (steaming, washing, impregnation, etc.), refining, screening and reject handling and bleaching. These steps are represented in Figure 3.2.

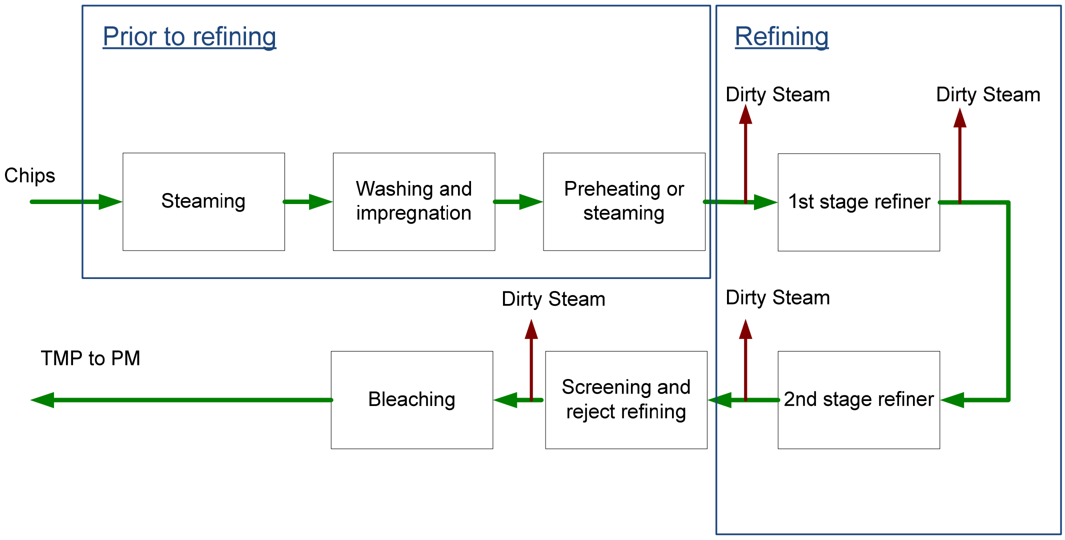

Figure 3.2: The TMP line process

<u>Prior to refining:</u> A TMP line transforms debarked wood chips to a Thermo Mechanical Pulp (TMP). After debarking, the chips need to be washed. The first step consists of pre-steaming and heating to around 85°C. Thereafter, warm water is added in order to remove surface impurities such as sand, metals and stones. After that a screw drainer removes dirty water. The dirty water is screened to eliminate most of the foreign particles and then re-injected in the chips washing.

The next step is called impregnation and chemicals. In this step the cleaned chips are pre-steamed one more time to moisten, soften and remove air. A screw follows which removes further air and makes cracks in the chips. Then, the impregnation takes place in the “impregnation vessel” where a chelating agent is mixed with the chips. The chelating agent makes the metal ions precipitate and the majority of them can then easily be filtrated after the vessel. This method decreases the mill´s global chemical consumption. The metal ions left in the chips are separated later in the process. Prior to the refiners, a pre-heater warms up the chips to about 100 °C.

<u>Refining:</u> A key part of the TMP unit is the refining process where the woodchips are ground. This is done using refiners which reduce the wood into smaller fragments and fibers. The refiners consume a huge amount of electricity, measured as the specific energy consumption (SEC) in MWh/ADt paper. It can be up to 3.3MWh/ADt paper (Sundholm, 1999). The HLMPP can accept up to two refiners in series, a primary stage and a secondary stage refiner, in the main line. Steam is blown out in the cyclones and pulp is progressively formed. This steam is not clean and is usually named TMP steam or dirty steam due to the presence of particles in it. A proportion of this dirty steam, the backward steam, is reused directly in the TMP lines for woodchip preheating purpose. However, the other share of this steam is recovered in a heat recovery unit in order to produce clean steam. See section 3.1.7 for more details about the steam system.

In the different mills investigated in this report, there are some cases with several refiners in the primary stage or in the secondary stage and sometimes a third stage occurs. Moreover, parallel lines might be present which means that the refiners have the same characteristics but the flow is divided in two parallel pipes. Table 3.2 explains the adopted strategy to handle these facts.

Table 3.2: Methods for additional refiners out of the HLMPP boundaries

Real case	HLMPP case
Parallel lines with the same SEC per refiners	One serial line with a double mass flow compared to the real case but the same SEC is applied
More than one refiner per stage or presence of a third stage	The SEC of the additional refiner is added to the previous refiner

<u>Screening and reject refining</u>: In this stage the pulp is sent to screening which is symbolized in the model by a splitter where the screened part goes to the reject treatment and the other directly to the disc filter. Two different kinds of reject refiners are possible: pressurized (Pabs> 1bar) or unpressurized (Pabs= Patm). Only one kind (pressurized or unpressurized) is used depending on the value specified in the Excel sheet. They are both made of two reject refiners in series. Steam is separated by cyclones after each refiner and is recovered in heat recovery units. A reject screener occurs and the accepted pulp joins the previously accepted one and goes to the disc filter prior to the bleaching unit. The refused share is injected back to the beginning of the refining stage.

<u>Bleaching:</u> In the disc filters, clear and cloudy filtrates [3]are separated from the pulp stream. The pulp passes through a screw press then goes to a perox bleaching tower (to remove pigments) and one more screw press just after it. Most of the filtrates extracted by the screw press are reused in the TMP process and a part of them is sent to the effluent treatment.

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[3] Clear filtrate is white water without most of the fibres. Cloudy filtrate contains more fibres than clear filtrate.

3.1.3 RCF line

The HLMPP also has the possibility to include a RCF line (also called a DeInked Pulp-DIP line). Recycled paper is injected in a drum pulper where there are two zones. One zone is for slushing, called defibering, and the other zone is for screening. It is followed by two consecutive screening units and a flotation[4] system. Many dewatering machines are employed in the RCF line such as disc filters, band press and screw press. A dispergater is used to attain the best quality pulp.

Three flotation machines help to improve the pulp brightness by removing ink particles and enhance cleanliness by removing dirt specks. This is called deinking (Göttsching & Pakarinen, 2000). All the steps are shown in Figure 3.3.

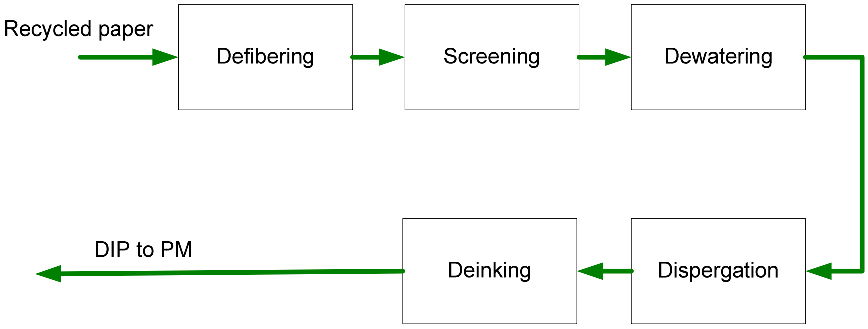

Figure 3.3: The RCF line process

3.1.4 Stock preparation

The stock preparation describes the preparation of the chemical pulp, imported by the mill. Therefore, in the HLMPP, it is used only for mass balance purpose.

3.1.5 Paper machine

In TMP mills, paper is made of different materials such as TMP, Kraft pulp, RCF and filler[5]. The materials are mixed in the blending chest and are cleaned before entering the wire section, steam box (if existing) and cylinder drying. The HLMPP simplifies the process by including two drying sections, one for coating paper and one for uncoated paper. The coating section has an optional air flotation unit and a gas infra red dryer. A certain amount of broke[6] is returned back to the blending chest depending on the mills. The HLMPP PM process can be seen in Figure 3.4. The PM lines and particularly the dryers are the largest steam consumers and they require clean steam also called LP (Low Pressure) steam, see Section 3.1.6 for details about the steam production.

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[4] Flotation is a separation process for suspension cleaning using air bubbles that attach themselves to the particles and transport them to the surface of the suspension. Main application: deinking (Göttsching & Pakarinen, 2000).

[5] Filler defines any inorganic substance added to the pulp during the manufacturing of paper (Goyal, 2010).

[6] Broke is paper that has been damaged in the wire, press section or drying section. It is recovered in the PMs and is returned to the blending chest.

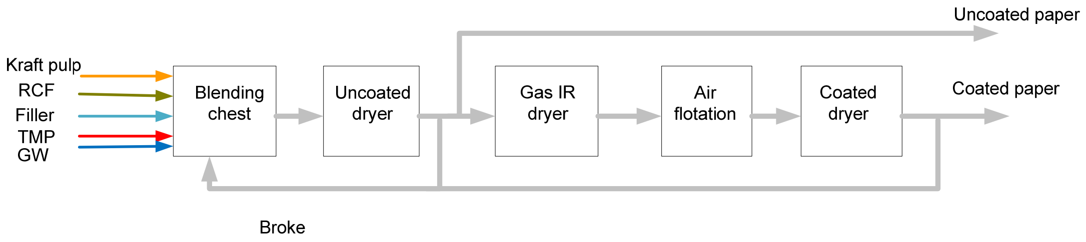

Figure 3.4: The PM process

3.1.6 District heating, effluent and steam production

District heating: None of the mills in this study produce heat for district heating to a close city. However, some of the mills have an "internal" district heating grid for process heating purposes. The internal district heating grid aims at distributing the heat from one section in the mill to another and thus is considered as double streams (hot and cold) in the HLMPP since it is first warmed and then it releases its heat content to different streams located at different parts of the mill.

Effluent: All the effluents need to be cooled down before entering the waste water treatment. Usually the target temperature is around 30-35 °C in order to maintain biological treatment in the sewage plant.

Steam production: Two categories of steam are found in the mill, clean steam and dirty/TMP steam. The dirty steam is produced by the refiners in the TMP lines and the clean steam can come from either a boiler (bark, oil, electrical, etc.), or the steam recovery of dirty steam. The TMP steam can be immediately used in the TMP lines for the preheating and steaming steps. However, this corresponds to a small amount and usually, around 2/3 of the TMP steam is recovered in order to produce clean steam (Sundholm, 1999). An example of clean steam production is shown in Figure 3.5 and the TMP steam recovery system is displayed in Figure 3.6.

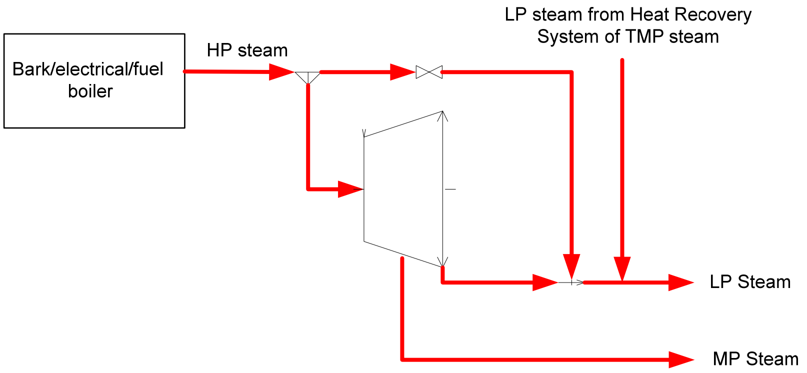

Figure 3.5: The production of clean steam with different steam pressure LP, MP and HP

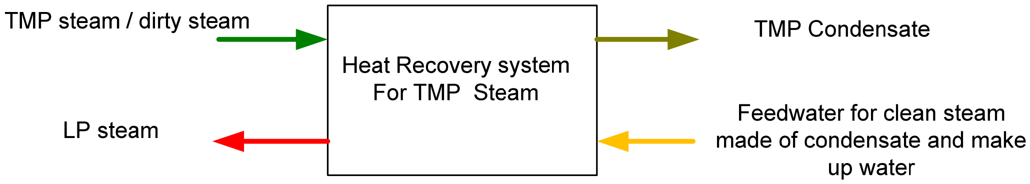

Figure 3.6: The heat recovery system for TMP steam

4 Validation of the HLMPP

In the following section, the reliability of the HLMPP is described based on previous studies performed by the developers of the model. Afterwards, an HLMPP simulation of the FRAM SC paper model mill is presented and compared with a previous pinch analysis carried out for the same mill. Finally, how the HLMPP can be used to study different process modifications is described.

4.1 Previous studies for validation of the HLMPP

A paper mill case has been tested with the HLMPP and compared to a pinch analysis previously realized for the same mill (Hakala, Manninen, & Ruohonen, 2008). The tested mill has three PMs that produce publication papers based on GW and PGW. A detailed pinch analysis gives a minimum hot utility consumption of 2.4 MW and a minimum cold utility consumption of 13.7 MW (Ruohonen, Hakala, Hippinen, & Ahtila, 2007). The HLMPP analysis was done in order to compare HLMPP results with the results from the previous detailed analysis. Figure 4.1 and 4.2 illustrate the small differences between both models (Detailed vs HLMPP).

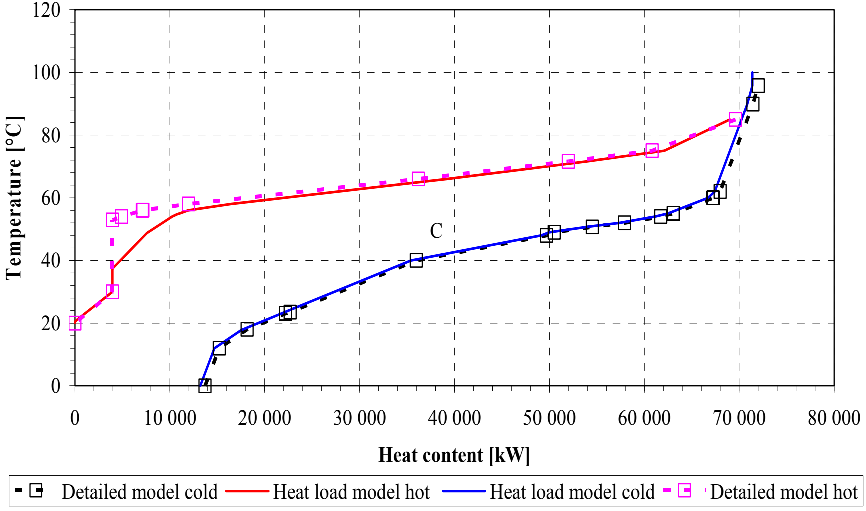

Figure 4.1: CC; comparison of detailed model and HLMPP of the paper mill (Hakala, Manninen, & Ruohonen, 2008)

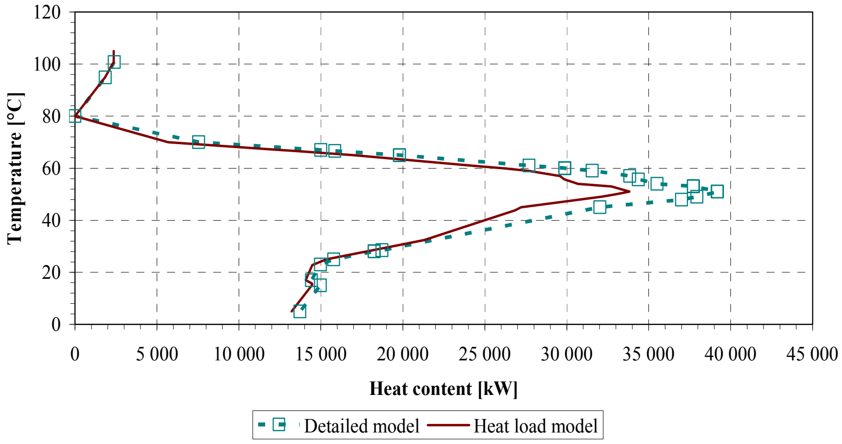

Figure 4.2: GCC; comparison of the detailed model and the HLMPP of the paper mill (Hakala, Manninen, & Ruohonen, 2008)

As can be seen in the figure, the results are almost identical regarding the minimum and cold utility demands and also the pinch temperature.

The same procedure was followed for a TMP mill and the results are shown in Figure 4.3 (Ruohonen, Hakala, & Ahtila, Testing of Heat Load Model for Pulp and Paper in two TMP cases).

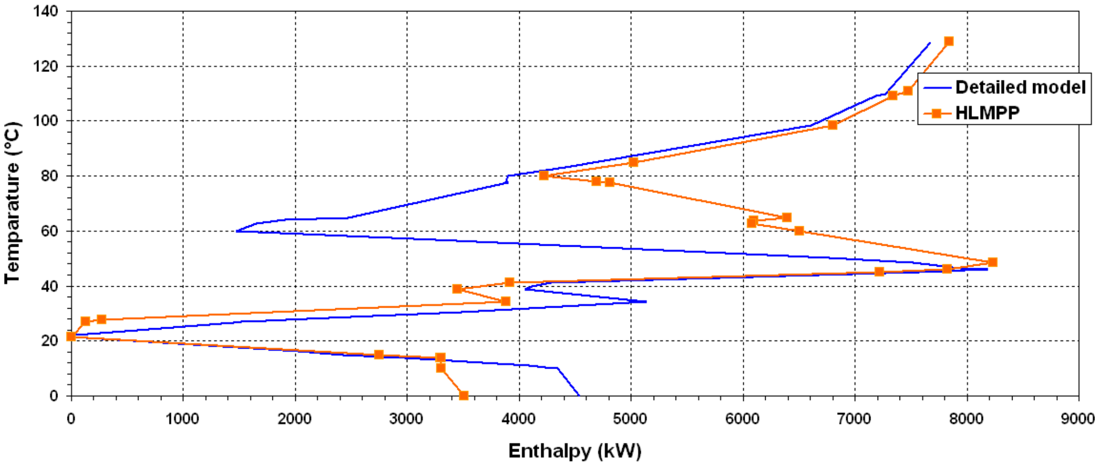

Figure 4.3: GCC of the process in detailed model and HLMPP (Ruohonen, Hakala, & Ahtila, Testing of Heat Load Model for Pulp and Paper in two TMP cases)

As can be seen in the figure, the pinch temperatures were almost identical for the detailed model and the HLMPP, as were the minimum hot utility demands (2% of difference). However, the minimum cold utility demands differed by 29%. The main reason is that HLMPP models the heat content of the exhaust air heat recovery of the paper machine as linear when, in fact, the dew point varies between 50 and 65°C when the dryer exhaust air moisture content ranges from 110 to 160 g_{water}/kg_{air}. Thus, in the model, all the heat of condensation is spread from the exhaust air temperature just before heat recovery, [70-85] °C, until the exhaust air temperature after heat recovery, [40-50] °C. This leads to a modification of the CC and the GCC shapes and this is the main uncertainty concerning the accuracy of the HLMPP.

