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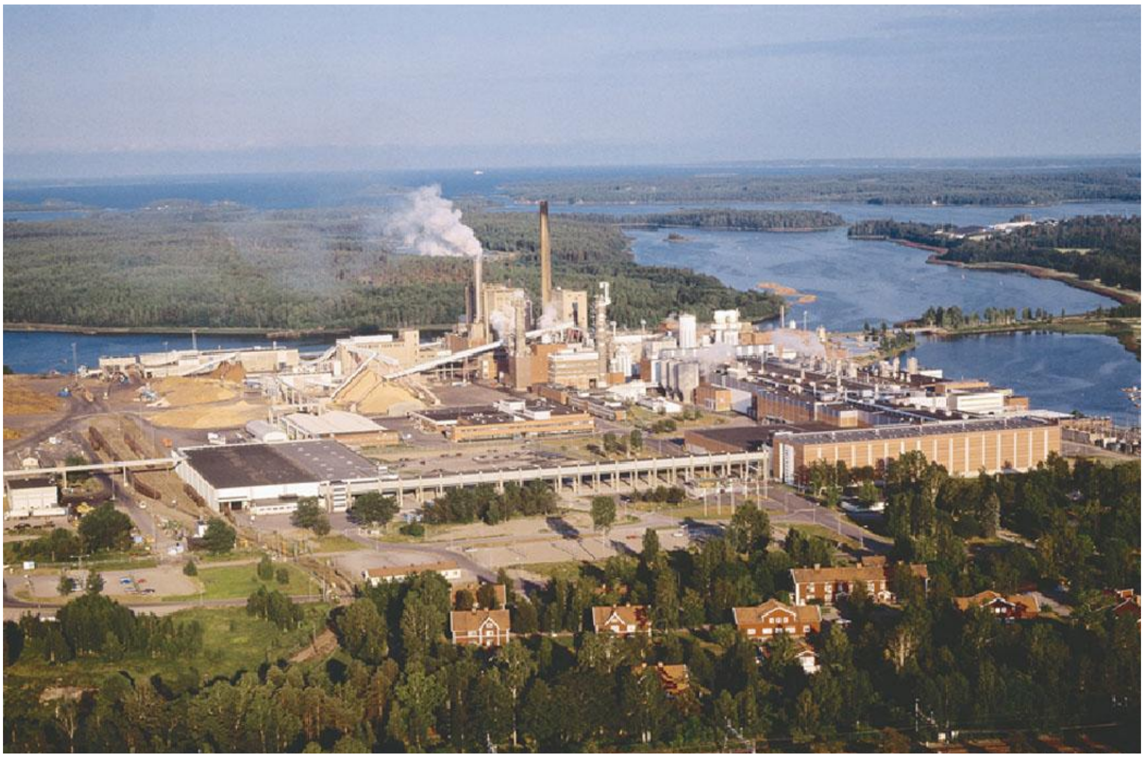

Measures for increased energy efficiency at Iggesund mill

Pinch analysis of the pulp production lines at a paperboard mill

Master's Thesis within the Innovative and Sustainable Chemical Engineering programme

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Department of Energy and Environment
Division of Heat and Power Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2011

MASTER'S THESIS

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Cover:
Picture of the Iggesund paperboard mill.

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ABSTRACT

Swedish pulp and paper industry is facing a future with increased competition from manufacturers with access to faster-growing raw materials, cheaper labour and more modern mills. To survive and stay competitive, investments in more efficient production could be one option. This thesis addresses the potential for increased energy efficiency at Iggesund Paperboard - Iggesund mill. The mill is an integrated pulp and paperboard mill that is almost self-sustaining in energy aspects, producing most of its own need for electricity, and is a provider of heat to the local district heat system.

To evaluate the energy situation, pinch analysis was used for identifying and evaluating the energy saving potential. The analysis is limited to the pulping process and the chemical recovery cycle. A new recovery boiler will be in place by June 2012 and the energy situation has been adapted to these future conditions. Based on data collected on site, today's energy situation was mapped and the potential for energy savings evaluated.

The author can conclude that energy savings are possible. The pinch analysis shows that up to 18 MW of steam theoretically can be saved in the future process. Besides this there is also a wish to reduce the use of primary heat in the district heat production. Available heat sources for process integration are mainly flue gases, hot bleach plant effluents and flash steam.

In order to partly realise this saving potential, two stream saving retrofits are presented. By changing the preheating of boiler feed water, 7.9 MW of steam can be saved, which is equal to 2.6% of the mill's total steam demand. If a more extensive retrofit is constructed the savings increase to 13 MW, which is equal to 4.4% of the total steam demand. Increased process integration will reduce the capacity for district heat production but still the more extensive retrofit has the opportunity to produce 44% of the needed district heat peak load.

Furthermore, this thesis also presents a retrofit evaluating the maximum potential for district heat production that aims to produce 22 MW of peak district heat, but without possibility for other steam saving actions. Finally, it is also concluded that when comparing the mill to others, there is a potential for reduction of the steam demand at the wood yard.

Keywords: Pinch analysis, Integrated pulp and paperboard mill, Energy efficiency, Steam savings, District heat

Åtgärder för ökad energieffektivitet vid Iggesunds bruk
Pinchanalys av massatillverkning vid ett kartongbruk
Examensarbete inom masterprogrammet *Innovative and Sustainable Chemical Engineering*
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Avdelningen för Värmeteknik och maskinlära
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SAMMANFATTNING

Svensk massa- och pappersindustrin möter en framtid med ökad konkurrens från tillverkare med tillgång till snabbare växande råvaror, billigare arbetskraft och modernare anläggningar. För att överleva och förbli konkurrenskraftiga kan investeringar i effektivare produktion vara en lösning. Examensarbetet angriper potentialen för öka energieffektivitet vid Iggesund Paperboard - Iggesunds bruk, ett integrerat massa- och kartongbruk. Bruket är nästan självförsörjande på energi och producerar en stor del av det egna elektricitetsbehovet samtidigt som det är leverantör av värme till det lokala fjärrvärmenätet.