4.2 Analysis of the FRAM Magazine paper Model Mill for validation of the HLMPP

During the work presented in this thesis, the FRAM model mill was the first mill to be analyzed using the HLMPP in order to practice using the tool and also to further validate it. The FRAM mill will be shortly described in the subsequent text and then the results obtained with the HLMPP will be described and discussed. A normal pinch analysis has previously been done for this model mill (Axelsson & Berntsson, 2005) and thus these results will be compared to the results obtained using the HLMPP.

4.2.1 The FRAM model mill

The FRAM,"Future Resource Adapted pulp Mill", Magazine paper mill is a Nordic project about a magazine paper mill model which was finished in June 2005. It consists of designing an integrated SC-paper reference mill which produces magazine paper using the best proven technologies available in 2003 in the Nordic countries. The mill is modelled with WinGEMS and includes one wood handling line, one TMP plant, one bleach plant and one paper machine. The paper recipe is presented in Table 4.1 (Åberg, Ebbe, Lundström, Backlund, Sivard, & Delin, 2005).

Table 4.1: Paper recipe for the FRAM magazine paper machine

Recipe		**PM**
TMP	[%]	58
GW	[%]	0
Kraft	[%]	12
RCF	[%]	0
Filler	[%]	30
Total prod	[ton/d]	**1306**

All the WinGEMS process charts were provided and details of each stream were available in an Excel file. As a result, the HLMPP required data were set according to the WinGEMS data and also to the FRAM report (Åberg, Ebbe, Lundström, Backlund, Sivard, & Delin, 2005). The mill is designed to be a net exporter of steam with 1.2GJ/ton paper. It means that there is no boiler and that all the clean steam comes from the TMP steam heat recovery. The steam mill demand is 64.5MW.

4.2.2 Results of the simulation and comparison with the detailed pinch analysis

The results of the detailed pinch analysis and the HLMPP will be compared below. However, to be comparable the systems considered must be the same. Indeed, in order to use a similar stream data set as the one that HLMPP builds, the process ventilation streams (reformer and chip bin ventilation, air from dryer) discussed in the detailed pinch report are included (Axelsson & Berntsson, 2005). The corresponding CC and GCC can be seen in Figure 4.3 and 4.4. The detailed pinch analysis of this FRAM model mill investigates preheating opportunities and heat recovery of the dryers exhaust gas.

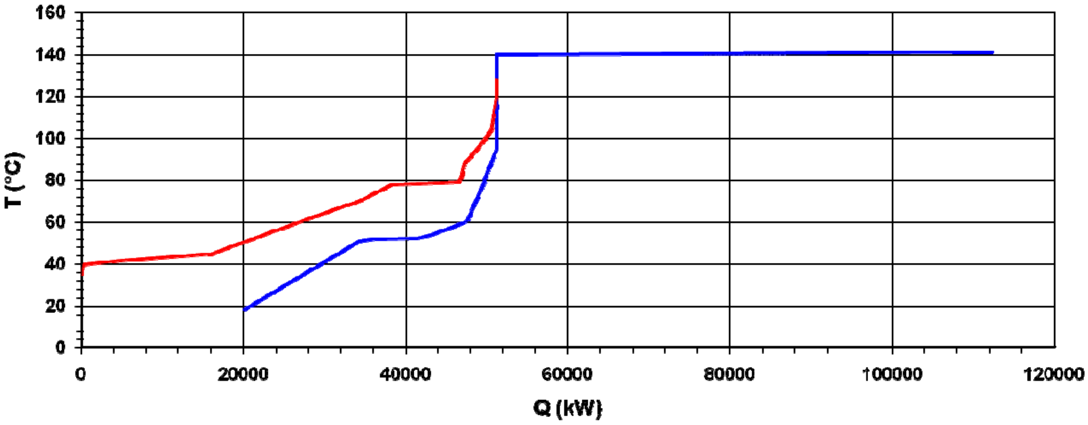

Figure 4.3: CC for the FRAM detailed case with process ventilation streams included

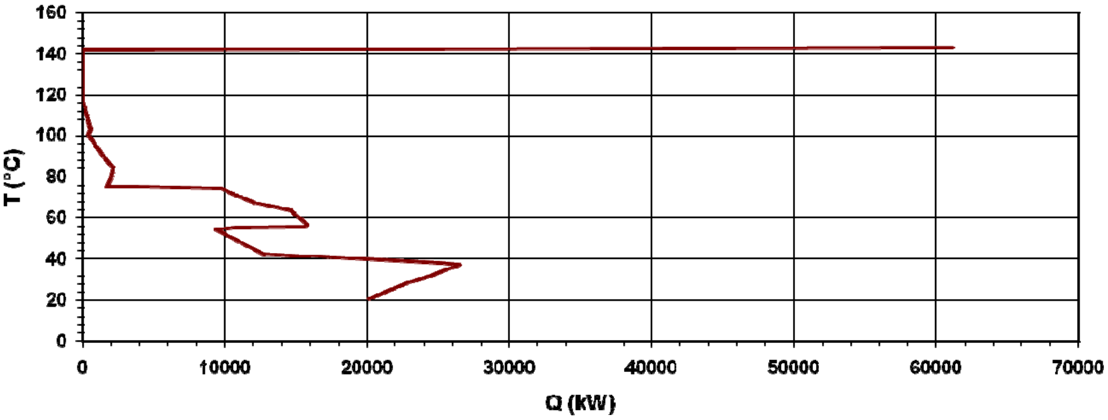

Figure 4.4: GCC for the FRAM detailed case with process ventilation streams included

For the detailed case, the minimum hot utility demand is 61.1MW and the minimum cold utility demand is 20.1MW. The pinch temperature is 124°C. Thus a potential of 3.4MW of steam could be saved with an updated HEN.

The HLMPP was used to model the FRAM mill using input data from the WinGEMs model and the FRAM report. Three streams are kept unchanged between the detailed case and the HLMPP case (due to technical considerations):

- The total steam demand of the dryer, press section and calender (horizontal line in the CC and GCC) is 61.1MW
- The motor cooling is 9.5MW from 70 to 40°C
- The refiner cooling is 1.7MW from 65 to 35°C

The HLMPP automatically integrates preheating opportunities of chips (See streams 43, 44 and 45 in Appendix 1) and in order to have the same system between the detailed pinch analysis and HLMPP, these are removed.

The corresponding CC and GCC gained using the HLMPP can be seen in Figure 4.5 and 4.6. The dotted lines represent the previous results of the detailed case.

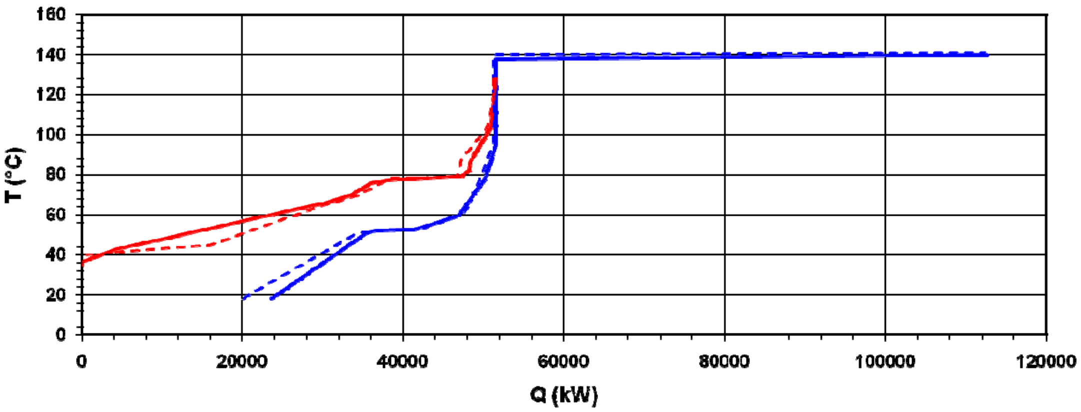

Figure 4.5: CC for the FRAM HLMPP case compared to the detailed case

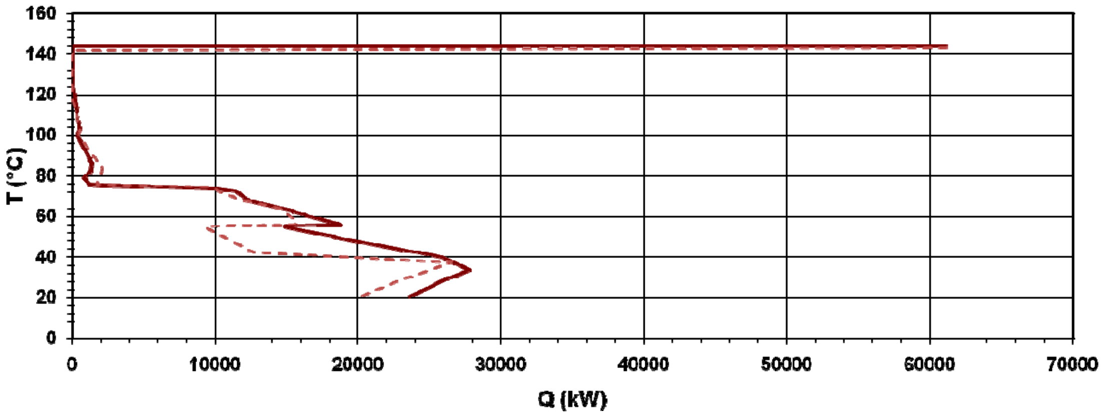

Figure 4.6: CC for the FRAM HLMPP case compared to the detailed case

For the HLMPP case, the minimum hot utility demand is also 61.1MW and the minimum cold utility demand is 23.6MW. The pinch temperature is again 124°C. Thus, apart from the dryer, press section and calender steam demand, all the other hot utility demands can be covered by a MER network.

The minimum hot utility demand is the same between both cases. One can notice a difference of 17% for the minimum cold utility demand between both cases. The main reason is that the fresh water consumption heated up before the warm water tank is higher in the detailed case with 11.7MW and only 9.7MW for the HLMPP case so a 20% variation between both cases.

4.3 Further improvement potentials possible to investigate using the HLMPP

The HLMPP is a flexible tool that allows easy identification of potentials to decrease the hot utility demand and/or the cold utility demand. For each mill, a reference case is simulated which is defined by specific climate conditions (air and water) and production. In addition, several sensitivity analyses are done for all the mills. Contingent on the mills reference case results, different scenarios are investigated such as:

- increasing the exhaust air moisture content of the dryers up to 160 g_{water}/kg_{air}

- removal of the internal district heating
- further cooling of waste water
- cut of fresh water consumptions in PMs by 20%

These different scenarios are further explained in each mill chapter respectively together with the reasons to why they were chosen.

5 First mill: Braviken Holmen

The Braviken mill, owned by the Holmen group, was opened in 1977. Located close to Norrköping, in the Braviken bay, the mill has progressively replaced the old mill in central Norrköping due to space limitation. In 1986, the old mill was shut down and Braviken substituted it completely. The raw materials used, for a corresponding paper production of 727 ktonnes of paper, are listed below, given per year (Holmen, 2008):

- Wood (spruce) from the nearby forests of middle Sweden, 1.01 Mm^3f
- Waste paper, 370 ktonnes
- Sulphate pulp, 4 ktonnes
- Around 1.7 TWh /year of electricity i.e. an average consumption of 194 MW

5.1 General overview -description of the system

The Braviken mill started production in 1977. It has a yearly average production capacity of 790 000 tonnes of paper per year and has three TMP (Thermo Mechanical Pulp) lines, two DIP (DeInked Pulp) lines and three PMs (Paper Machine). A mass yield of 98% is achieved for the TMP lines and 85% for the RCF lines. The general process is displayed below in Figure 5.1. As the Kraft pulp consumption is low compared to TMP and DIP (See previous paragraph), it is not considered in this study.

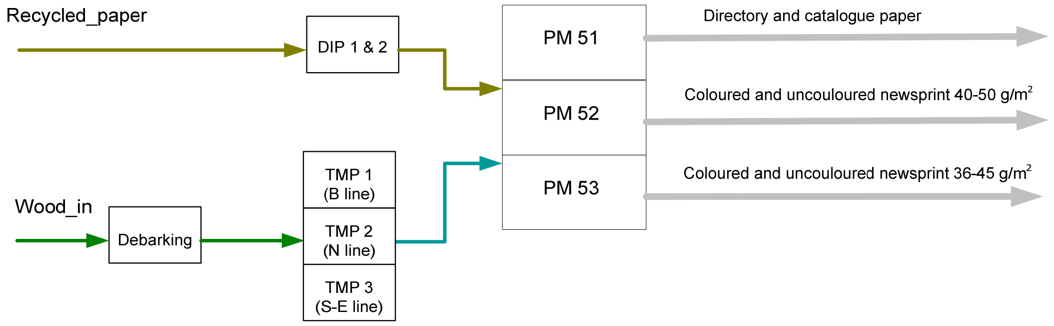

Figure 5.1: General process of the Braviken plant as simulated in the HLMPP

5.1.1 The TMP lines

The debarking line feeds all the three TMP lines with woodchips. The first TMP line, the B-line, consists of two pressurized primary stage High Consistency (HC)-refiners and a two stage reject system with two pressurized HC-refiners. The second TMP line, the N-line, is made of five pressurized primary stage HC refiners[7] and three secondary stage atmospheric refiners and reject system with a pressurized HC refiner and a Low Consistency (LC) refiner[8]. The third line, the SE line, has two pressurized primary stage HC refiners and two secondary stage pressurized HC refiners all in

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[7] HC refiner stands for high consistency refiner where the dry matter is high (around 40%). HC refiners produce dirty steam. The SEC for a HC refiner is higher than the SEC for a LC refiner.

[8] LC refiner stands for low consistency refiner where dry content is low (around 5%). LC refiners do not produce any steam. The SEC is lower than for a HC refiner.

parallel and a third stage with two LC refiners and a reject system with a pressurized HC-refiner. See Figure 5.2 for details.

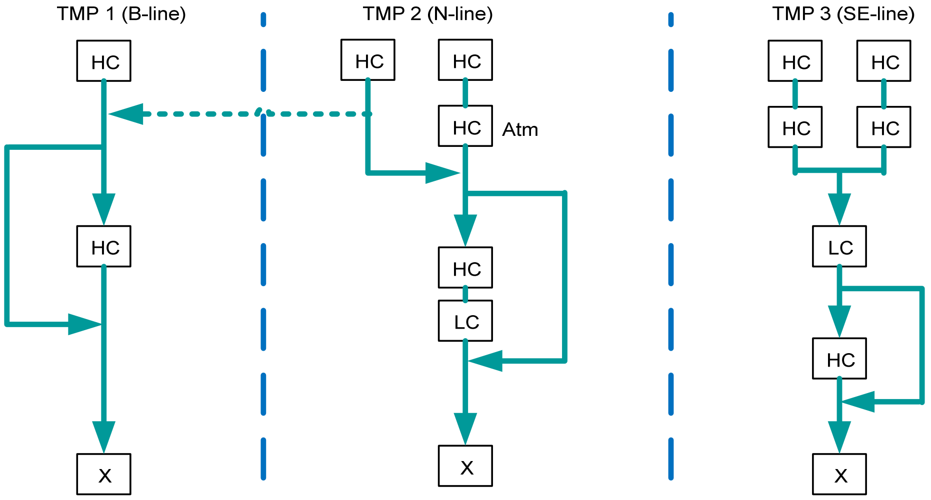

Figure 5.2: The TMP lines, one square box represent one stage (which may contain several refiners)

As one can notice, the B-line and N-line might communicate but for the simulated production case, this was not considered.

Concerning the TMP lines, the specific energy consumption (SEC) of each refiner is summarized in Table 5.1. LC refiners consume less electricity than HC refiners. However, the TMP steam production is very small (if any) for a LC refiner and, thus, is not included in the HLMPP.

Table 5.1: SEC of all the refiners as specified in the model

[MWh/ADt]	TMP 1 (B-line)	TMP 2 (N-line)	TMP 3 (SE-line)
Main line refining 1st stage	1.6	1.4	1.2
Main line refining 2nd stage	0.0 (None)	0.3	0.5
Reject line refining 1st stage	0.8	0.6	0.5
Reject line refining 2nd stage	0.0 (None)	LC refiner	0.0 (None)

The TMP3 line has also a third stage main line refining as described in Figure 5.2 but it is only LC refiners that do not contribute to the TMP steam production and thus are not taken into consideration for steam production in this study.

5.1.2 The DIP lines

There are two DIP lines, also called RCF in the HLMPP. However, in HLMPP, only one DIP is used to model both of them since the processes are similar.

5.1.3 The PM lines

The recipes of each PM are described in the Table 5.2 below.

Table 5.2: Paper recipe for Braviken paper machines

Recipe		**PM51**	**PM52**	**PM53**
TMP	[%]	78	65	53
GW	[%]	0	0	0
Kraft	[%]	0	0	0
RCF	[%]	19	32	44
Filler	[%]	3	3	3
Total prod	[ton/d]	**669**	**950**	**939**

The RCF content in PM53 is the largest one with 44%. Braviken is the largest TMP mills studied in this master thesis with 2558 tons of paper/day simulated. By comparing the simulated production case with the yearly average production capacity (790 ktonnes/year), one can notice that an overcapacity scenario was simulated. The web after the press section has a dry content of 44% for PM51 and 50% for both PM52 and PM53. for all PMs, the paper is drought until 92%.