Pinchanalys är den metod som valts för att utvärdera energisituationen och är ett användbart verktyg för att identifiera och utvärdera potential för att spara energi. Iggesunds bruk är ett integrerat kartongbruk men rapporten är begränsat till massaprocessen och kemikalieåtervinningscykeln. En ny sodapanna ska vara på plats senast i juni 2012 och energisituationen har därför anpassats till denna framtida situation. Baserat på data insamlade från bruket har dagens energisituation kartlagts och potentialen för energibesparingar utvärderats.

Författaren kan konstatera det finns en potential för att minska energibehovet. Pinchanalysen visar att upp till 18 MW ånga kan sparas teoretiskt i den framtida processen. Dessutom finns en önskan om att minska användningen av primärvärme i fjärrvärmeproduktionen. Tillgängligt värme att använda för processintegration finns främst i rökgaser, varmt blekerifiltrat och flashånga.

I syfte att delvis uppnå den teoretiska besparingspotentialen har två ångsparande förbättringsförslag presenterats. Genom förbättrad matarvattenförvärmning kan 7.9 MW ånga sparas, vilket motsvarar 2.6 % av brukets totala ångbehov. Om en mer omfattande ombyggnation görs kan besparingarna öka till 13 MW, motsvarande 4.4 % av det totala behovet. Ökad processintegration kommer att minska kapaciteten för fjärrvärmeproduktion, men det senare förslaget har ändå möjlighet att täcka 44 % av det maximala effektbehovet.

Dessutom presenteras också ett förslag som utvärderar den maximala potentialen för produktion av fjärrvärme, vilket resulterar i en produktion på 22 MW fjärrvärme vid toppbelastning, men utan andra möjligheten för ångbesparande åtgärder. Om man sedan slutligen jämför bruket med andra liknande bruk, identifieras en potential för att ytterligare minska ångbehovet genom förbättringar i vedgården.

Nyckelord: Pinchanalys, Integrerat massa- och kartongbruk, Energieffektivitet, Ångbesparingar, Fjärrvärme

Contents

Preface

In this master thesis a pinch analysis has been used to evaluate the energy situation at Iggesund Paperboard – Iggesund mill. The work has been carried out during the spring of 2011 in cooperation between the Division of Heat and Power Technology at Chalmers University of Technology and Iggesund Paperboard, and is part of a Ph.D. project on "Process integration and energy system studies for different 'development paths' for pre-treatment and gasification of biomass", by Johan Isaksson.

I would like to express my gratitude to my examiner Professor Thore Berntsson, my supervisor Johan Isaksson, my external adviser Ander Åsblad and my contacts at Iggesund, Klas Simes and Sten Valeur.

This project had never been possible without the help and support from the staff at Iggesund mill. Special tanks to Kjell Zimmerman, Kjell Sjölander and Rolf Ågren for their knowledge and extra help, and to Eric Elserth for an extra nice treatment when visiting the hardwood pulping.

Finally I would like to thank all the staff at the Division of Heat and Power Technology for providing a nice working climate and making the thesis workers feel welcome.

Göteborg July 2011

Karin Glader

Notations

ADt	Air dry ton pulp, 90% dryness
BFW	Boiler feed water
BL3	Bleach plant fibre line 3
C	Cold stream
CC	Composite curve
C_p	Specific heat capacity [kJ/(kg K)]
D0	Bleaching with Chlorine dioxide (ClO_2), first time
D1	Bleaching with Chlorine dioxide (ClO_2), second time
D2	Bleaching with Chlorine dioxide (ClO_2), third time
DH	District heat
EOP	Alkali extraction of lignin reinforced with oxygen and hydrogen peroxide
EP	Alkali extraction of lignin reinforced with hydrogen peroxide
FRAM	Future resource adapted pulp mill
FW	Fresh water, between 4°C and 25°C
GCC	Grand composite curve
GP	Gas fired boiler
MCW	Mechanically cleaned water, 18°C
H	Hot stream
HW	Hot water, 85°C
KM1	Paperboard machine 1
KM2	Paperboard machine 2
MER	Maximum energy recovery
MW	Medium temperature water, 40°C
P11	Oil boiler
P12	Solid fuel boiler
SBB	Solid Bleached Board
SP3	Recovery boiler 3
SP4	Recovery boiler 4
SP5	New recovery boiler
TM4	Pulp drying machine
WW	Warm water, 65°C
ΔT_{min}	Minimum temperature differences [K]

1 Introduction

1.1 Background

Converting wood into pulp, paper and lumber, has over the years been profitable and has provided Sweden with a stable industry. However in recent years the Swedish pulp and paper industry has found it more difficult to compete against manufacturers with access to faster-growing raw materials, cheaper labour and more modern mills. In order to stay on the market and be competitive, there is a need for improvements in profitability. The methods chosen for improved profitability is to invest in more efficient production, improvement of the product quality and the introduction of new so called “green” products.

Iggesund Paperboard is an integrated pulp and paperboard mill, member of the Holmen Group, situated in Iggesund, on the cost of North Middle Sweden. The mill produces chemical pulp for further manufacturing into paperboard products and only 20% is sold as market pulp. The Iggesund mill is an almost self-sustaining mill, producing most of its own need for electricity, and is a provider of heat to a nearby sawmill as well to the local district heating network. It also delivers electricity to Ströms mill. In order to further improve the profitability they now want to improve the energy efficiency, so that they can reduce the fuel consumption and/or use the energy surplus made available for the production of new “green” products.