5.1.4 Steam and water balance

The fresh water consumption has a major influence on the pinch analysis below the pinch temperature. Indeed, the heat demand for the warm water tank reaches 27.2MW with the daily production detailed in Section 5.1.3. Three kinds of water usage are distinguished at Braviken. The first one is the fresh water used in the PMs which is warmed in a tank called warmed water tank to achieve a target temperature between 58 and 60 °C depending on the PM line. The second is the makeup water for the steam process as the steam cycle is not a closed loop. The third corresponds to cooling water or other process water which is not heated up in a tank and is injected directly in the process. The HLMPP automatically calculates the third category but for the two first, data is required.

The consumption of fresh water of each PM is presented in Table 5.3. The fresh water inlet temperature varies seasonally between winter and summer. According to Braviken measurements, the fresh water early average value is 10.1°C and the mean yearly air temperature is 8.8°C. For the makeup water, see the Table 5.4. This stream is pressurized and is heated up to just below the saturated temperature.

Table 5.3: Fresh water to warm water tank and make up water for steam process

		PM51	PM52	PM53
Start temperature	[°C]	10.1	10.1	10.1
Mass flow	[m^3/ton of paper]	4.0	3.1	5.4
Target temperature	[°C]	60	59	58

Table 5.4: Make up water for steam cycle

		Stream data
Start temperature	[°C]	10.1
Mass flow	[kg/s]	18.3
Target temperature	[°C]	130.0

The steam balance is extracted from a 2009 data file “Ångförbrukning per användare” and is adjusted in order to correspond to the simulated production (See Section 5.1.3). It is summarized in Table 5.5. For the simulated production the total steam consumption is 136.5MW where 65.0MW comes from a bark boiler and the rest from the steam recovery system recovering TMP steam.

Table 5.5: Steam consumers

Unit	Steam consumption [MW]
PM51	
Wire section	0.0
Press section	3.7
Dryer	25.5
Winding	1.0
Warm water tank	0.6
PM52	
Wire section	0.0
Press section	4.7
Dryer	20.5
Winding	1.5

Warm water tank	0.7
PM53	
Wire section	2.5
Press section	4.6
Dryer	23.7
Winding	1.3
Warm water tank	3.4
TMP and DIP lines (Chips preheating/steaming, dispergator, etc.)	7.4
Internal district heating, VVG warming	6.7
Steam condensate warming	5.1
Make up water for steam cycle	6.0
Others	17.6
Total steam consumption	**136.5**

5.2 Quality of the data gathering and adjustments

With help from the mill personnel the HLMPP data gathering file was almost completely filled in except few parameters described here.

For all the PMs dryers, the web temperature after the dryers was undefined. Therefore the Norske Skog Skogn value was used, 85°C. Moreover, the exhaust air temperature for PM52 is considered equivalent to PM53, so 80°C. A very important parameter is the exhaust air temperature leaving the dryers after heat recovery. No such figures were specified and thus, a common temperature of 50°C was set for all the PMs air heat recovery system. The 50°C corresponds to the worst case scenario among all the other mills investigated at Norske Skog (that is all other mill investigated had exhaust air temperatures of 50°C or lower for their PMs).

All the waste waters are collected in the same pipe and, after mixing, the temperature is 40°C. It needs to be cooled down in order to maintain an optimal biological treatment and a target temperature of 35°C is chosen corresponding to the Norske Skog mills.

The mill also feeds an internal district heating system which distributes warm water in the whole site. It has a mass flow of 150 kg/s. As this district heating is a process stream aiming at supplying heat to different processes in the mill, it is made of two streams in the pinch analysis, one hot (which supplies heat) and one cold stream (which needed to be heated up) with the same temperature range [60;80] °C .

5.3 Results for the HLMPP analysis

An average case was simulated because mean steam consumptions per unit are given in Table 5.5. As a consequence, yearly average air temperature is extracted from Braviken measurements. The average air temperature at Braviken is 8.8°C and the yearly average fresh water temperature is 10.1°C as explained in Section 5.1.4.

The results for the average case are presented in the subsequent text.

5.3.1 Average case

The results for the average case, in form of the CC and the GCC curve, are displayed in Figure 5.3 and 5.4.

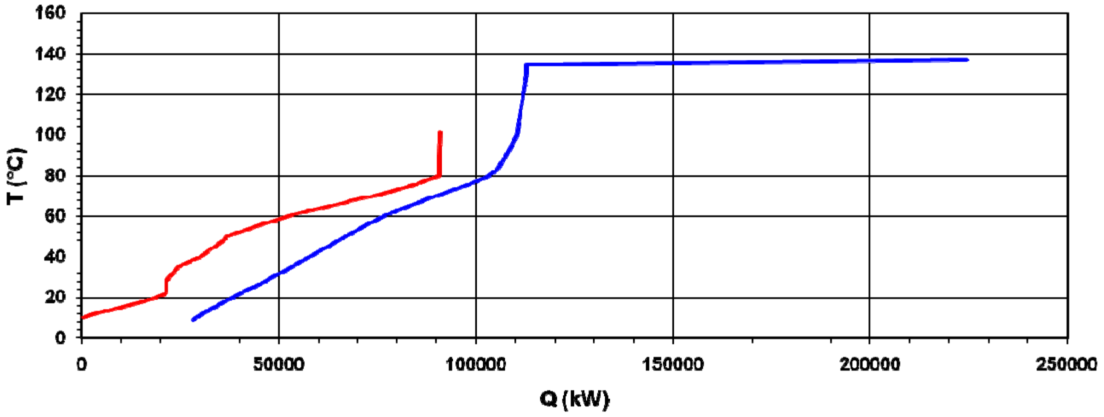

Figure 5.3: CC for the Braviken average case

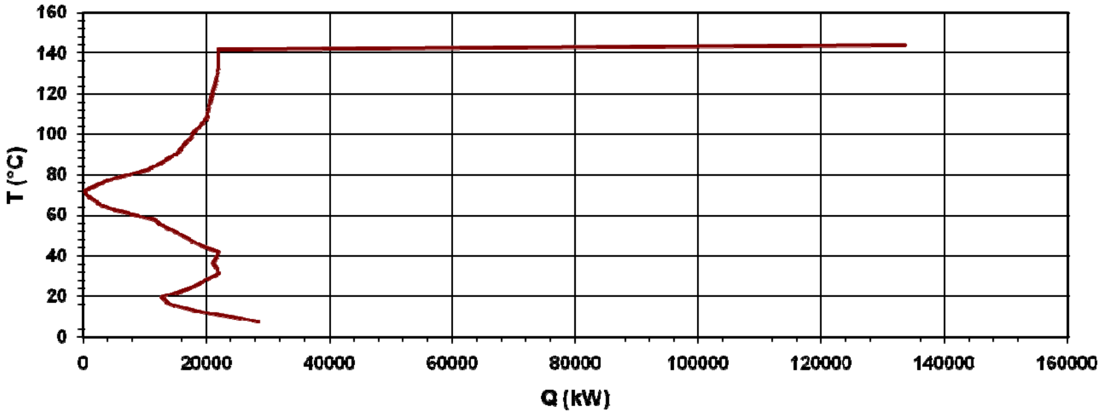

Figure 5.4: GCC for the Braviken average case

As can be seen in Figures 5.3 or 5.4, the pinch temperature for the average case is 72°C. The minimum cold utility demand amounts to 28.3MW and the minimum hot utility demand (minimum steam consumption) amounts to 133.6MW.

5.3.2 Potential for steam savings

How the potential for steam savings is calculated is further explained in Appendix 3.

By comparing the minimum hot utility consumption, 133.6MW, to the current steam consumption, 136.5MW, a potential for steam savings equal to 2.9MW was found, representing pinch violations in the existing HEN. In order to find the exact locations of the pinch violations and to be able to realize the steam savings, a normal pinch analysis needs to be performed after which the HEN needs to be rebuilt.

Excess heat, the minimum cold utility demand, is available up to 72°C. Applications are limited with such a low maximum temperature but some exists and these are described in Section 5.5.

5.4 Sensitivity analyses

Three sensitivity analyses are performed for the Braviken mill. The first analysis aims at studying the influence of reduced fresh water consumption in the PMs and makeup water for steam process by 20% (Section 5.4.1). The second analysis shows to what extent the dryer technology, in form of the exhaust air moisture content, impacts the potential for process integration (Section 5.4.2). Finally, the third analysis investigates the influence of the internal process district heating on the shapes of the CC and the GCC (Section 5.4.3).

All of sensitivity analyses are done for the average case.

5.4.1 Cut of fresh water consumption by 20%

The fresh water, which is heated up, requires substantial amounts of energy. In this analysis the water consumption in the PMs is decreased by 20% from 4.0 to 3.2m^3/ton of paper for PM51, from 3.1 to 2.5m^3/ton of paper for PM52 and from 5.4 to 4.3m^3/ton of paper for PM53. The same is done with the make up water used in the steam cycle so the water flow is decreased by 20% from 18.3 to 14.6 kg/s. Hence 28.5kg/s of fresh water is avoided. The flow of total effluent to waste water is adjusted by removing 28.5kg/s. It should be noted that Braviken has a fairly low water consumption to start with compared to the other mills analysed in this thesis. Figure 5.5 shows the resulting GCC for this analysis.

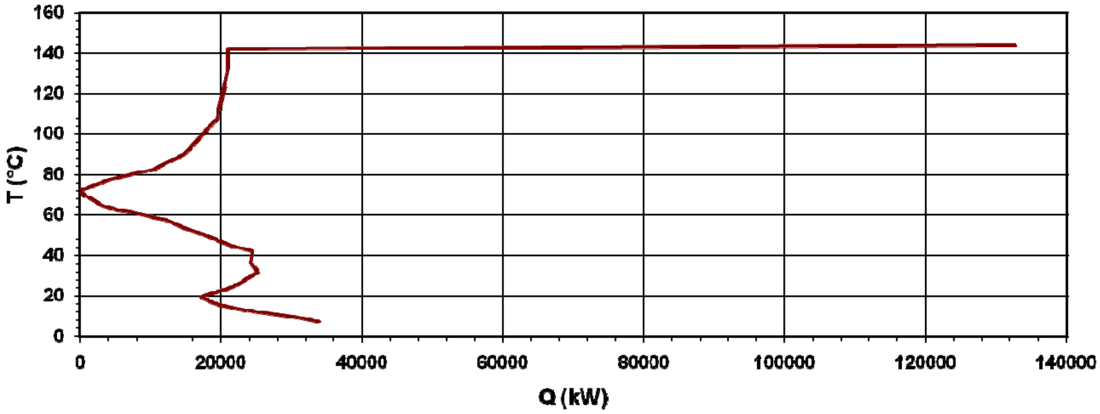

Figure 5.5: GCC for the analysis with 20% decreased water consumption

A lower fresh water consumption in the PMs (which means less flow to the warm water tank) changes only the minimum cold utility demand since the target temperature in of this water is below the pinch temperature. However, a lower make up water consumption influences both the minimum and the hot utility demands since its temperature range is both above and below the pinch temperature, which remains constant at 72°C. If the water consumption is decreased as described, the cold utility demand is 33.7MW instead of 28.3MW for the average reference case. The water consumption is a cold stream; it needs to be heated up. Thus, a lower fresh water heating demand will release extra heat below the pinch represented as the cold utility demand. The minimum hot utility demand, 132.7MW i.e. the minimum steam consumption is lower than the average reference case, 133.6MW, indicating an additional savings potential of 0.9MW.

5.4.2 Higher moisture content in air leaving the dryers

The exhaust air moisture leaving the dryers before going to the heat recovery system is currently at 110g water/kg air for PM51, 145g water/kg air for PM52 and 143g water/kg air for PM53. For a modern dryer the value can be ~160g water/kg air (Karlsson, 2000). Thus, in this analysis the exhaust air moisture is set to 160g water/kg air for all the PM dryers. Dryers with higher moisture content require lower air flow, thus a lower heating duty of incoming air. Figure 5.6 shows the GCC for this analysis.

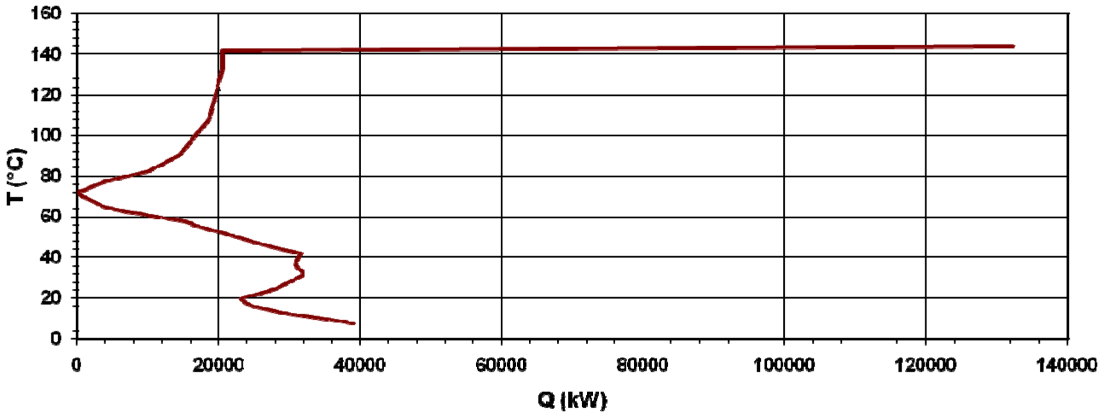

Figure 5.6: GCC for the analysis of more efficient dryers

As can be seen in the figure, the pinch temperature remains constant at 72°C when the exhaust air moisture is increased to 160 g water/kg air. However, the potential steam savings is increased to 4.3MW (compared to 2.9 for the average reference case). At the same time, the minimum cold utility demand is increased to 38.9MW because the exhaust air recovery is much more efficient with higher moisture content and some of the heat recovered is below the pinch temperature. For this scenario, 41.5MW of heat are recovered in the exhaust air heat recovery unit compared to 33.1MW for the average reference case.

5.4.3 Influence of the internal district heating

Due to a similar situation with the Norske Skog Skogn mill where it was shown that the presence of an internal district heating system caused pinch violations (Festin & Mora, 2009), it was decided to study the impact of the internal district heating. Hence, in this analysis the district heating streams are virtually removed from the stream data used in the pinch analysis. This would require a major rebuild of the HEN. Another alternative would be to only rebuild the HX where the pinch violations are. However, to identify the exact locations of pinch violations a normal pinch analysis needs to be done. Thus this analysis only shows how much pinch violations there are that are related to the internal district heating system in the existing HEN.

The results show an interesting potential as can be seen in Figure 5.7. By removing the internal district heating, the pinch temperature remains unchanged at 72°C and a total of 6.0MW of steam can be saved (compared to 2.9MW for the average reference case). At the same time, the minimum cold utility demand is decreased to 25.2MW (compared to 28.3MW for the average reference case) since more internal heat exchange is done.

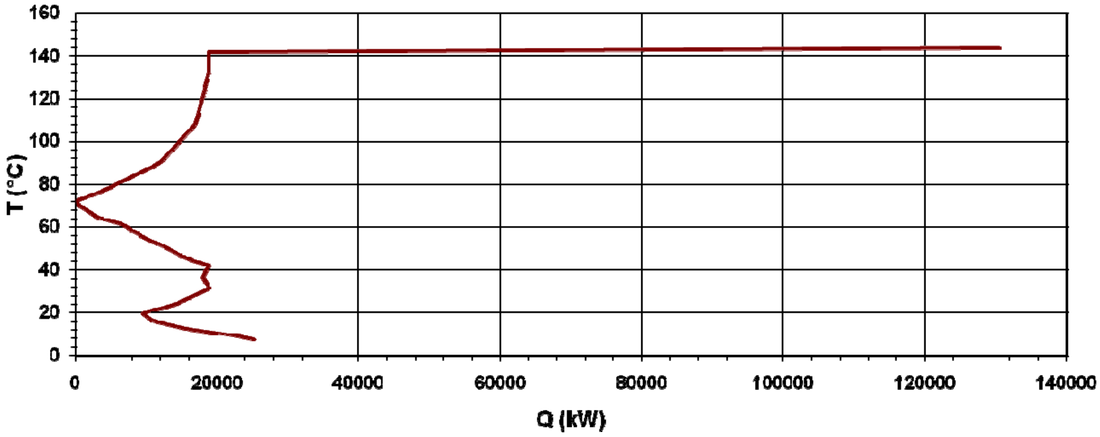

Figure 5.7: GCC for the case without district heating streams

5.5 Summary for Braviken

Table 5.6 summarizes the different results obtained for the Braviken mill.

Table 5.6: Summary of the different cases for the Braviken mill

	Potential for steam savings (MW)	**Potential warm water available* (MW)**	**Pinch temperature (°C)**
Reference average case	2.9	28.3	72.0
Sensitivity analyses			
1) -20% fresh water usage	3.8	33.7	72.0
2) modern dryers	4.3	38.9	72.0
3) no internal district heating	6.0	25.2	72.0

**This warm water can be up to 72°C (interval temperature) and this potential corresponds to the minimum cold utility demand*

As can be seen in the table, up to 4.4% of the current steam consumption can be avoided with an optimized, retrofitted HEN without any internal district heating system (see results for the third sensitivity analysis).

Potentials of warm water available correspond to the minimum cold utility demands found. The warm water temperature can be up to the pinch temperature so a maximum temperature of 72°C. That water has a low temperature thus there are not so many applications. The few possible applications can be pre-heating of external district heating water or export it to another close plant which might need it.

Braviken could also import excess heat. Indeed; a saw mill is under construction just nearby (which will be completed in 2010). Considering that the saw mill will have excess heat at around 90°C and that the pinch temperature at Braviken is 72°C further integration is also of utmost interest and could further reduce the process steam demand at the mill since the saw mill excess heat can be partly used.

The GCC shows promising potential for a heat pump (HP) concept of around 10MW. Appendix 4 describes how to identify HP opportunities with a GCC. An Organic Rankine Cycle (ORC) could also use this warm water as the heat source in such a cycle should be between 55 and 125°C (Hackl & Perret, 2009). However, the HLMPP is not a real pinch analysis and, hence, these opportunities must be further investigated.