1.2 Purpose

One way to investigate the energy improvement potential for a paper mill is to perform a process integration study by using pinch analysis. The purpose of the thesis is to map and analyse the current energy situation at Iggesund Paperboard, and from the analysis, based on the collected data, pinpoint how the energy situation could be improved.

The fact that the mill is integrated and already connected to a district heating network will provide conditions and limitations for process integration that not all mills have. Another factor with Iggesund Paperboard is that the production uses two separate pulp lines, giving more possible streams to integrate, but also demands considerations of production independency and stability.

1.3 Objective

The objective of this thesis is to evaluate today’s energy situation and from the results find out how much steam that could be saved, and how this affects the cooling load. In addition, measures, which partly or in whole can realise the theoretical saving potential, should be proposed. This is done mainly by suggesting retrofits in the heat exchanger network but it is also possible to discover unused sources of heat and to save energy by making process changes. A further ambition is to reduce the proportion of primary heat in the district heating network by increased use of energy surplus from the mill and in the future maybe increase the production.

Questions to be answered:

- What is the energy situation with the new recovery boiler in place?
- How can the energy situation be improved and how much steam is saved?
- What possibility is there for energy production to external users, e.g. district heat?

1.4 Scope

The purpose of this project, as stated in Section1.2, is to map and analyse the current energy situation, which will be done using pinch analysis. Currently a new recovery boiler is being built; hence it should be regarded in the analysis. The mill is also currently looking into the possibility of investing in gasification of biomass. This project should not study the possibility of introduction of gasification, but the thesis is part of a PhD project studying this issue. There is also a desire for increasing the production in the future since the new recovery boiler will be able to handle an increased capacity, but no attention will be given to that in this project.

The ambition here is instead to reduce steam usage/need and hopefully eliminate the need of fuel oil and to locate sources of excess heat at "useful" temperature levels. The operating conditions are to be fixed to the permitted level of pulp and paper production and performed for an annual average, since the calculated stream data for the new boiler, and its impact on the energy system, is an average case, i.e. a mix of the conditions during summer and winter production.

1.4.1 Process boundaries

The study has been limited to the pulping process and the chemical recovery cycle, excluding the paperboard machines with a few exceptions mentioned below. Existing energy and material flows between the pulp and paperboard production may be included. Limitations have been necessary to make the work feasible as a Master Thesis. In *Figure 1.1.*the general structure for the integrated plant can be seen together with the main energy and material flows.

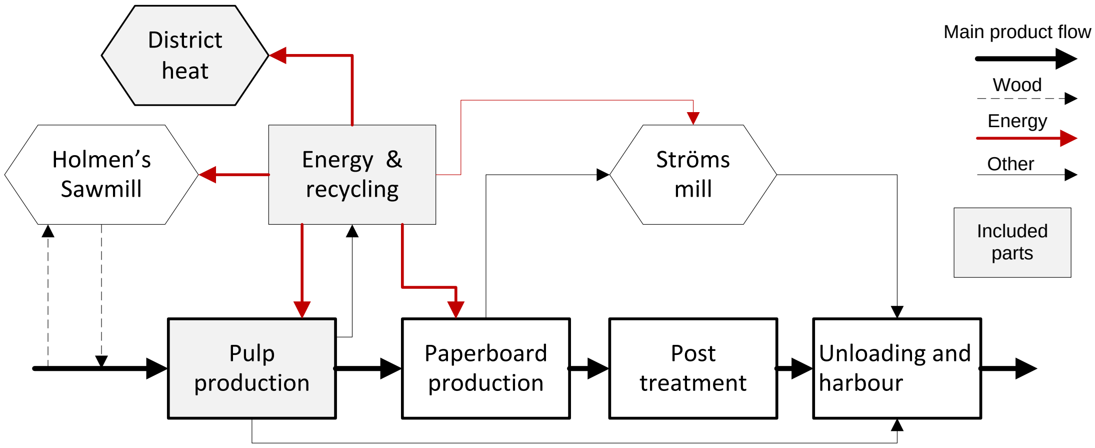

Figure 1.1: General plant structure

The pulp dryer, TM4, used to dry the market pulp is old. It will remain in use but will probably be updated with a new press and a new fan cabinet in the future. TM4 will not be included in the pinch analysis since suggestions of retrofits probably will be uneconomical, due to age.

The plant for preparation of bleaching chemicals is a steam consumer, but since it consumes less than 1 MW of 4 bar steam and no information distinguish the amount of process steam from indirect steam heating, the whole plant will be excluded. The sewage treatment is put outside the boundaries for this analysis but the effluent streams from the bleach plant are included. More detailed information about included and excluded parts can be seen in Chapter 5 Methodology.

The mill is connected to the local district heating network in Iggesund and supplies a nearby saw mill with heat. There is a possibility to connect the district heating network in Iggesund with the one in Hudiksvall due to the short distance between the two cities. This alternative will not be investigated but the possibility should be kept in mind when evaluating the results and suggesting future work.

1.5 Method

In order to fulfil the thesis' objective, this project consists of four main tasks: literature study, data collection, analysis and evaluation of results. The primary focus in the initial phase was on a literature study of theory and previous work within the field. In the next phase, the time was devoted to the process integration study itself, and the process integration study will be conducted using pinch analysis and a software called Pro_PI2. The data collection was performed in collaboration with personnel at Iggesund Paperboard, during which the mill was visited for a period of time. The pinch analysis provides information on how the system functions today and was used to suggest retrofits that will reduce the energy consumption.

1.5.1 Studied process cases

Two base conditions were used for the analysis. First a case with the current situation at the mill was generated and used as a reference case. Today's levels of steam use were also compared to model mills.

The second case is based on the process conditions after the installation of the new recovery boiler, which will be in place by June 2012. Together with the installation of a new boiler, a new turbine will be installed resulting in changes in steam and electricity production. This case was combined with some of the suggestions from the pre-studies made by Fortum (Sjökvist L., 2010) and the aim of the second case was to evaluate these suggestions from a pinch perspective.

2 Pulp and paper production

Pulp and paper is produced via a complex manufacturing process. Different production methods can be used and the manufacturing of pulp is usually divided into the subgroups chemical, mechanical or thermo mechanical pulping (Theliander, 2001). Given that Iggesund Paperboard is a chemical mill, only the chemical pulping technique will be covered in this section.

The most common chemical pulp production is by the Kraft process. In this process the cellulose is delignified using white liquor, which is a mixture of sodium hydroxide and sodium sulphide. A schematic presentation of the Kraft process can be seen in *Figure 2.1.* (Theliander, 2001)

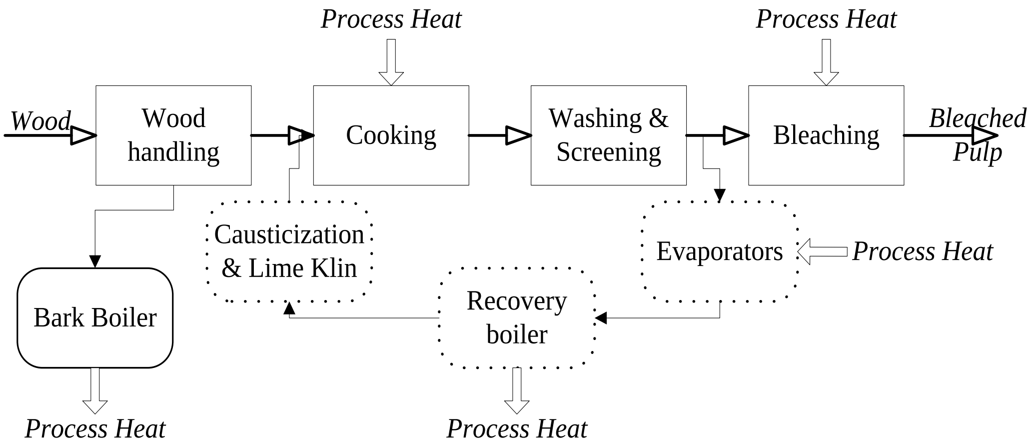

Figure 2.1: A schematic presentation of the Kraft process. Square boxes represent the fibre line and dashed boxes the recovery cycle

The main steps are wood handling, pulp production and pulp bleaching along with chemical and energy recovery. The different parts will be described in more detail, starting with the pulp production and bleaching.

2.1 The fibre line

The process units for conversion of wood into pulp are together called the fibre line. The purpose of the fibre line is to separate the wood fibres, consisting mainly of cellulose and hemicelluloses, by dissolving the binding lignin. (Theliander, 2001)

In the wood handling, the logs are de-iced and debarked in a rotating drum. This is done since bark has lower cellulose and higher ash content than wood. Before entering the cooking sector the logs are chopped into square chips and preheated to remove the air inside and increase the temperature. The chips are impregnated with white cooking liquor, in order to get an even distribution of liquor among the chips. Then the delignification is continued using more liquor in a batch or continuous cooking unit. The cooking conditions, i.e. pressure and temperature, will be changed during the cooking which continues until the lignin binding the cellulose has been dissolved. Lignin mixes with the spent cooking chemicals, called black liquor, and is removed from the pulp in the washing sequence. Not completely dissolved wood chips and other unwanted rejects are removed in the following screening. (Theliander, 2001)

Most often there is a need for further removal of lignin in the pulp and this is done in the bleaching sequence. The first step is usually oxygen bleaching followed by a number of combinations of e.g. chlorine dioxide bleaching, hydrogen peroxide bleaching and caustic soda. Finally the pulp is either dried and sold, or used in paper production onsite (Theliander, 2001).

2.2 The chemical recovery cycle

In a Kraft mill, the recovery of cooking chemicals has always been of economical interest, and is a necessity due to environmental regulations.

The black liquor from the washing is a diluted stream containing spent cooking chemicals, lignin, and around 40% of the carbohydrates entering the process. The multiple unit evaporation line increases the energy value of the black liquor by evaporating the water and thereby increasing the dry content to at least around 70%. The water is evaporated and recovered as a condensate that is cleaned in the stripper and then reused. The cooking chemicals are recovered by burning the strong black liquor in the recovery boiler. The released heat is use to produce steam and electricity. The cooking chemicals in the black liquor will form a smelt in the recovery boiler containing the cooking chemicals. This smelt is dissolved into a mixture called green liquor that is regenerated to white liquor in the causticizing process using calcium hydroxide. The reaction will form calcium carbonate that is regenerated to calcium hydroxide in the lime kiln and causticization. (Theliander, 2001)

2.3 Paper and paperboard production

The foremost use for pulp is for paper production. Paper exists in many different types for different use, and a paper with a thickness of over 200 g/m^2 is called paperboard or cardboard. The pulp is manufactured into paper using a paper machine which forms, drains, presses and dries the pulp into paper. The main sections of a general paper machine can be seen in *Figure 2.2* and the basic production principles are the same regardless of paper type. (Persson, 1996)

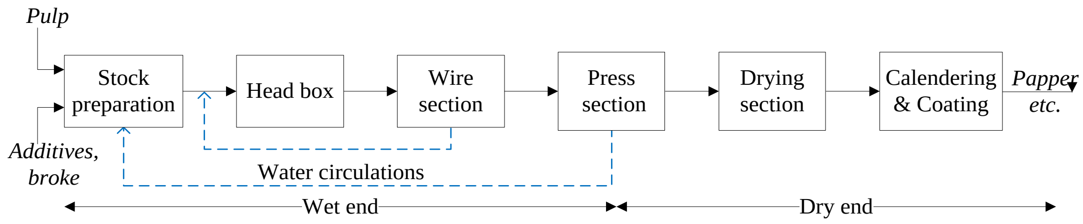

Figure 2.2: A schematic presentation of a paper machine.