6 Second mill: Norske Skog Follum

Norske Skog Follum (Follum) started production in 1873. The mill consists of two PMs, PM1 and PM7, PM7 was rebuilt in 1995. The characteristics of the Follum mill are described in Table 6.1.

Table 6.1: Important data for Follum (Norske Skog Follum, 2010)

Machines		**PM1**	**PM7**
Trimmed width	[cm]	560	560
Paper quality		Improved Newsprint	MFC
Production capacity	[ton/year]	145 000	135 000
Dip content	[%]	0	0

6.1 General overview/ Description of the system

The Follum mill has two PM lines fed with TMP (from two TMP lines) and filler but no DIP. PM7 also uses some imported Kraft pulp. Figure 6.1 displays the general process overview.

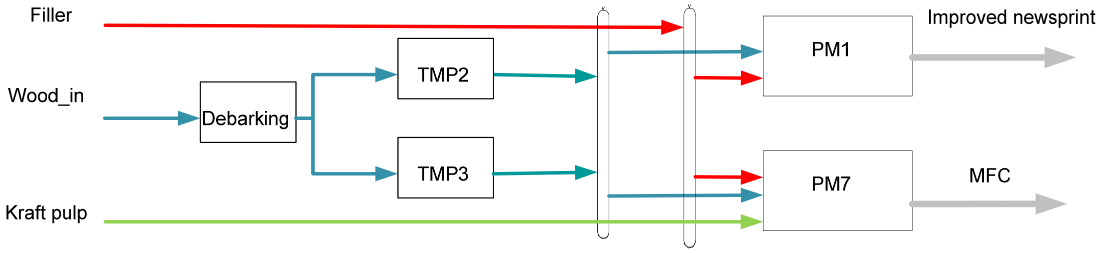

Figure 6.1: Overview of the plant's process

6.1.1 The TMP lines

<u>TMP2:</u> This line represents 70% of the total pulp production from the mill. The main line refining is made of two pressurized stages which consume 1.2 MWh/ADt and 1.1 MWh/ADt of electricity respectively. The main line sorting accept ratio is 70%. The remaining 30% goes to the reject line refining. The specific energy consumption of the pressurized reject refining is included in the numbers reported for the second stage of the main line.

<u>TMP3:</u> The TMP3 line produces 30% of the total pulp production. The main line refining consists of one pressurized stage using 1.6 MWh/ADt of electricity. From the main line refining, 45% of the produced pulp is sent to the reject refining line where 1.2 MWh/ADt of electricity is used in a pressurized reject refiner.

6.1.2 The PM lines

The paper recipe and the production rate of each PMs used in the simulation are shown in Table 6.2.

Table 6.2: Paper recipe for Follum paper machines

Recipe		**PM1**	**PM7**
TMP	[%]	94	94
GW	[%]	0	0
Kraft	[%]	0	4
RCF	[%]	0	0
Filler	[%]	6	2
Total paper prod	[ton/d]	377	345

After the press section the web has a dry content of 42% for both PMs and needs to be drought until 91.5% for PM1 and until 94% for PM7. Coated paper is produced in PM7.

As one can observe in the Table 6.2, Follum makes use of mainly TMP produced on-site and imports few percents of Kraft pulp. Thus the TMP lines generate a lot of dirty steam which is partly recovered to clean steam. More details regarding this is given in Section 6.1.3.

6.1.3 Steam and water balance

The fresh water consumption has a major influence on the pinch analysis. For Follum, two kinds of water usage are distinguished. The first one is the fresh water used in the PMs which is warmed in a tank called warmed water tank to achieve a temperature range of [30, 55 °C] depending on the PM line. The second one corresponds to cooling water or other process water which is not heated up.

The consumption of fresh water of each PM is presented in Table 6.3. The fresh water inlet temperature varies seasonally between 1°C (winter) and 16°C (summer). The overall fresh water consumption which includes the fresh water for the refiners and other fresh water used as process water is equal to 16 m^3/ton of paper.

Table 6.3: Fresh water to warm water tank

Fresh water to warm water tank		PM1	PM7
Start temperature	[°C]	1/16	1/16
Mass flow	[m^3/ton of paper]	7	12
Target temperature	[°C]	45	32

The steam balance with all the steam consumers is presented in Table 6.4. For the simulated production rate, the total steam consumption is 47.9MW where 14.1MW comes from a bark and sludge boiler and the rest from the steam recovery system recovering TMP steam.

Table 6.4: Steam consumers

Unit	Steam consumption [MW]
PM1	
Warm water tank	2.7
Ventilation	1.9
Press section	1.7
Dryer	14.6
PM7	
Warm water tank	1.1
Ventilation	2.3
Press section	1.2
Dryer	12.0
Debarking	0.6
TMP2	
Preheating+steaming	4.1
Refining	0.4
TMP3	

Preheating+steaming	1.8
Refining	0.4
Sewage treatment	2.3
Other	0.8
TOTAL	47.9

The steam consumptions in Table 6.4 are extracted from the “Energikart” (2004 data). Another steam balance was given called “Massebalanser dampnettet v5” but without detailed consumption of steam per unit. However, this last steam balance file mentions a certain amount of TMP steam blown out which accounts for 2.0MW on average level. After discussing with Lasse Blom (specialist pulp and fibre at Norske Skog Focus AS), it was found that the steam is blown out due to a relative slow regulation at the boiler, and therefore it is intermittent. As a consequence, the potential of steam savings given in Sections 6.3.4 and 6.4 are independent of this amount TMP steam blown out.

6.2 Quality of the data gathering

With help from the mill personnel the HLMPP data gathering file was almost completely filled in except few parameters described here. For the PMs, no measurements were found for the exhaust air moisture content and temperature. After discussion with mill personnel the values found at Skogn were used also for the Follum mill (120 g water/kg air and 73°C). No heating or cooling is done of white water and other filtrates (cloudy filtrates, etc.).

6.3 Results of the simulation

An average case was simulated because mean steam consumptions per unit were used as a basis for the numbers presented in Table 6.4. For average yearly air temperature, climate data from the Norwegian Meteorological Institute (eKlima, 2009) was used. The average air temperature at Follum is 4.7°C and the fresh water is also at 4.7°C because average air and water temperature are close (Livingstone & Lotter, 1996).

The results for the average case are presented in the subsequent text.

6.3.1 Average case

Figure 6.2 and 6.3 shows the resulting CC and GCC for the average case.

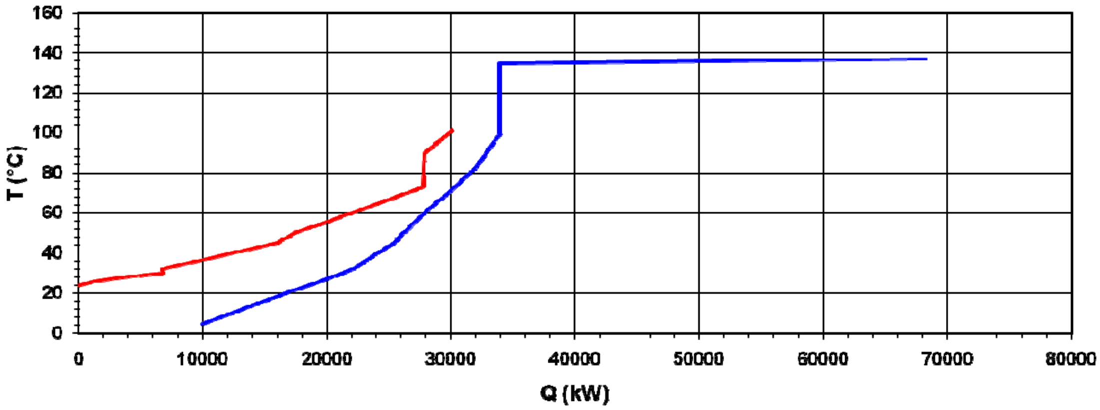

Figure 6.2: CC for the Follum average case

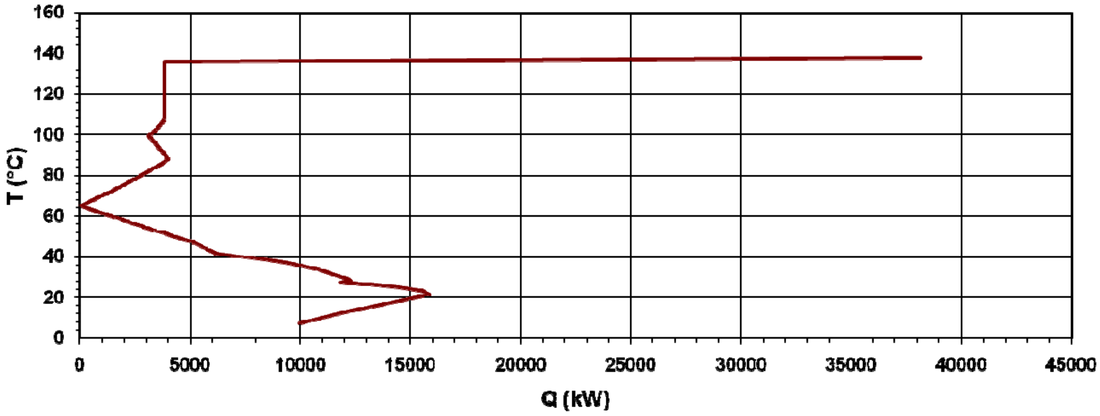

Figure 6.3: GCC for the Follum average case

For the average case, the minimum hot utility demand is 38.2MW and the minimum cold utility demand is 10.0MW. The pinch temperature is 65°C.

6.3.2 Potential for steam savings

How the potential for steam savings is calculated is further explained in Appendix 3.

By comparing the minimum hot utility consumption, 38.2MW, to the current steam consumption, 48.1MW, a potential for steam savings equal to 9.7MW was found, representing pinch violations in the existing HEN. In order to find the exact locations of the pinch violations and to be able to realise the steam savings a normal pinch analysis needs to be performed after which the HEN needs to be rebuilt.

Excess heat, the minimum cold utility demand, is available up to 65°C. Applications are limited with such a maximum temperature but some exists and are detailed in Section 6.5.

6.4 Sensitivity analysis

Two sensitivity analyses are performed for the Follum mill. The first analysis aims at studying the influence of reduced fresh water consumption in the paper machines by 20% (Section 6.4.1). The second analysis shows to what extent the dryer technology and the exhaust air moisture content impacts the potential for process integration (Section 6.4.2). Both sensitivity analyses are done for the average case.

6.4.1 Cut of fresh water consumption in PMs by 20%

The fresh water consumption in the PMs is heated up and thus requires substantial amounts of energy. In this analysis the water consumption in the PMs is decreased by 20% from 7 to 5.6m^3/ton of paper (PM1) and from 12 to 9.6m^3/ADt (PM7). Hence 30 kg/s of fresh water is avoided. The flow of total effluent to waste water is adjusted by removing 30 kg/s. Figure 6.4 shows the resulting GCC for this analysis.

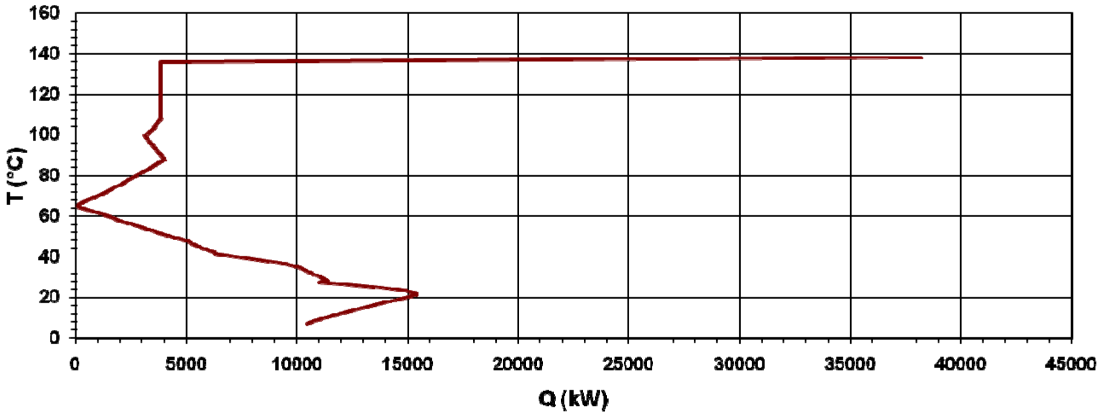

Figure 6.4: GCC for the analysis with decreased water consumption in the PMs

A lower fresh water consumption in the PMs (which means less flow to the warm water tank) changes only the minimum cold utility demand since the target temperature in of this water is below the pinch temperature. If the water consumption is decreased as described, the cold utility demand is 10.5MW instead of 10.0MW for the average reference case. The pinch temperature, 65°C and the minimum hot utility demand, 38.2MW i.e. the minimum steam consumption remain identical compared to the reference average case. All in all, the 20% reduction of water consumption shows no large effect on the potential for savings.

6.4.2 Higher moisture content in air leaving the dryers

The exhaust air moisture leaving the dryers before going to the heat recovery system (done here through a scrubber) is currently at 120 g water/kg air. For a modern dryer the value can be ~160g water/kg air (Karlsson, 2000). Thus, in this analysis the exhaust air moisture is set to 160g water/kg air for both PM dryers. Dryers with higher moisture content require lower air flow, thus a lower heating duty of incoming air. Figure 6.5 shows the GCC for this analysis.

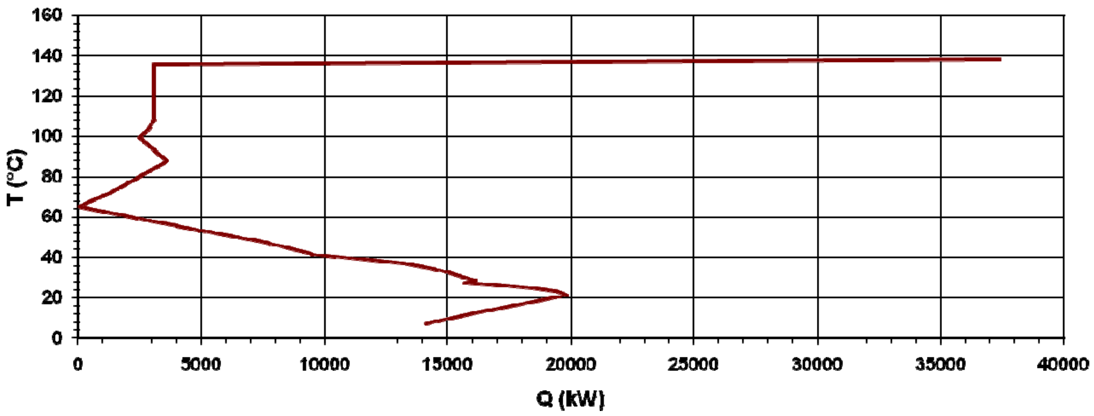

Figure 6.5: GCC for the analysis of more efficient dryers

As can be seen in the figure, the pinch temperature remains constant at 65°C when the exhaust air moisture is increased to 160 g water/kg air. However, the potential steam savings is increased to 10.5MW (compared to 9.7MW for the average reference case). At the same time the minimum cold utility demand is increased to 14.1MW because the exhaust air recovery is much more efficient with higher moisture content and some of the heat recovered is below the pinch temperature. For this scenario, 15.0MW of heat are recovered in the exhaust air heat recovery unit compared to 11.8MW for the average reference case.

6.5 Summary for Follum

Table 6.5 summarizes the different results obtained for the Follum mill.

Table 6.5: Summary of the different cases for the Follum mill

	Potential for steam savings (MW)	**Potential warm water available* (MW)**	**Pinch temperature (°C)**
Reference average case	9.7	10.0	65
Sensitivity analyses			
1) -20% fresh water flow	9.7	10.5	65
2) modern dryers	10.5	14.1	65

**This warm water can be up to 65°C (interval temperature) and this potential corresponds to the minimum cold utility demand*

As can be seen in the table, up to 21.9% of the current steam consumption can be avoided with an optimized, retrofitted HEN (see results for the second sensitivity analysis).

Potentials of warm water available correspond to the minimum cold utility demands found. The warm water temperature can be up to the pinch temperature so a maximum temperature of 65°C. That water has a low temperature thus there are not so many applications. The few possible applications can be pre-heating of district heating water, export it to another close plant which might need it, etc. However, no plant which can use this warm water is located nearby Follum.

Further, the GCCs show a promising potential for a HP concept of around 3MW. Appendix 4 describes how to identify HP opportunities with a GCC. However, the HLMPP is not a real pinch analysis and, hence, this option must be further investigated.

7 Third mill: Norske Skog Saugbrugs

Saugbrugs was inaugurated in 1859. During the nineties, Norske Skog Saugbrugs invested in a new boiler, a new PM line called PM6 (1991), a major rebuild of the PM5 (1998) and PM4 (1992). Saugbrugs produces SC paper on all of the PMs. The pulp production consists of TMP (86%) and GW (14%). The characteristics of Saugbrugs are detailed in Table 7.1.

Table 7.1: Important data for the Saugbrugs mill (Norske Skog Saugbrugs, 2010)

Machines		**PM4**	**PM5**	**PM6**
Trimmed width	[cm]	460	620	862
Paper quality		SC	SC	SC
Production capacity	[ton/year]	125 000	125 000	300 000
Dip content	[%]	0	0	0

7.1 General overview/ Description of the system

The Saugbrugs mill has three PMs fed with TMP, Kraft pulp, GW pulp and filler but no DIP. Only the TMP and the GW pulps are produced in the mill in a single TMPl line and a single GW line. The TMP line provides 48% in average of the PMs total mass input. The GW line will probably be shut down in a near future but is included in the analysis. Figure 7.1 displays the general process overview.