In the stock preparation pulp is diluted to a dry content between 0.1% and 1%, and different chemicals are added. In a non integrated or partly integrated paper mill the pulp enters in bales and the first step is repulping. Stock preparation also includes proportioning of different pulps, blending of main components and finally mechanical treatment for changing the fibres properties. After these treatments the pulp will be known as stock, hence the name stock preparation. (Paulapuro, 2000; Persson, 1996)

The paper machine forms a web out of the pulp fibres. The diluted stock is distributed onto an endless moving woven cloth belt, wire, via the head box. On the wire the fibres are forced together from the draining of water, making them form hydrogen bonds, increasing the strength of the paper. The cloth will retain the fibres onto its surface and drain the water, increasing the dryness to a final state of around 20%. If paperboard or cardboard is produced there will be more than one stock preparation unit and head box, in order to form a multi layered paper. (Paulapuro, 2000; Persson, 1996)

In order to reach the dry content desirable for paper, around 90-95%, the web is first pressed mechanically and then dried using steam. In the mechanical pressing the waters is squeezed from the fibres, often using rolls. The higher amount of water pressed from the fibres the better heat economy for the mill, since less water needs to be evaporated in the next step. The final drying is usually achieved using steam heated cylinders that the paper passes on to evaporate the remaining water. The dryer cylinders are arranged in sections with increasing steam pressure to avoid web damages. Between the drying sections different finishing processes can be used. The paper passes through the calendaring, evening the thickness, and for some types of paper different coatings are applied. Finally the paper is cut and winded up on rolls, for transport to further handling or to customers. (Paulapuro, 2000; Persson, 1996)

3 Pinch analysis Theory

In this section the basic theory of pinch analysis is covered. The information is based on course material by P. Franck and S. Harvey (2008). For further reading *Pinch Analysis and Process Integration* by Ian C. Kemp (2007) is recommended.

Pinch analysis was introduced during the late ‘70s and is a methodology for analysing complex industrial processes in order to find energy and thereby save money. By classifying the process streams as either hot or cold, the minimum need for external hot and cold utility demand can be presented and possible heat exchanger networks configurations identified. A hot stream is a process stream that requires to be cooled and conversely a cold stream requires to be heated. It should be noted that the definitions have nothing to do with actual temperature. The users themselves will also decide how many of the process streams are worth including.

In order to explain how pinch analysis works, an example will be used throughout this chapter. The example is much simpler then a real industrial system, but will still provide the theoretical methodology explanation needed. The example system is a small multi stream system, consisting of both hot and cold streams, *Table 3.1.*

Table 3.1 Streams in the example process

Stream	**FC_p [kW/K]**	**T_{start} [°C]**	**T_{traget} [°C]**	**Q= FC_p* ΔT [kW]**	**ΔT_{min}**
C1	23	100	400	6 900	20
C2	25	200	400	5 000	20
C3	27	150	360	5 670	20
H1	32	450	250	6 400	20
H2	25	400	100	7 500	20

All streams have a specified flow and heat capacity which will affect their integration practicability. In a heat exchanger there is a lowest allowed temperature difference, which can be used between the exchanged streams, ΔT_{min}. Usually the value is set by economical constrains, since external utility demand decreases and heat exchanger area increases as ΔT_{min} increases. The value of ΔT_{min} is important in a pinch analysis.

A practical way to display the streams, in the multi stream system, is to draw a temperature enthalpy diagram called composite curve (CC). From the CC the minimum hot and cold utility demand can be seen, as well as the pinch temperature, *Figure 3.1.* A change in ΔT_{min} will affect the pinch temperature and the minimum utility demand.

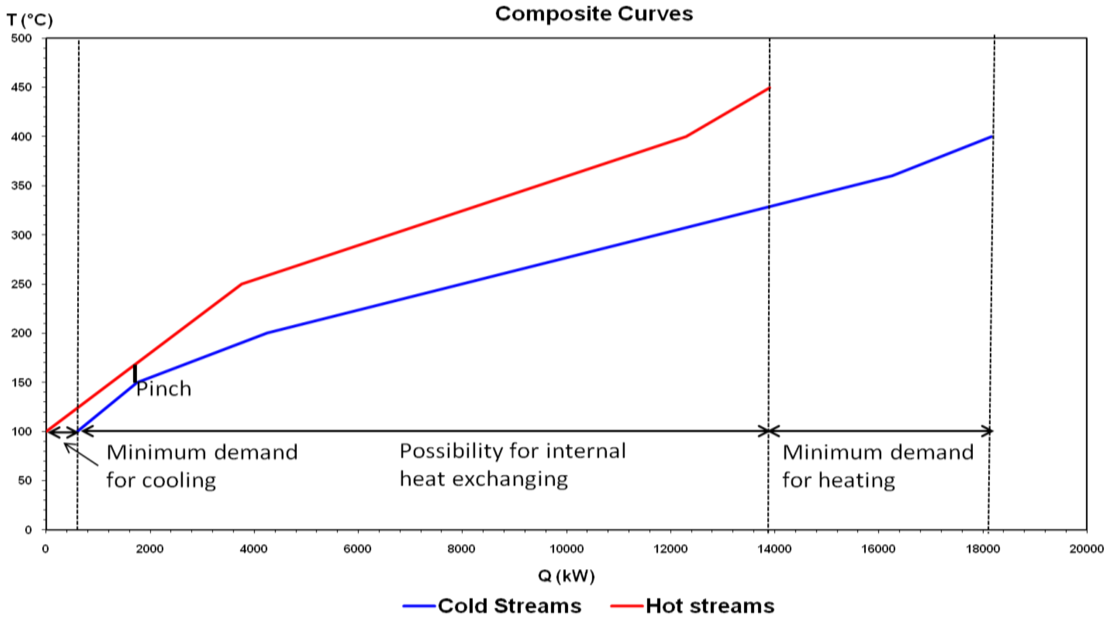

Figure 3.1: The composite curves for the example process.

If the hot and cold CC in *Figure 3.1* are combined the grand composite curve (GCC), *Figure 3.2,* will be generated. This diagram more clearly presents the location of the pinch and also shows at which temperature heating at lowest can occur and the highest temperature for cooling. GCC are extremely useful when there is an interaction between process and utility streams. The temperatures used in the GCC are shifted, meaning that the temperatures of hot streams are lowered with $\Delta T_{min}/2$ and the temperatures of cold are lifted with $\Delta T_{min}/2$.

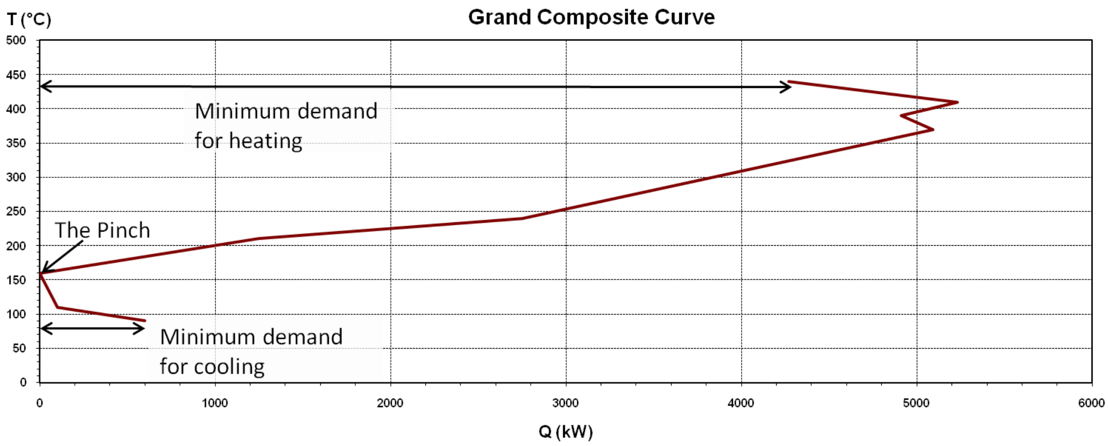

Figure 3.2: The grand composite curve for the example process.

3.1 Designing the network

Pinch network design should follow these three “golden rules” (*Figure 3.3*):

1. No cooling above the pinch, meaning that utility cooling of hot streams should be below.
2. No heating below the pinch, meaning that utility heating of cold streams should be above.
3. No transfer of heat through the pinch.

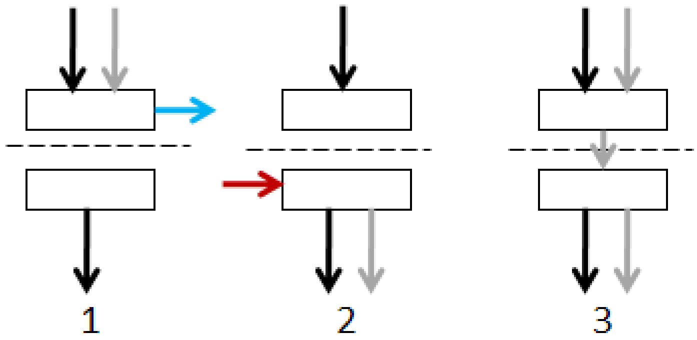

Figure 3.3: The golden rules of pinch

To minimise the energy consumption there should not be any pinch violations, that is breaking any of the three pinch rules.
From the stream representation the network design starts directly above or below the pinch, by adding the heat exchangers close to the pinch. When designing the network it is applicable to use the Tick-off rule that implies that one of the heat exchanged streams should be completely satisfied for each added unit. The example heat exchanger network can be seen in *Figure 3.4*.

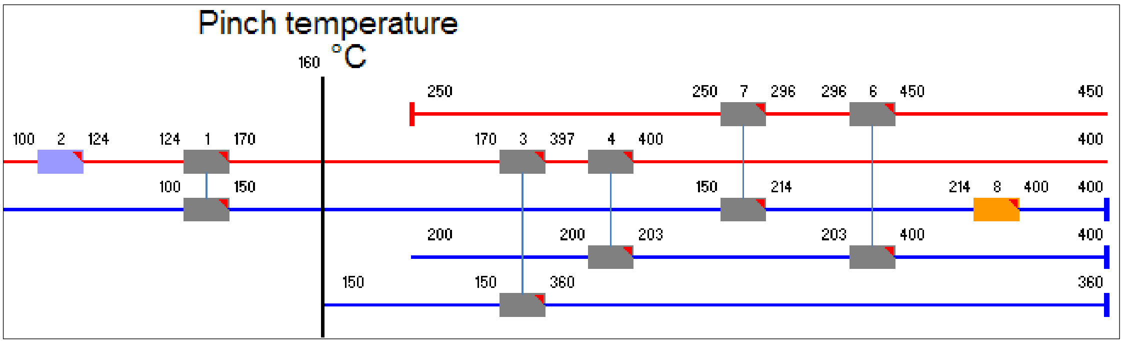

Figure 3.4: Heat exchanger network design for the example process

The target is to reach a maximum energy recovery (MER). Hot utility and cold utility will be introduced to the process in order to satisfy the heating and cooling demand.