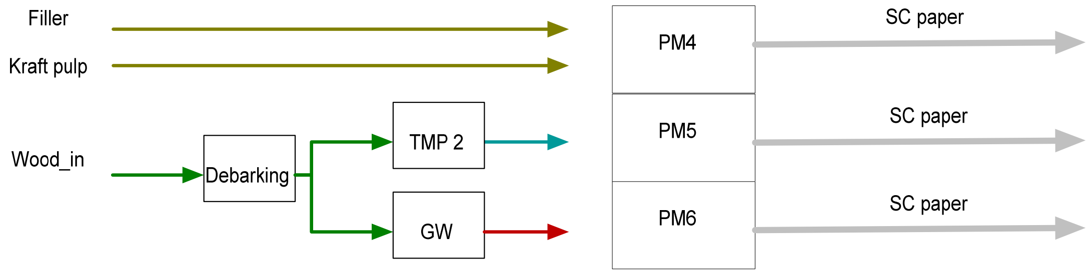

Figure 7.1: Overview of the plant's processes

7.1.1 The TMP line

TMP 2 produces all the TMP used in the PMs. The main line refining is made of two pressurized stages which consume 1.2 and 0.8 MWh/ADt of electricity respectively. The reject refining is also pressurized and consists of two stages consuming 1.2 and 0.6 MWh/ADt of electricity respectively.

7.1.2 The PM lines

The paper recipe and the production rate of each PMs used in the simulation are shown in Table 7.2.

Table 7.2: recipe and daily production rate of the paper lines

Recipe		**PM4**	**PM5**	**PM6**
TMP	[%]	19	59	55
GW	[%]	35	0	0
Kraft	[%]	16	8	12
RCF	[%]	0	0	0
Filler	[%]	30	33	33
Total paper prod	[ton/d]	**298**	**326**	**737**

After the press section the web has a dry content of 48% for all the PMs and needs to be drought until 97.5% for both PM4 and PM5 and 97.3% for PM6.

7.1.3 Steam and water balance

The consumption of fresh water of each PM is presented in Table 3.3. One can notice that the PM4 and PM5 water consumption are higher than the water consumption in any of the other PMs studied in this report (see Section 2.1.3 and 4.1.3). The fresh water temperature varies between winter, 1°C and summer, 15.7°C.

Table 7.3: Fresh water to warm water tank

Fresh water to warm water tank		**PM4**	**PM5**	**PM6**
Start temperature	[°C]	1/15.7	1/15.7	1/15.7
Mass flow	[m^3/ton of paper]	15.1	22.5	6.5
Target temperature	[°C]	54	60	56

The steam balance for a winter period is presented in Table 7.4. For the simulated production rate the total steam consumption is 105.1MW where 44.4MW comes from a boiler and the rest from the steam recovery system recovering TMP steam.

Table 7.4: Steam consumers

Unit	Steam consumption [MW]
PM4	
Dryer	11.8
Wire silo	3.9
Fresh water	2.9
PM5	
Dryer	17.5
Ventilation	2.6
Fresh water	5.1
PM6	
Dryer	27.1
Steambox	2.2
Wire silo	12.2
Fresh water	1.3
Ventilation	3.1
TMP2	
Miscellaneous	15.4
TOTAL	**105.1**

7.2 Quality of the data gathering

With help from the mill personnel the HLMPP data gathering file was almost completely filled in except few parameters described here.

The temperature variation of a filtrate (currently heated with steam), from the wire silo, was estimated to have a starting temperature of 50°C and a target temperature of 60°C. All the cooling duties in each line use reference values and the coolant exit temperature is assumed to be 30°C.

7.3 Results of the simulation

A winter case was simulated because mean steam consumptions per unit during a winter week are used in Section 7.1.4. For the air temperatures climate data from the Norwegian Meteorological Institute (eKlima, 2009) was used. Winter denotes the coldest average monthly temperature, January (air is at -2.9°C and water at 1°C).

The results for the winter case are presented in the subsequent text.

7.3.1 Winter case

The results for the winter case, in form of the CC and GCC curve, are displayed in Figure 7.2 and 7.3.

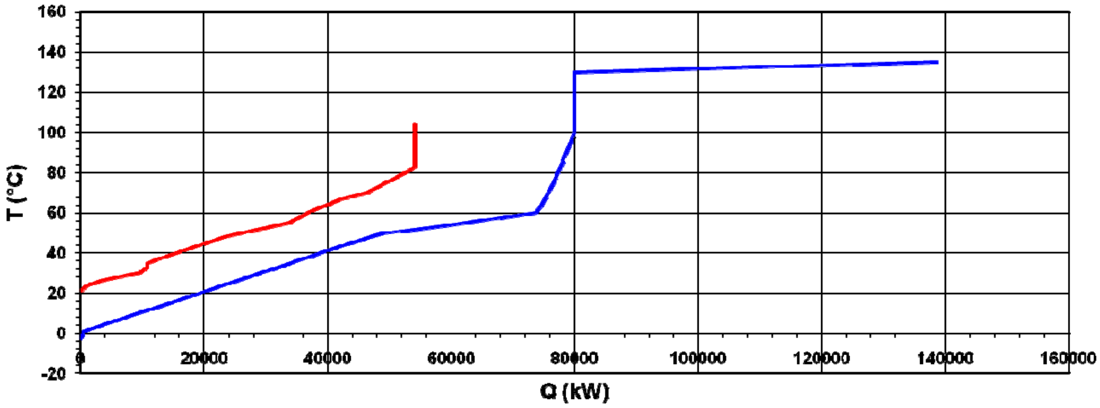

Figure 7.2: CC for the Saugbrugs winter case

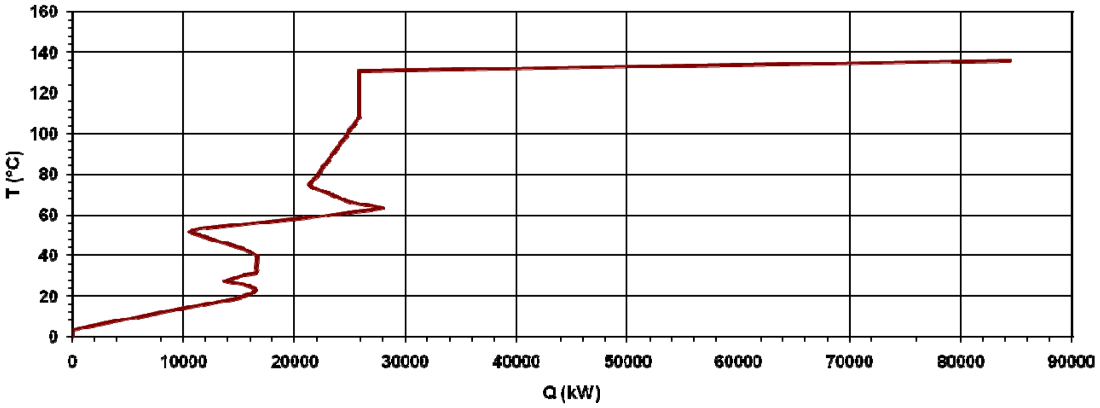

Figure 7.3: GCC for the Saugbrugs winter case

As can be seen in the Figures 7.2 and 7.3, the pinch temperature is very low during winter, only 0°C. The main reason for this is the high fresh water consumption and the cold water temperature. As a result, the minimum cold utility demand is 0MW and the minimum hot utility demand is 84.4MW.

7.3.2 Potential for steam savings

How the potential for steam savings is calculated is further explained in Appendix 1.

By comparing the minimum hot utility consumption, 84.4MW, to the current steam consumption, 105.1MW, a potential for steam savings equal to 20.7MW was found, representing pinch violations in the existing HEN. In order to find the exact locations of the pinch violations and to be able to realise the steam savings a normal pinch analysis needs to be performed after which the HEN needs to be rebuilt.

Potential for steam savings could be higher if the pinch temperature is increased. One solution aiming at raising the pinch temperature is investigated in the sensitivity analysis.

7.4 Sensitivity analyses

Three sensitivity analyses are performed for Saugbrugs mill.

The first aims at increasing the pinch temperature by further cooling of the waste water (Section 7.4.1). The second analysis studies the influence of reduced fresh water consumption in the PMs (Section 7.4.2).The last analysis (Section 7.4.3) shows to what extent the dryer technology, in form of the exhaust air moisture content, impacts the potential for process integration

All of sensitivity analyses are done for the winter case.

7.4.1 Further cooling of the waste water

In this sensitivity analysis it is assumed that the waste water is cooled until 20°C instead of the current 35°C. The sewage plant needs waste water at 35°C on account of the biological treatment but the idea is to use a part of the heat content of the waste water leaving the sewage plant. The waste water looses 1-3 degrees Celsius all along the sewage treatment but it is considered to be still at 35°C when leaving the sewage unit in this simulation.

The results show an interesting potential as can be seen in Figure 7.4.

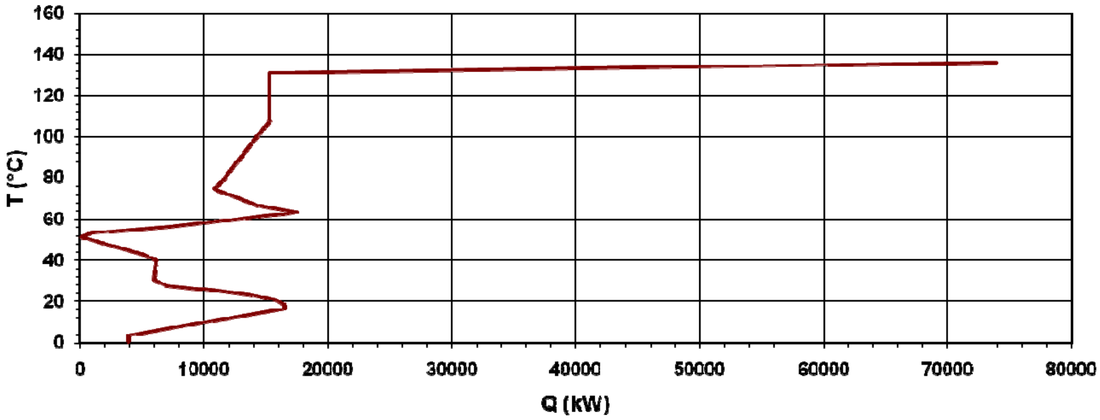

Figure 7.4: GCC for the case with further cooling of the waste water

The new pinch temperature is 52°C (compared to 0°C in original winter case) and a total of 31.2MW of steam can be saved (compared to 20.7MW). The minimum cold utility demand is 3.9MW compared to 0MW previously. However, this change requires a major rebuild of the HEN and thus must be further examined by a normal pinch analysis.

7.4.2 Cut of fresh water consumption by 20% in PMs

The fresh water which is heated up requires substantial amounts of energy. This is particularly true for Saugbrugs due to the mill´s high water consumption. In this analysis the water consumption in the PMs is decreased by 20% from 15.1 to 12.1m^3/ton of paper (PM4), from 22.5 to 18m^3/ton of paper (PM5) and from 6.5 to 5.2m^3/ton of paper (PM6). Figure 7.5 shows the resulting GCC for this analysis. Hence 38.4kg/s of fresh water is avoided. The flow of total effluent to waste water is adjusted accordingly.

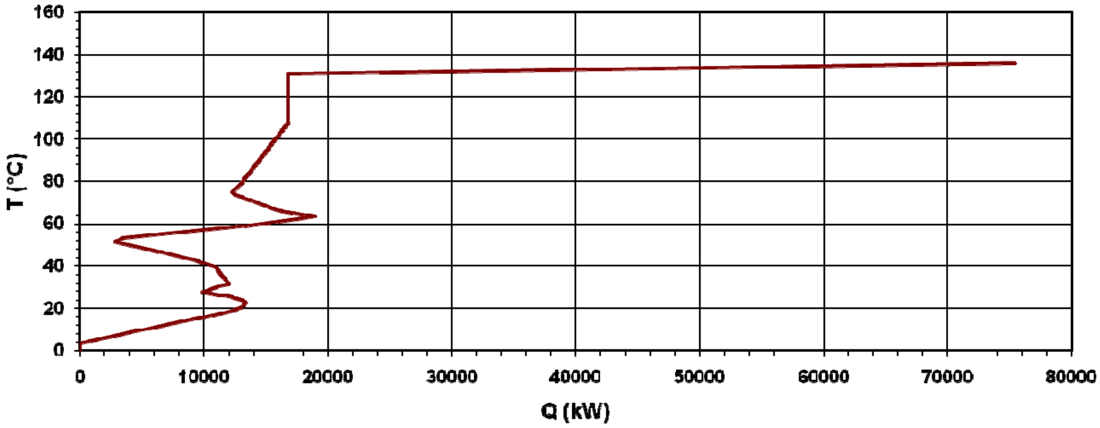

Figure 7.5: GCC for the analysis with decreased water consumption in the PMs

As can be seen in the figure, a lower fresh water consumption in the PMs (which means less flow to the warm water tank) gives the same pinch temperature, 0°C. But the decreased water usage leads to an increased potential for steam savings equal to 26.5MW compared to 20.7MW for the reference winter case. A higher decrease of fresh water consumption, if technically feasible, would put the pinch temperature up to 52°C and the shape of the GCC would look more like the one for the first sensitivity analysis (See Section 7.4.1).

7.4.3 Higher moisture content in air leaving the dryers

The exhaust air moisture leaving the dryers is currently between 112 and 135 g water/kg air. For a modern dryer the value can be ~160 g water/kg air (Karlsson, 2000). Thus, in this analysis the exhaust air moisture is set to 160 g water/kg air for all three PM dryers. Dryers with higher moisture content require lower air flow, thus a lower heating duty of incoming air.

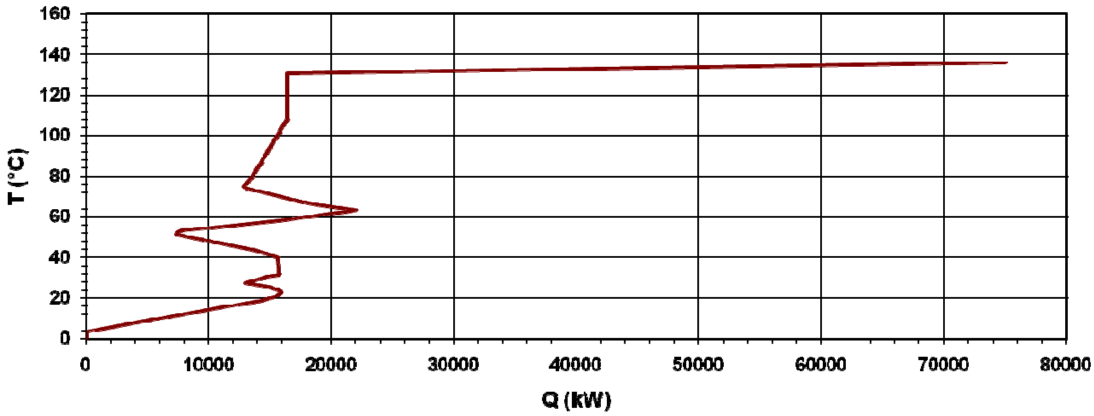

Figure 7.6: GCC for the analysis of more efficient dryers

As can be seen in Figure 7.6 the pinch temperature remains at 0°C when the exhaust air moisture is increased to 160g water/kg air. However, the potential for steam savings is increased to 30.1MW compared to 20.7MW for the reference winter case. The exhaust air heat recovery is much more efficient with higher moisture content. For this scenario, 27.2MW of heat are recovered in the exhaust air heat recovery unit compared to 20.9MW for the average reference case.

7.5 Summary for Saugbrugs

Table 7.5 summarizes the different results obtained for Saugbrugs.

Table 7.5: Summary of the different cases for Saugbrugs

	Potential for steam savings [MW]	**Warm water available* [MW]**	**Pinch temperature [°C]**
Reference winter case	20.7	0.0	0
Sensitivity analyses			
1) further cooling of waste water	31.2	3.9	52
2) -20% fresh water to PMs	26.5	0.0	0
3) modern dryers	30.1	0.0	0

**This warm water can be up to 52°C (interval temperature) and this potential corresponds to the minimum cold utility demand*

As can be seen in the Table 7.5, up to 29.7% of the current steam consumption (with the first sensitivity analysis) can be avoided if the HEN is extensively rebuilt.

Potential warm water available corresponds to the minimum cold utility demands found. The warm water temperature can be up to the pinch temperature so a maximum temperature of 52°C, which is low. Moreover it occurs only with the first sensitivity analysis and with only 3.9MW.Thus there are not so many applications which can be of interest for the Saugbrugs mill.

8 Fourth mill: Norske Skog Skogn

The Skogn mill is the largest newsprint producer in Norway producing around 600 000 ton/year. The first newsprint production started in 1966. The three PMs all produce newsprint. Main features for the Skogn mill are found in Table 8.1.

Table 8.1: Important data for the Skogn mill (Norske Skog Skogn)

Machines		**PM1**	**PM2**	**PM3**
Trimmed width	[cm]	667	670	847
Paper quality		Newsprint	Newsprint	Newsprint
Production capacity	[ton/year]	172 000	186 000	242 000
Dip content	[%]	23	0	66

8.1 General overview/ Description of the system

At the Skogn mill, there are two TMP lines (TM1 and TM2 which has two parallel streams TM2A and TM2B), three PMs and one RCF line. In the paper recipe, the TMP produced stands for 62.5%, the RCF for 31.8% and the rest is filler. The TM1 line is not taken into consideration in this study since it is rarely used. Figure 8.1 displays the general process overview.

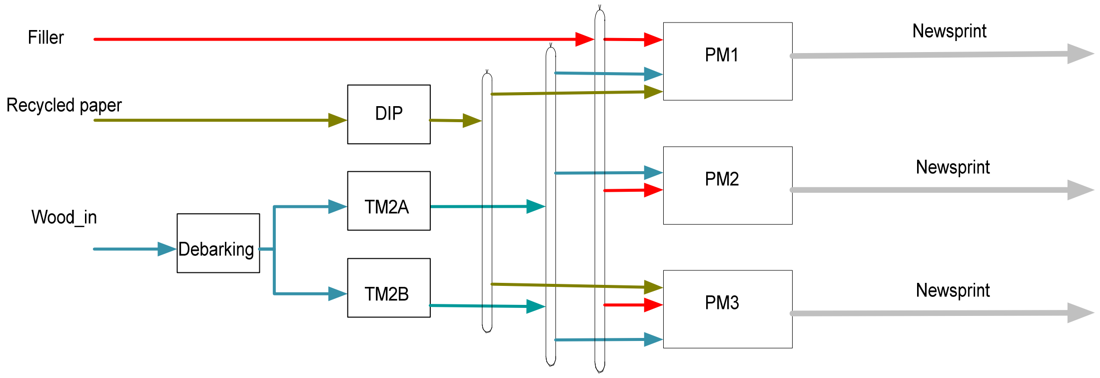

Figure 8.1: Overview of the plant's process

8.1.1 The TMP lines

TM2A: This line represents 52.3% of the total TMP production at the mill. The main line refining is made of two pressurized stages which consume 1.5 and 0.7 MWh/ADt of electricity respectively. There is no reject refining in the TMP2A line. The reject from the screening of TMP is recirculated back to the LC-refining of the main line where 0.2 MWh/ADt of electricity are used.