The steps of a pinch analysis can be summarised as follows:

1. Data extraction and definition of relevant streams
2. Decision of suitable ΔT_{min}
3. Construction and analysis of CC and GCC
4. Identification of pinch violations
5. Suggestions of possible retrofits if it is not a grass root design
6. Optimisation of suggested design

3.2 Pro_PI2

Pro_PI2 is an add-in for Microsoft Excel, developed by Chalmers Industriteknik AB, which will be used in the pinch analysis. The add-in generates CC, GCC and provides information about the pinch temperature as well as minimum utility demands. With Pro_PI2 it is also possible to obtain a graphical stream representation which can be used to design the heat exchanger network, see *Figure 3.3* above, and locate pinch violations in an existing network.

Here Pro_PI2 will be used to generate the CC and GCC, but also for presenting the existing heat exchanging network and for the suggestion of possible retrofits. Inputs needed are target and starting temperatures for all streams, their mass flow and specific heat capacity, C_p.

4 The Iggesund mill

Iggesund Paperboard is a manufacturer of high quality virgin fibre paperboard used in the packaging and graphics sectors, produced at the Iggesund Mill and the Workington Mill. The company is a member of the Holmen Group and Europe´s leader within this production area. (Iggesund, 2011b)

The Iggesund mill is an integrated mill, producing both pulp and paperboard. At the site there are two fibre lines, one pulping softwood and one hardwood, optimised to reach the quality needed for the paperboard production. The main part of the pulp is then converted into paperboard in two paper machines, KM1 and KM2. Integrated with the mill's heating system is also Holmen Timber, a saw mill, and the local district heating system. The mill's annual production capacity amounts to 350,000 tone bleached pulp of which 80% is converted into paperboard. Over the last years the average production has been 320,000 tone of pulp (Iggesund, 2011a).

An overview of the process flows at Iggesund is presented in *Figure 4.1* and will now be described in more detail. The reference for the process description is the technical description report (Iggesund, 2011a) if nothing else is stated.

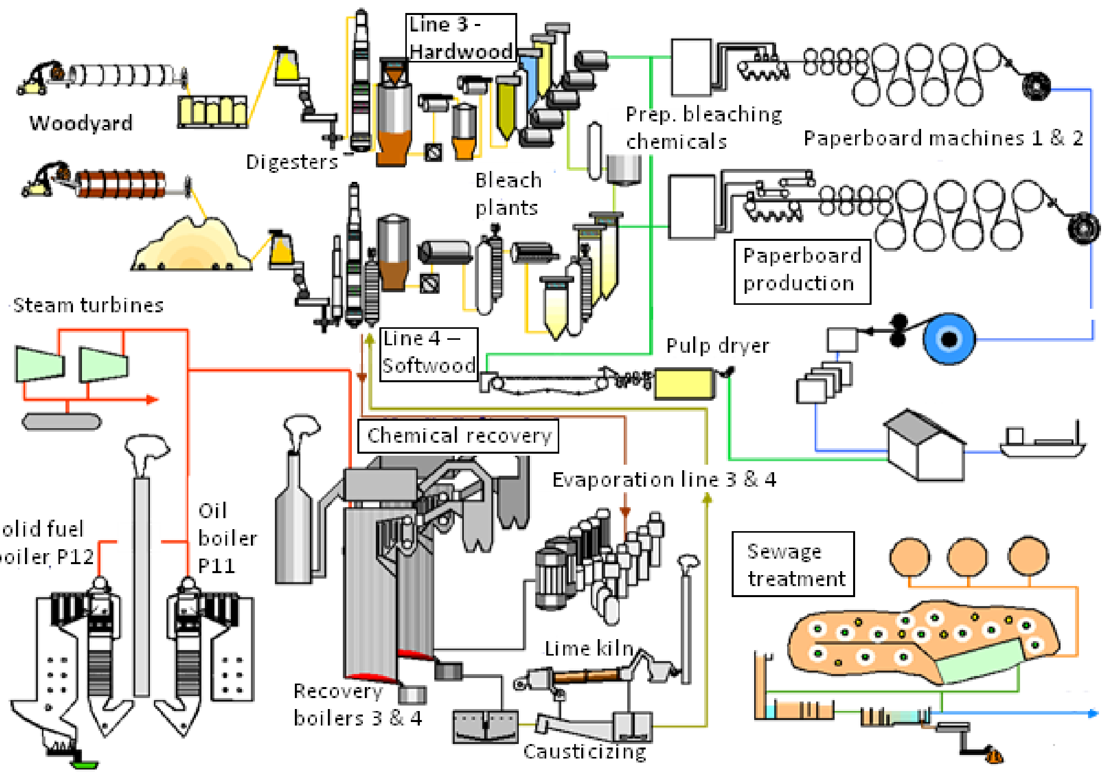

Figure 4.1: Main parts of the pulp and paperboard processes at Iggesund (Iggesund, 2010c)

4.1 The fibre lines

Wood arriving to the mill is debarked, chopped and delivered to the two fibre lines in one of two lines processing either softwood or hardwood. During the cold season steam and hot water is used to defrost the logs and water is always used to clean the logs. The woodyard also handles softwood chips from the saw mill for the softwood pulp production. Bark and wood residue is transported to the solid fuel boiler, SP12.

Pulping is occurring in two continuous pulping lines, which can be seen in *Figure 4.1*. Line 3 that now pulps hardwood is the smaller line built in 1967 and converted to hardwood in 1990. After passing an impregnation zone the wood chips are digested in a hydraulic continuous digester with two cooking circulations in the cooking zone. Passing down through the digesters the mixture reaches the washing zone, where it is washed whit the fresh with liquor in counter current way, which is removed in the top and brought to the flashes before reaching the evaporation line. The pulp passes the washing diffuser and screening before reaching the bleach plant, where it is bleached in a five step bleaching sequence D0(EOP)D1(EP)D2. The hardwood bleach plant does not have an oxygen prebleaching since it will soften the fibres, which is not wanted for the paperboard production (Johansson M.H., 2005).