TM2B: TMP2B produces 47.7% of the total TMP in the mill. Two pressurized stages using 1.1 and 0.7 MWh/ADt of electricity are used in the main line refining. Like for TMP2A, no reject refining is done.

8.1.2 The PM lines

The paper recipe is described in Table 8.2 below.

Table 8.2: recipe and daily production rate of the three paper lines

Recipe		**PM1**	**PM2**	**PM3**
TMP	[%]	71	89	28
GW	[%]	0	0	0
Kraft	[%]	0	0	0
RCF	[%]	23	0	66
Filler	[%]	6	11	6
Total paper production	[ton/day]	**518**	**528**	**626**

After the press section, the web has a dry content of 44% for PM1 and 43% for both PM2 and PM3 and it needs to be drought until 93% for all the PMs.

8.1.3 Steam and water balance

The consumption of fresh water for each PM is presented in Table 8.3. The fresh water temperature varies seasonally between 7°C (winter) and 13°C (summer). The overall fresh water consumption which includes the fresh water for the refiners and some sealing water due to leaks is equal to 12.75 m^3/ton of paper.

Table 8.3: Fresh water to warm water tank

Fresh water to warm water tank		**PM1**	**PM2**	**PM3**
Start temperature	[deg C]	7/13	7/13	7/13
Mass flow	[m^3/ton of paper]	11.2	11.1	8.5
Target temperature	[deg C]	56	56	56

The steam balance for an average week, divided for different steam consumers, is presented in Table 8.4. The total steam consumption is 104.8 MW where 55.7 MW comes from a boiler and the rest from the steam recovery system recovering TMP steam.

Table 8.4: Steam consumers

Unit	MW
PM1	
Dryer	19.4
Steam box	5.4
Steam 10MW process	4.0
VVF-internal district heating	1.4
PM2	
Dryer	20.2
Steam box	2.1
Steam 10MW process	1.9
VVF-internal district heating	1.2
PM3	
Dryer	23.9
Steam box	3.0
"Tyst" boiler	0.1
Steam for wire silo filtrate	5.9
VVF/warm water 5MW	0.5
VVF/VVC	2.5
TOTAL	104.8

8.2 Quality of the data gathering and adjustments

With help from the mill personnel the HLMPP data gathering file was almost completely filled in except few parameters described here. Data from a previous pinch analysis study (Festin & Mora, 2009) was used when information could not be found elsewhere. Moreover, a Flowmac simulation has previously been done for the whole plant. From this Flowmac simulation the PMs filtrate heating duties included in the HLMPP were found. Finally, Metso has made some measurements in the drying section of PM1 regarding the exhaust air moisture and temperature and these values were also used for PM2 and PM3 when information was lacking.

The mill feed an internal district heating system for process heating which distributes between 5 and 21MW of warm water due to seasonal variation. In average, the load corresponds to 13MW. As this district heating is a process stream aiming at supplying heat to different locations in the mill, it is made of two streams in the pinch analysis, one hot (which supplies heat) and one cold stream (which needed to be heated up) with the same temperature range [60;85] °C .

8.3 Results for the HLMPP analysis

An average case was simulated which corresponds to an average air temperature at Skogn of 5°C (eKlima, 2009)and an average fresh water of 10°C.

The results for the average cases are presented in the subsequent text.

8.3.1 Average case

Figures 8.2 and 8.3 show the resulting CC and GCC for the average case.

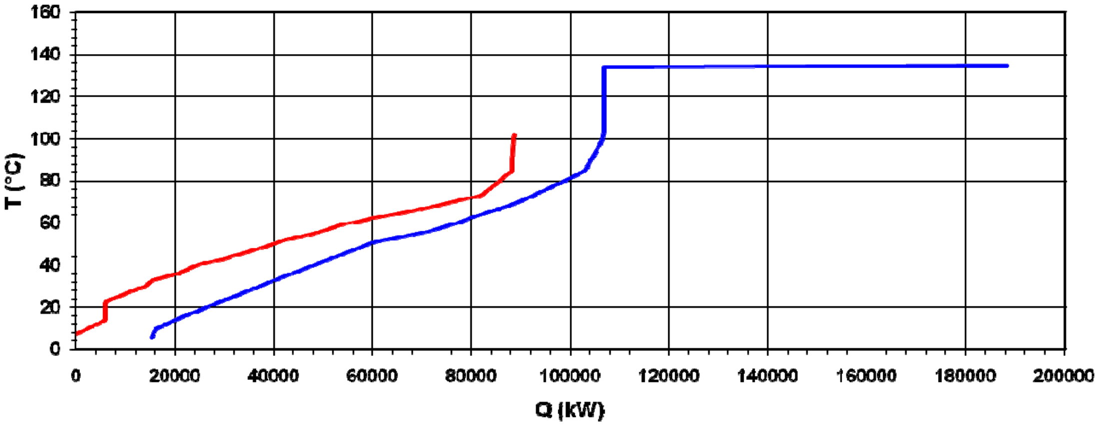

Figure 8.2: CC for the Skogn average case

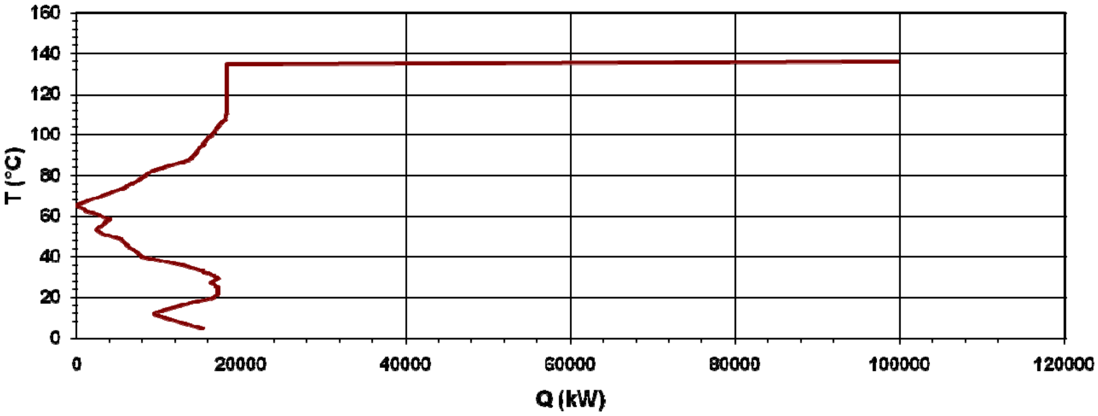

Figure 8.3: GCC for the Skogn average case

For the average case, the minimum hot utility demand is 99.7MW and the minimum cold utility demand is 15.3 MW. The pinch temperature is 65°C.

8.3.2 Potential for steam savings

How the potential for steam savings is calculated is further explained in Appendix 1.

By comparing the minimum hot utility consumption, 99.7MW, to the current steam consumption, 104.8MW, a potential for steam savings equal to 5.1MW was found, representing pinch violations in the existing HEN. In order to find the exact locations of the pinch violations and to be able to realise the steam savings a normal pinch analysis needs to be performed after which the HEN needs to be rebuilt.

8.4 Sensitivity analysis

Three sensitivity analyses are performed for the Skogn mill. The first analysis aims at studying the influence of reduced fresh water consumption in the PMs by 20% (Section 8.4.1). The second analysis investigates the influence of the internal process district heating on the shape of the CC and the GCC (Section 8.4.2). Finally, the third analysis shows to what extent the dryer technology, in form of the exhaust air moisture content, impacts the potential for process integration (Section 8.4.3).

All of sensitivity analyses are done for the average case.

8.4.1 Cut of fresh water consumption in PMs by 20%

The fresh water, which is heated up, requires substantial amounts of energy. In this analysis the water consumption in the PMs is decreased by 20% from 11.2 to 9.0 m^3/ton of paper for PM1, from 11.1 to 8.9 m^3/ton of paper for PM2 and from 8.5 to 6.8m^3/ton of paper for PM3. Hence 39.2kg/s of fresh water is avoided. The flow of total effluent to waste water is adjusted accordingly. Figure 8.4 shows the resulting GCC for this analysis.

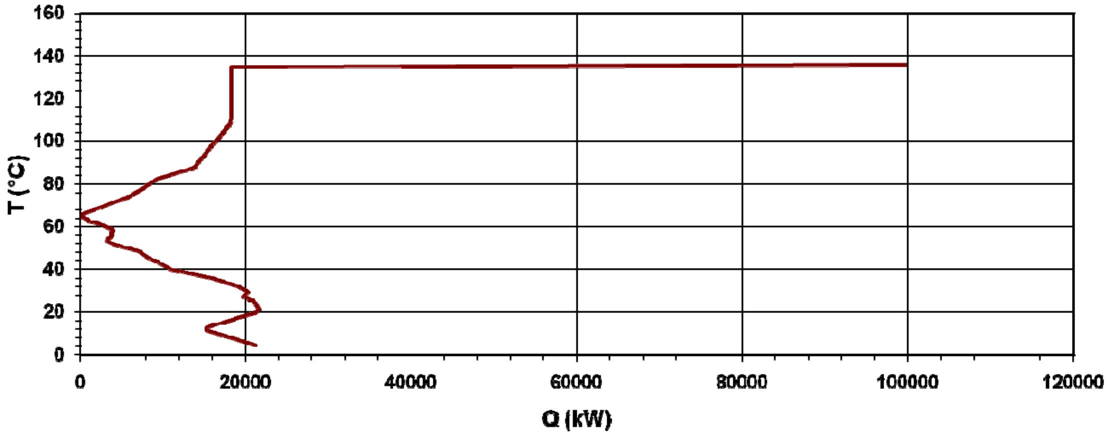

Figure 8.4: GCC for the analysis with decreased water consumption in the PMs

A lower fresh water consumption in the PMs (which means less flow to the warm water tank) changes only the minimum cold utility demand to 21.1MW instead of 15.3MW for the average reference case. The pinch temperature (65°C) and the minimum hot utility demand (99.7MW) i.e. the minimum steam consumption remain constant.

8.4.2 Influence of the internal district heating

A previous pinch analysis, performed for a part of the mill, showed that the district heating represents a big share of the pinch violations since the heat was transferred through the pinch (Festin & Mora, 2009). Hence, in this analysis the district heating streams are virtually removed from the stream data used in the pinch analysis. This would require a major rebuild of the HEN. Another alternative would be to only rebuild the HX where the pinch violations are. However, to identify the exact locations of pinch violations a normal pinch analysis needs to be done. Thus this analysis only shows how much pinch violations there are that are related to the internal district heating system in the existing HEN.

The results from the analysis show an interesting potential as can be seen in Figure 8.5. By removing the internal district heating, the pinch temperature is reduced to 54°C (compared to 65°C in original average case) and a total of 7.5MW of steam can be saved (compared to 5.1MW for the original average case). Thus in total some 2.4MW of pinch violations are associated with the internal district heating system.

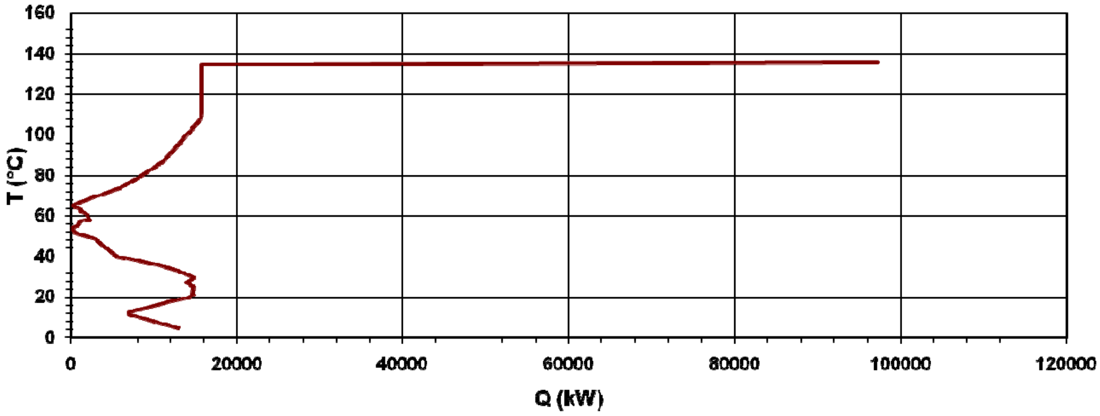

Figure 8.5: GCC for the case without district heating streams

8.4.3 Higher moisture content in air leaving the dryers

The exhaust air moisture leaving the dryers is currently around 120 g water/kg air. For a modern dryer the value can be ~160g water/kg air (Karlsson, 2000). As a result, in this analysis the exhaust air moisture is set to 160g water/kg air for all three PM dryers. Dryers with higher moisture content require lower air flow, thus a lower heating duty of incoming air. Figure 8.6 shows the GCC for this analysis.

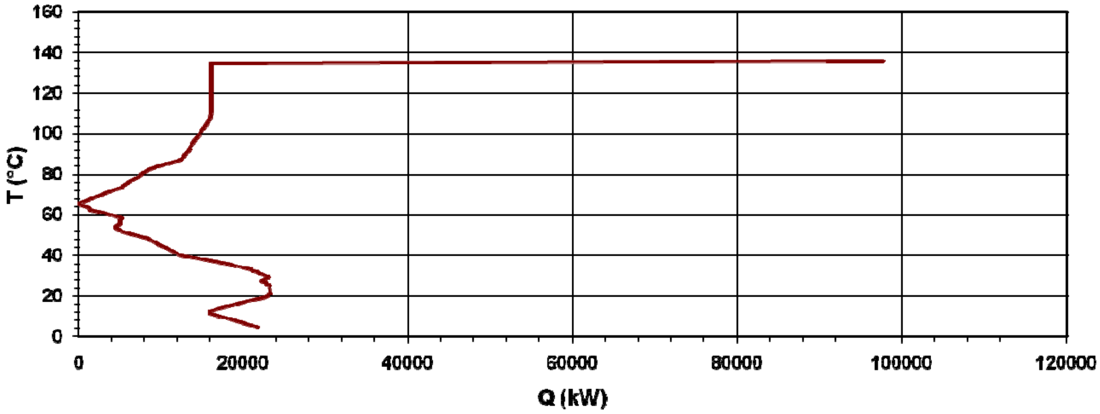

Figure 8.6: GCC for the analysis of more efficient dryers

As can be seen in the figure, the pinch temperature remains constant at 65°C when the exhaust air moisture is increased to 160 g water/kg air. However, the potential steam savings is increased to 7.2MW (compared to 5.1 for the original average case). At the same time the minimum cold utility demand is increased to 21.8 MW. The exhaust air heat recovery is much more efficient with higher moisture content. For this scenario, 45.5MW of heat are recovered in the exhaust air heat recovery unit compared to 41.2MW for the average reference case.

8.5 Summary of results for the Skogn mill

Table 8.5 summarizes the different results obtained for the Skogn mill.

Table 8.5: Summary of the different cases for the Skogn mill

	Potential for steam savings (MW)	**Potential warm water available (MW)**	**Pinch temperature (°C)**
Reference average case	5.1	15.3	65
Sensitivity analyses			
1) no internal district heating	7.5	12.9	54
2) -20% fresh water to PMs	5.1	21.1	65
3) modern dryers	7.2	21.8	65

As can be seen in the table, up to 7.2% of the current steam consumption can be avoided with an optimized, retrofitted HEN (see results for the second sensitivity analysis).

Potentials of warm water available correspond to the minimum cold utility demands found. The warm water temperature can be up to the pinch temperature so a maximum temperature of 65°C. That water has a low temperature thus there are not so many applications. The few possible applications can be pre-heating of district heating water, export it to another close mill that might need it, etc.

The GCC for the average case shows a promising potential for a HP concept of around 3.1MW. Appendix 3 describes how to identify HP opportunities with a GCC. However, since the HLMPP is not a real pinch analysis this must be further investigated.

9 Discussion

Even though the origins of pinch violations are not determined with HLMPP, the different amounts for theoretical potential of steam savings found in the four previous chapters describing each mill correspond in a relatively accurate way (See Section 4.1). Here a comparison between results for the different mills will be done and some links between the mills features and their potential of steam savings will be investigated. For comparison, the FRAM mill described in Section 4.2 is also included in this part. After the comparison, different biorefinery concepts will be discussed according to the choice of strategy for utilization of the steam savings: keep unchanged the steam production or decrease the steam production in order to match the new steam demand for the paper process.

9.1 Interpretation of HLMPP results

Please note that only the reference cases are represented in this analysis and that higher savings potentials were identified for the different sensitivity analyses. Figure 9.1 ranks the mills by technical age of equipment, from the youngest (FRAM mill) on the left to the oldest (Follum) on the right. The age refers to technical age which was given by Pöyry. The FRAM mill does not have a real age since it is a modelled mill but it is assumed here to be one year old and hence the youngest mill studied. The steam consumptions are calculated by dividing the total mill steam demand with the simulated daily production thus the amount is in $\text{kWh}_{\text{steam}}$/ton paper.

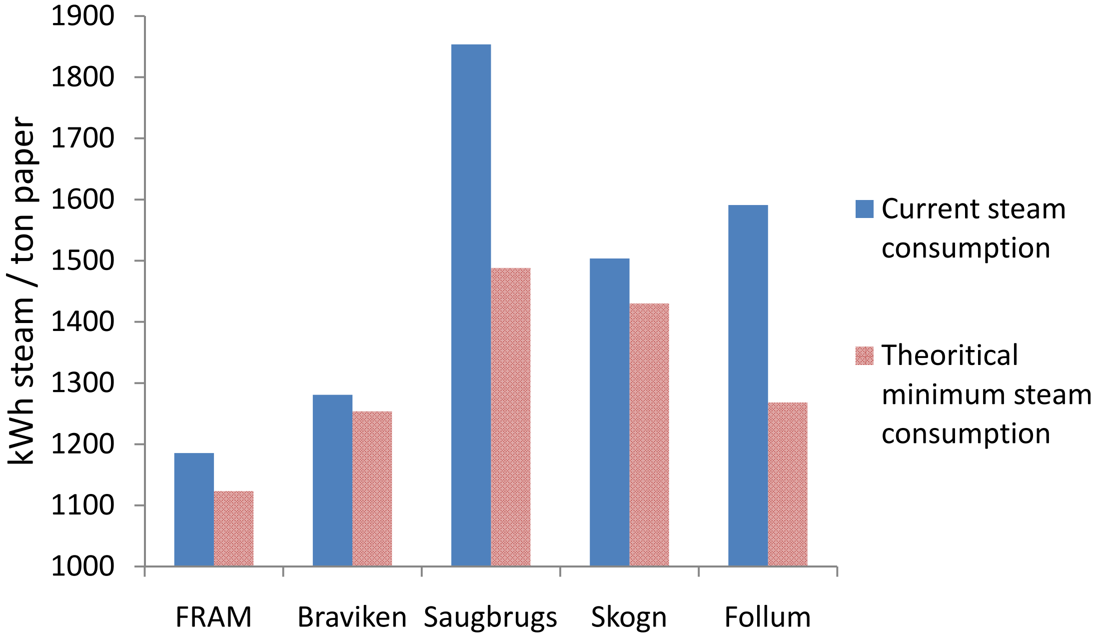

Figure 9.1: Mills current and theoretical minimum steam consumptions

The FRAM and Braviken mills, which are less than twelve years old, have the lowest current steam consumption and the potentials for further steam savings are rather low. The three Norske Skog mills are older and have higher current steam consumption. However, larger potentials for steam savings can be achieved with a detailed pinch analysis (except for the Skogn mill where the potential for steam savings is a bit smaller).

No influence between the paper recipe, most especially the TMP content, and the potential for steam savings was established from the results as can be seen in Figure 9.2. Neither does the installed capacity for each mill affect the potential for steam savings, as displayed in Figure 9.3.

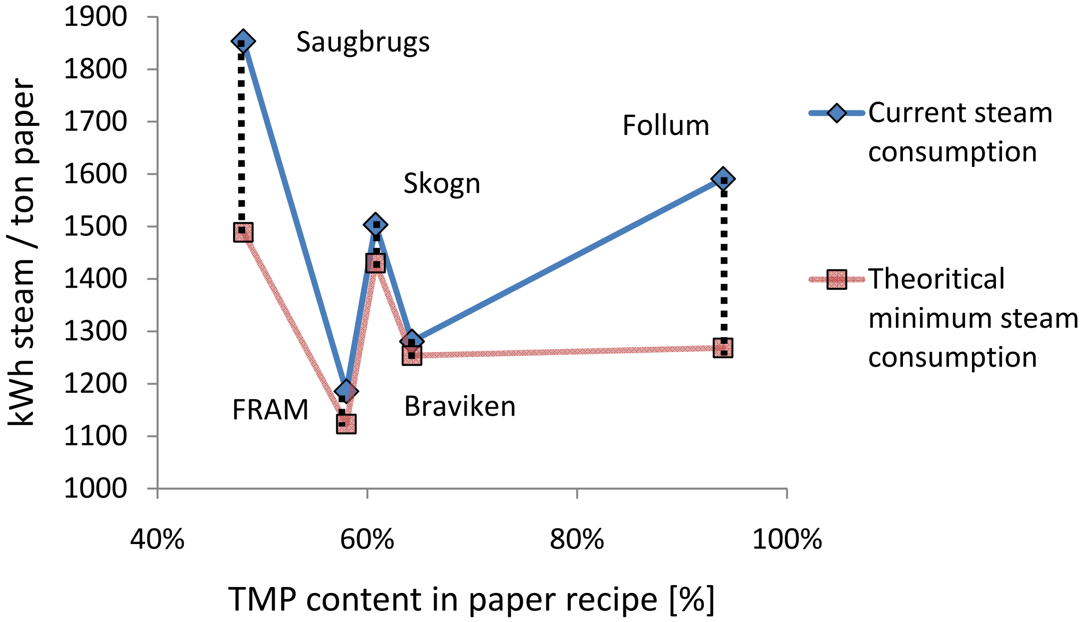

Figure 9.2: Influence of the TMP content on the current and theoretical minimum steam consumption

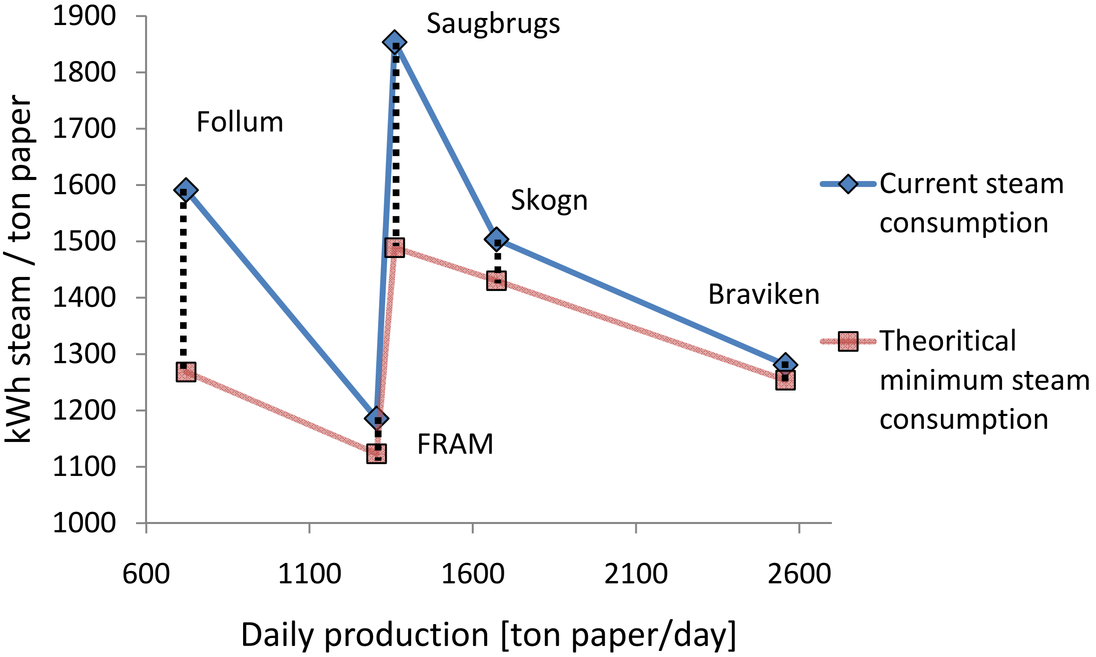

Figure 9.3: Influence of the daily production on the current and theoretical minimum steam consumption

However, a relation between the average fresh water to warm water tank consumption for each mill and the corresponding current and minimum steam consumption was found, as plotted in Figure 9.4. The lower the fresh water to warm water tank consumption is; the lower the current steam consumption is, as well as the potential for steam savings. On the other hand, the higher the fresh water to warm water tank consumption is; the higher the current steam consumption is as well as the potential for steam savings. The reason is that when the fresh water to warm water tank consumption is high, mills need to (partly) use steam to heat it up since internal heat available through internal heat exchange is not enough.

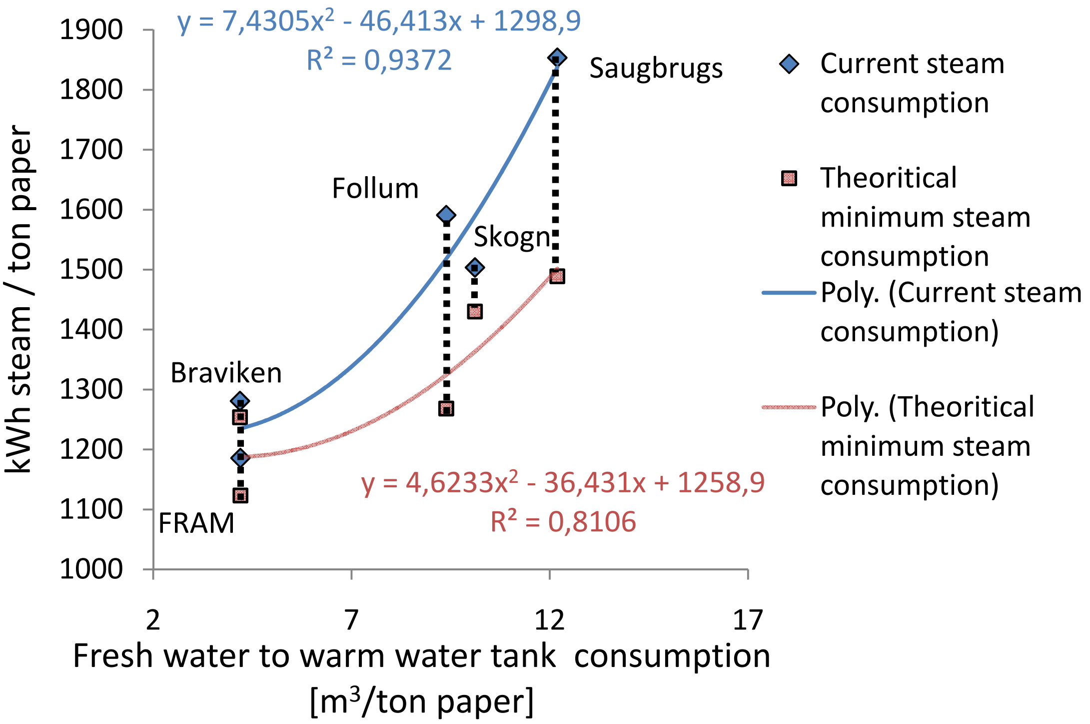

Figure 9.4: Influence of the fresh water to warm water tank on the current and theoretical minimum steam consumption

The correlation between fresh water user and steam demand was the only observation possible to notice among the ones studied. As a consequence, no other trends were found according to these results more than that steam savings generally can be found and that these TMP mills should be able to use around 1123-1489 kWh_{steam}/ton paper. Each TMP mill has its own features and therefore needs a separate HLMPP analysis, followed by a pinch analysis if the results from the HLMPP analysis look promising.

9.2 Biorefinery concepts

In this part, it is assumed that the TMP mills have upgraded their HEN after doing a detailed pinch analysis and that they thus can reduce their process steam demand, giving them either a steam surplus or the possibility to reduce the steam production as discussed in subsequent text. Concerning the potential utilization of excess warm water, the implementation of a HP, an ORC or preheating opportunities for district heating return water were mentioned in each mill chapter (see Sections 5, 6, 7, 8) when possible and are applicable to different extent for the different mills. However, as shown in Section 4.1, the uncertainties of HLMPP were mainly located in the theoretical cold utility demand. Thus, the warm water applications are not discussed further. That is not the case with the minimum hot utility demand and corresponding potential for steam savings where the HLMPP results were shown to more accurately match the results of a detailed pinch analysis. Hence some applications utilizing the saved steam are described here.

Biorefinery applications for TMP mills are multiple, especially if there is a steam surplus. Two possibilities are faced by decision makers at the mills when making steam savings:

- Continue to produce the same amount of steam even though the paper process does not consume all of it anymore, giving a surplus of steam which can be utilized in other (new) processes (see Section 9.2.1)
- Decrease the amount of steam produced in order to match the steam production to the new, lower paper process steam demand (see Section 9.2.2)

9.2.1 The steam production remains unchanged

The mills would keep the same steam production but due to the steam savings steam would be available for other processes apart from the paper process. These processes could be external or internal at the mill.

Depending on the localization of the mill, the steam can be exported to a close plant that might need it. Surplus steam can also be used to deliver heat to a district heating grid supplying a town not too far away (even though such heating is most efficiently done using excess heat of suitable temperature, not steam).

If the extra steam cannot be exported then the mill must deal with it and think about the most profitable usage. Drying of biomass is a very interesting concept which increases the value for both transportation and combustion of the biomass and also facilitates an upgrade to solid fuels (pellets, briquettes, and powder), liquid fuels (pyrolysis oil, ethanol etc) or gaseous fuels (syngas to be converted to methanol, Dimethyl ether-DME, hydrogen, etc) via gasification (The Swedish Energy Agency, 2008). However, biomass for drying needs to be available. Also, low temperature drying not using steam could be of interest.

A well known and mastered usage of surplus steam is to utilize it for electricity production in a condensing steam turbine in order to increase electricity self-sufficiency of the mill. Condensing steam turbines work with low pressure steam suitable with the LP steam which can be made available. However the electric efficiency of a condensing turbine is rather low.

9.2.2 The steam production is decreased

Currently, the general process steam balance at the four studied mills show that they all need clean steam produced by TMP steam heat recovery as well as by boilers. However, if the process steam demand is decreased, the TMP steam production or the clean steam production in the boilers can be decreased.

By reducing the clean steam production from the boilers, the quantity of combustible in the boiler will be decreased. Usually the mills burn bark extracted from the debarking unit so the decreased burning would allow them to export some of the bark.

Many mills also have oil or natural gas as their marginal fuel. If this is the case, steam savings are quite profitable.

If the clean steam coming from the boiler remains constant then a smaller steam production from the TMP steam heat recovery system would be required and thus less TMP steam is required (see the steam cycle Section 3.1.6). Thus, it would be possible to replace old high electricity consuming single disc, HC refiners with more efficient refiners with a smaller SEC. This can be achieved by double discs refiners or LC refiners, which use less electricity and consequently produce less TMP steam. Double disc refiners consume around 15% less electricity compared to single disc refiners. The consistency also affects the SEC. For instance the electricity reduction is 7% if the refining consistency is reduced from 50% to 38%. Electricity consumption is a main concern for TMP mills and thus this last suggested option for utilization of saved steam can be of large interest for all TMP mills(Sundholm, 1999).

10 Conclusions

This study has demonstrated the potential for steam savings for four TMP mills located in Sweden and Norway along with different ways to further influence their hot and cold utility demands. As can be seen from the results, the current steam consumption and theoretical minimum steam consumption per ton of paper produced for the reference cases differ between the studied mills. The TMP content in paper recipe, technical age and daily production capacity were not shown to affect the potential for savings or the steam demand. The only correlation found out of the ones investigated were between the fresh water to warm water tank consumption and the steam use and potential for steam saving.

Even though the HLMPP has a good accuracy, it is a model which does not depict each mill perfectly. However, according to the results for each mill, one can see the interest of carrying out a complete pinch analysis. The potential for energy savings identified is between 2.1% and 20.3% (with only the reference cases) for the different mills and the amounts of extra warm water available are substantial for most of the studied mills.

However, the theoretical potential for steam savings given by the HLMPP results is not a 100% reachable but following up this work by doing a normal pinch analysis will show how the mills can realize parts of this potential. According to previous studies done at the Heat and Power Technology division, usually around 70% of the identified potential can be realized with good economic performance.

Moreover, the sensitivity analyses showed that the steam reductions identified can be higher if the fresh water consumption is decreased (for Braviken) or by removing the internal district heating system (for the Braviken and Skogn mill). The dryer technology and the exhaust air moisture also affect both minimal heating and cooling demand and if new more efficient dryers are installed, all of the mills studied could decrease more their steam demand. The GCCs show that integration of HPs may be an interesting option for Braviken, Follum and Skogn. However, a detailed pinch analysis is needed in order to investigate how to implement and integrate the HP in an efficient way. Finally, the Saugbrugs mill can improve its energy situation by further cooling of the waste water after the effluent treatment.

Applications for the steam savings and extra warm water available are numerous as explained in each mills section and in the Discussions section. One general conclusion that can be drawn is that the TMP mills have quite low pinch temperatures (compared to kraft mills) and thus the extra warm water available is not so hot. As a result, it might be more interesting in keeping a low amount of excess warm water especially when the mills do not recover it because it exactly corresponds to a cooling demand.

All in all, all the TMP mills studied in this report are advised to carry out a detailed pinch analysis in order to precisely identify where the pinch violations in the current HEN are. Thus, once the potentials for savings, are located, the pinch analysis would then detail how to update its existing HEN and how to get as close as possible to the identified potentials by still respecting economical conditions (distance between streams, complexity of rebuild, etc.). The pinch analysis can also be used to investigate the potential for efficient integration of different biorefinery concepts or the implementation of a HP, an ORC, etc.

11 Further work

In this section further work, both regarding the HLMPP tool and the different studied mills, is suggested.

The HLMPP tool - comments and improvements:

The linearization in the heat content of the exhaust air heat recovery just after the dryers is a cause of uncertainty and it would be more accurate to consider it by adding one more heat exchanger below the dew point in the exhaust air heat recovery.

As for three out of the four mills no mill visits were done and many misunderstandings have occurred all along the thesis. The worst case scenario was when someone filled a wrong value. To ensure good quality and time saving, each mill should be visited. Some data required in the Excel file took some time to be understood by the mills employees. It implies the need to improve the description of the input data needed in the input data sheet. For instance, TMP vapour share to heat recovery was difficult to explain because usually it was considered like TMP steam whereas it comes from flash separators thus is not pressurized.

Other investigations using the HLMPP:

Four sensitivity analyses were tried in this thesis (removal of internal district heating, modern dryers, further cooling of waste water and lower fresh water consumption). However, more analyses could have been tried such as lower exhaust air temperature after heat recovery of dryer's air or try to reduce the cooling demand. It was not tried in this report but cooling demand might be as well a problem for specific mills even in Nordic countries. So instead of recovering the exhaust air leaving the dryer, it may be worth to release this air directly to the atmosphere (depending on the pinch temperature at the mill).

Follow up by doing a pinch analysis is recommended for all the mills:

All of the studied mills are advised to carry out a detailed pinch analysis in order to get as close as possible to the potential steam savings identified. Thus, the pinch violations in the HEN are located and modifications would be suggested to update the existing HEN and how to get as close as possible to the identified potentials by still respecting economical conditions (distance between streams, complexity of rebuild, etc.). Moreover a complete pinch analysis would investigate the feasibility of integration of HPs or an ORC which were just briefly mentioned in this report due to the uncertainties regarding the results for minimum cooling demand given by the HLMPP.

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Appendix

Appendix 1: Stream data table of the HLMPP

Appendix 2: Explanations of HLMPP stream data table

Appendix 3: Calculation of potential for steam savings

Appendix 4: Integration of a Heat pump in the GCC

Appendix 1: Stream data table of the HLMPP

Name	Process part	Description
1	PM1	COLD: Water to process
2	PM1	COLD: Other water to process
3	PM1	COLD: Air to uncoated drying
4	PM1	COLD: Air to coated drying
5	PM1	COLD: PM filtrate 1 warming up
6	PM1	COLD: PM filtrate 2 warming up
7	PM1	COLD: PM filtrate 3 warming up
8	PM1	HOT: LTO cylinder drying exhaust air
9	PM_STEAMCOND	HOT: Drying steam condensing
10	PM1	HOT: PM filtrate to effluent
11	PM1	HOT: Cooling duties
12	PM_WEB	COLD: Web heating to drying temperature
13	PM_WEB	COLD: Web drying uncoated
14	PM_WEB	COLD: Web drying coated
15	PM2	COLD: Water to process
16	PM2	COLD: Other water to process
17	PM2	COLD: Air to uncoated drying
18	PM2	COLD: Air to coated drying
19	PM2	COLD: PM filtrate 1 warming up
20	PM2	COLD: PM filtrate 2 warming up
21	PM2	COLD: PM filtrate 3 warming up
22	PM2	HOT: LTO cylinder drying exhaust air
23	PM_STEAMCOND	HOT: Drying steam condensing
24	PM2	HOT: PM filtrate to effluent
25	PM2	HOT: Cooling duties
26	PM_WEB	COLD: Web heating to drying temperature
27	PM_WEB	COLD: Web drying uncoated
28	PM_WEB	COLD: Web drying coated
29	PM3	COLD: Water to process

30	PM3	COLD: Other water to process
31	PM3	COLD: Air to uncoated drying
32	PM3	COLD: Air to coated drying
33	PM3	COLD: PM filtrate 1 warming up
34	PM3	COLD: PM filtrate 2 warming up
35	PM3	COLD: PM filtrate 3 warming up
36	PM3	HOT: LTO cylinder drying exhaust air
37	PM_STEAMCOND	HOT: Drying steam condensing
38	PM3	HOT: PM filtrate to effluent
39	PM3	HOT: Cooling duties
40	PM_WEB	COLD: Web heating to drying temperature
41	PM_WEB	COLD: Web drying uncoated
42	PM_WEB	COLD: Web drying coated
43	TMP	COLD: Chips warming in chips silo
44	TMP	COLD: Chips steaming in impregnation
45	TMP	COLD: Chips preheating before refining
46	TMP	HOT: Vapour from reject refining and elsewhere condensing
47	TMP	HOT: Vapour condensate cooled and returned to process
48	TMP	HOT: TMP filtrate to effluent treatment
49	TMP	HOT: TMP filtrate cooling down
50	TMP	HOT: TMP filtrate2 cooling down
51	TMP	HOT: TMP filtrate3 cooling down
52	TMP	HOT: TMP cooling duties
53	PROSTEAM_USAGE	HOT: TMP steam own usage condensing
54	PROSTEAM_USAGE	HOT: TMP steam own usage condensate cooled and returned to process
55	PROSTEAM_LTO	HOT: TMP steam condensate (from LP generation)
56	PROSTEAM_LTO	COLD: Preheating returning LP condensate
57	PROSTEAM_LTO	HOT: LP steam usage in the process

58	PROSTEAM_LTO	HOT: LP condensate cooling
59	TMP2	COLD: Chips warming in chips silo
60	TMP2	COLD: Chips steaming in impregnation
61	TMP2	COLD: Chips preheating before refining
62	TMP2	HOT: Vapour from reject refining and elsewhere condensing
63	TMP2	HOT: Vapour condensate cooled and returned to process
64	TMP2	HOT: TMP filtrate to effluent treatment
65	TMP2	HOT: TMP filtrate cooling down
66	TMP2	HOT: TMP filtrate2 cooling down
67	TMP2	HOT: TMP filtrate3 cooling down
68	TMP2	HOT: TMP cooling duties
69	TMP3	COLD: Chips warming in chips silo
70	TMP3	COLD: Chips steaming in impregnation
71	TMP3	COLD: Chips preheating before refining
72	TMP3	HOT: Vapour from reject refining and elsewhere condensing
73	TMP3	HOT: Vapour condensate cooled and returned to process
74	TMP3	HOT: TMP filtrate to effluent treatment
75	TMP3	HOT: TMP filtrate cooling down
76	TMP3	HOT: TMP filtrate2 cooling down
77	TMP3	HOT: TMP filtrate3 cooling down
78	TMP3	HOT: TMP cooling duties
79	GW	HOT: GW filtrate cooling down
80	GW	HOT: GW filtrate2 cooling down
81	GW	HOT: GW filtrate3 cooling down
82	GW	HOT: GW bleaching filtrate cooling down
83	GW	HOT: GW bleaching filtrate2 cooling down
84	GW	HOT: GW bleaching filtrate3 cooling down
85	GW	HOT: GW filtrate to effluent treatment cooling down

86	GW	HOT: GW cooling duties
87	RCF	HOT: RCF filtrate cooling down
88	RCF	HOT: RCF filtrate2 cooling down
89	RCF	HOT: RCF filtrate3 cooling down
90	RCF	COLD: RCF dispergation
91	RCF	COLD: PM filtrate 1 warming up
92	RCF	COLD: PM filtrate 2 warming up
93	RCF	COLD: PM filtrate 3 warming up
94	RCF	HOT: RCF cooling duties
95	DEBARKING	HOT: Debarking effluent cooling down
96	DEBARKING	HOT: Debarking cooling duties
97	INTEGRATE	HOT: Total effluent to cooling before waste water treatment
98	DISTRICT_HEATING	COLD: District heating consumer side
99	DISTRICT_HEATING	HOT: District heating producer side

Appendix 2: Explanations of HLMPP stream data table

- Debarking

Effluents from the bark press are cooled (stream 95[9]) before going to the waste water treatment. The cold duty is handled by the debarking cooling stream (stream 96).

- TMP lines

Preheating opportunities are investigated by integrating the Chips warming in chips silo with pre-steaming (streams 43 for TMP; 59 for TMP2; 69 for TMP3[10]), chips steaming in impregnation (streams 44 for TMP; 60 for TMP2; 70 for TMP3) and chips preheating before refining (streams 45 for TMP; 61 for TMP2; 71 for TMP3). These are the first streams used in the CC and the GCC prior to the refining stages. Currently, all of these preheating opportunities use steam but they might replace it by other streams if possible (the CC and GCC answers this question).

The total amount of vapour formed in the refiners and chips silo during heating is cooled down (streams 46 and 47 for TMP; 62 and 63 for TMP2; 72 and 73 for TMP3). TMP filtrates which must be sent to effluent treatment are cooled down (streams 48 for TMP; 64 for TMP2; 74 for TMP3). Filtrates which do not need to go to effluent treatment are also chilled (streams 49, 50 and 51 for TMP; 65, 66 and 67 for TMP2; 75, 76 and 77 for TMP3). The global cooling duties are combined in one stream (stream 52 for TMP; 68 for TMP2; 78 for TMP3).

- PM lines

There are three PM lines in the HLMPP so three times the same process (and three times the number of streams). The fresh water in to warm water tank is the water consumed in the PMs which need to be heated up. Two different streams per PM line can be set (steams 1 and 2 for PM1; 15 and 16 for PM2; 29 and 30 for PM3).

The air used to remove the water content of the wet web in the dryers is also heated to around 100°C. There are two air streams per PM line, one is for the uncoated paper and one for the coated paper (streams 3 and 4 for PM1; 17 and 18 for PM2; 31 and 32 for PM3). After the drying section, heat recovery of the moist air is done (stream 8 for PM1; 22 for PM2; 36 for PM3).

Up to three filtrates heating duties per PM line may be configured (streams 5, 6 and 7 for PM1; 19, 20 and 21 for PM2; 33, 34 and 35 for PM3). These filtrates are also called white water.

The PM web consumes the largest amount of steam in TMP mills. Steam is used in the drying section to evaporate the water content in the web up to the targeted dry content. First, the web is heated up to the drying temperature (streams 12 for PM1; 26 for PM2; 40 for PM3). Then the web enters the dryers and steam is used for drying

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[9] Streams in red = hot stream

[10] streams in blue = cold stream

(streams 13 for PM1, 27 for PM2 and 41 for PM3 for uncoated paper and streams 14 for PM1, 28 for PM2 and 41 for PM3 for coated paper).

- RCF line

The disc filter separates liquid from solid material and produces two different types of filtrates: cloudy and clear. They are both cooled down with three different start-target temperatures and mass flows possible (stream 87, 88 and 89). All the mill filtrates are considered in these streams (not only those from the disc filter).

Dispergation[11] is achieved by a disperging steam, a dispergator unit and a heater (steam 90). Several collected filtrates may require to be warmed up hence three different start-target temperatures and mass flow can be configured (stream 91, 92 and 93). The RCF cooling duties are regrouped in one line and necessitate to be cooled further (stream 94).

- Effluent

All the effluents produced at the mill need to be cooled down before entering the waste water treatment (steam 97).

- District heating

It is included in the Main flow sheet and is heated by the heat_load_district-heating heat exchanger (stream 98). A corresponding hot stream (stream 99) is added with opposite start and target temperatures since the district heating which occurs at the studied mills are for process purpose.

- Additional streams easily integrated

In the TMP lines, PROSTEAM_LTO and PROSTEAM_USAGE can be implemented in the pinch analysis. LTO is the abbreviation for heat recovery in Finnish. The meaning of PROSTEAM_USAGE (stream 53 and 54) is to calculate the amount of heat in the TMP steam used at the TMP line. The meaning of PROSTEAM_LTO (stream 55, 57 and 58) is to calculate the amount of extra steam that can be used elsewhere on the site.

In the PM lines, the PM_STEAMCOND could have been activated. It consists of further cooling of the paper machines steam drying condensate (stream 9 for PM1; 23 for PM2; 37 for PM3).

Nevertheless none of these features are used in this report and hence they are not deeper explained.

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[11] Dispergation realizes ink particle detachment and fragmentation (Göttsching & Pakarinen, 2000).

Appendix 3: calculation of potential for steam savings

In order to estimate the maximum potential for steam savings, the same methods is used for all the mills. A steam balance was provided detailing all the steam consumers and producers during a winter week for Saugbrugs or yearly average value for Braviken, Follum and Skogn.

When one winter week steam consumption values are known, climate data of January is used because it is the coldest month of the year for Follum. It means that the worst case scenario is simulated from an energy point of view. If the average steam consumption values are known then average climate data was used.

The load factor is also taken into consideration in order to adjust the average amount of consumed steam to the simulated production case.

Two different steam consumers must be distinguished:

- Those which have to use steam due to high temperature levels (district heating at high temperature, etc.) and/or technical reasons (dryers, steam box, etc.). Unknown consumers are also included here. This category is called the “inevitable steam consumers”.
- Those which currently use steam but could use other hot streams to exchange heat through heat exchangers because they do not require high target temperature ex: fresh warm water heating, filtrate heating duties, chips warming/preheating, etc. This category is named “preventable steam consumers”. They might still consume steam totally or partially after the pinch analysis but it must be investigated.

The first category is not in the interest of the study because no improvements can be achieved with a HEN. However, the last category can sometimes be prevented depending on the result of the pinch analysis. Table A presents the different steam consumers and their respective categories. The right column describes also the maximum target temperatures of all the preventable steam consumers which prove why they belong to this category.

Table A: Category of the steam consumers

Inevitable	**Preventable***
Dryers	Warm water tank, max. temperature 60°C
Steam boxes	Air heating (ventilation in dryers), max. temperature 100°C
Press sections	Chips warming, max. temperature 70°C
Winding	Chips steaming in impregnation max. temperature 80°C
Process steam (losses)	Chips preheating before refining, max. temperature 100°C
TMP Refining	Make up water for steam, max. temperature 130°C
“Tyst” boiler	Wire silo, max. temperature 60°C
Others (unknown so include in this category)	Dispergation in RCF, max. temperature 75°C

** The maximum temperature details the maximum target temperature found among all the mills studied.*

According to the different steam balances provided by each mill described in Section 2.4, the amount of inevitable steam and preventable steam are presented in Table B.

Table B: Amount of inevitable and preventable steam for each mill

[MW]	Preventable	Inevitable	Total
Braviken	24.8	111.7	136.5
Follum	13.9	33.9	47.9
Saugbrugs	46.5	15.4	105.1
Skogn	23.3	80.1	103.4

The Braviken average reference case will help to illustrate these different amounts of steam consumptions. Braviken reference case GCC is displayed in Figure A. All the inevitable steam consumers are specified as a cold stream in the stream data. For Braviken, it corresponds to 111.7MW and is drawn as a horizontal line in the GCC. The preventable steam consumers are investigated through the CC/GCC. The minimum hot utility consumption for the preventable steam consumers can reach 21.9MW which is 2.9MW below the current preventable steam consumption (24.8MW).

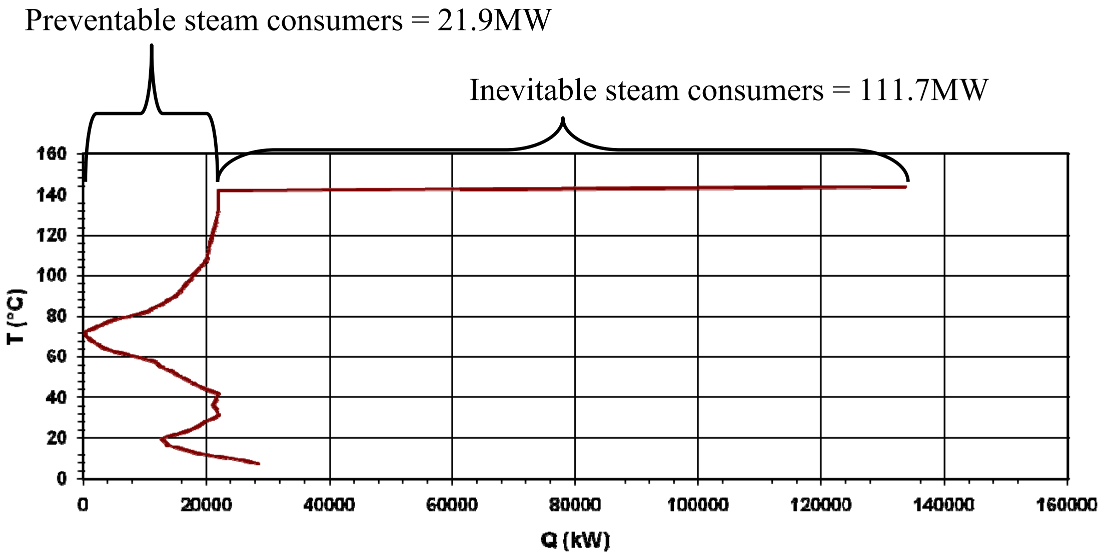

Figure A: GCC of the Braviken average reference case with the different steam category users

Hence, with a retrofitted HEN (a MER), 2.9MW of steam can be saved for the whole Braviken mill.

Appendix 4: Integration of a Heat pump in the GCC

A heat pump (HP) is a device that takes heat from a stream at a low temperature and delivers heat at a higher temperature. It is therefore possible to achieve steam savings if a HP is installed across the pinch i.e. by removing heat from below the pinch where the system has an excess of heat and delivering heat above the pinch where the system has deficit of heat.

The possibility to integrate a HP in a MER network can be studied with the GCC. In practice however, the potential for savings is different, as the heat exchanger network does not recover as much heat internally and as it may be convenient to select one single stream as a heat source rather than several hot streams (Festin & Mora, 2009).

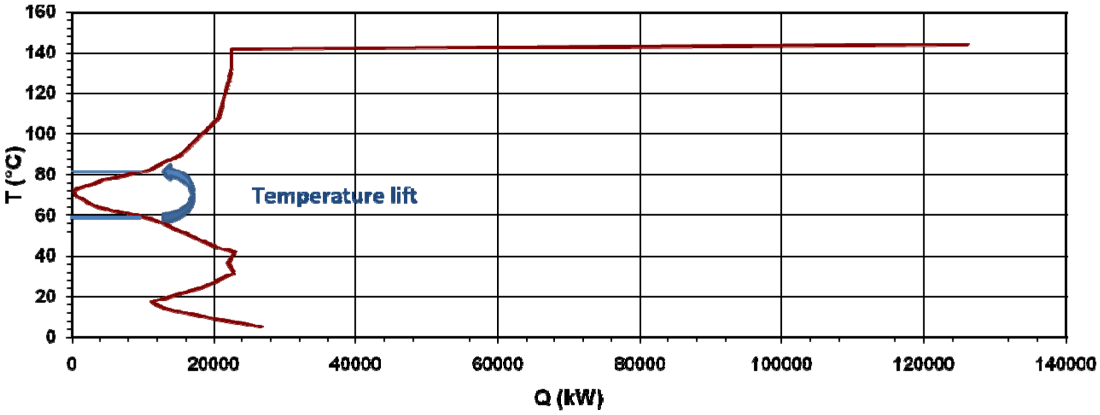

Figure B: Integration of a heat pump, closed compression cycle with an ordinary GCC

In Figure B, heat available at 59.0°C is lifted to 82.5 °C where the system has a heat deficit. For this temperature lift a closed compression cycle HP works and it would lead to about 10MW of steam savings. Assuming a Coefficient of performance of 5, the electrical consumption would be 2MW.