The process line for pulping of softwood is similar to the hardwood line. It has been operating since 1990 as a continuous 2-vessel unit, with one pre impregnation unit and one digester. This digester also has a cooking zone and a washing zone. In contrast to the hardwood line the softwood line includes oxygen bleaching, since the softwood fibres is not soften to the same extent (Johansson M.H., 2005). Bleaching is continued in a four-stage diffuser bleach plant with the sequence D0(EOP)D1D2. In both bleach lines hot water is used to wash the pulp between every stage, producing bleach effluents which partly are sent to drain (Sjökvist L., 2010). The EOP stages are pressurised and consumes 4 bar steam. After the bleaching the pulp is stored in towers for transportation to the paperboard machines or the pulp dryer.

4.2 Paperboard production

The main product is Invercote, which is a solid bleached board, SBB. Invercote is produced using two paperboard machines, KM1 and KM2 (Iggesund, 2011b). The paperboard production also includes different post treatment steps, before it is finally packed and sent to customers or further treatment at nearby Ströms mill.

In the paperboard machine fully bleached pulp is layered into a paperboard using different pulp mixes depending on wanted properties of the SBB. KM1 was built in 1963 and produces a four layer SBB, while KM2 from 1971 produces a five layer SBB. KM1 and KM2 are steam consumers and have their own separate temperate water system.

4.3 The pulp dryer, TM4

About 20% of the produced pulp is dried in the pulp drying machine, TM4, which is the oldest process unit, built in 1960. The main reason for using the dryer, at the integrated mill, is to be able to have an even production of pulp and thus be less sensitive to sudden production changes on the paperboard machines. The machine is old and in need of renovation or replacement.

4.4 The chemical recovery cycle

The recover cycle for chemicals is illustrated in *Figure 4.2*.

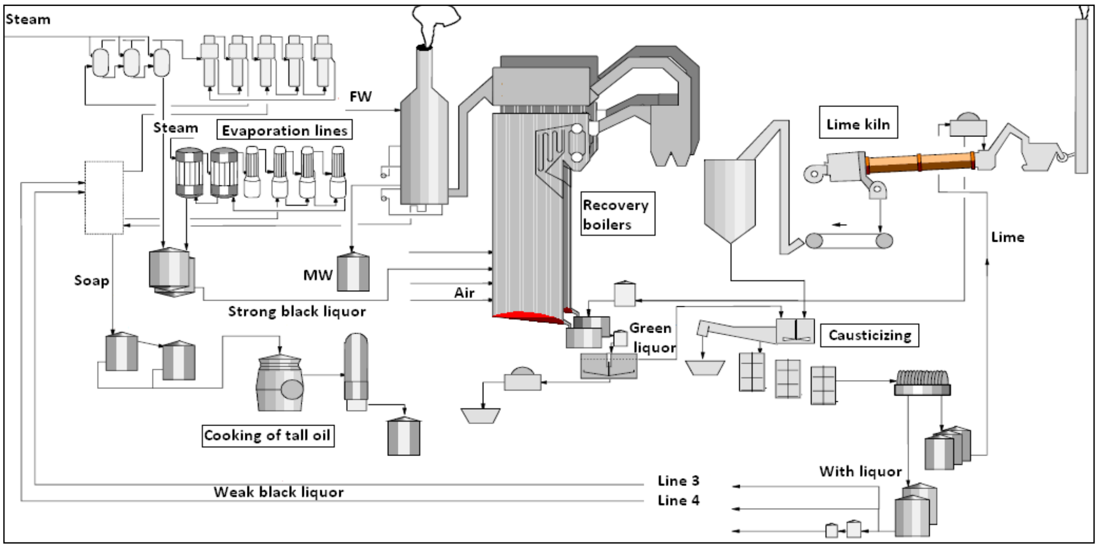

Figure 4.2: The chemical recovery cycle at Iggesund (Iggesund, 2010c)

Black liquor from the pulp lines is evaporated in two evaporation lines. Line 3 is the older one, with five Kestner-units[1], and was later complemented with an final concentrator. After the treatment the black liquor has reached a dry content of 65%. The evaporation capacity is 190 t_{water}/h and steam can be drawn from one of the effects to be used for preheating of internal district heat. Line 4 is a six unit process with an evaporation capacity of 200 t_{water}/h. Under normal operation the black liquor from line 3 is mixed with the liquor from line 4 before the last unit, in order to reach a higher dry content of around 74%.

Steam from both of the last evaporation units are condensed in the surface condensers while producing medium temperature water, MW. The condensed vapour is removed fin each effect and separated into different classes of condensates and the secondary condensate is broth to the integrated stripper, which is part of the gas and condensate handling system. Volatile gases from the process are burnt in a gas fired boiler, GP, or in the lime kiln. Soap extracted from the evaporation units is converted into tall oil and sold.

The black liquor, now with a dry content of around 74%, is burnt in the recovery boiler. The recovery boiler is the heart of the pulp production mill, covering most of the production site's steam demand. Currently the recovery cycle is being upgraded by replacing the two existing recovery boilers, SP3 and SP4, with one new boiler and installing a new steam turbine.

Included in the chemical recovery cycle are also the lime kiln from 2007 and the causticizing process from 2003. Here the green liquor from the recovery boilers is regenerated into white liquor.

[1] Units manufactured by Kestner, now GEA

4.5 Steam & Water systems

60 bar steam is currently generated in two recovery boilers, SP3 and SP4, the solid fuel boiler, P12 and the oil boiler, P11. At site there is also steam generated in a gas boiler, GP, burning process gases but at lower pressure around 13 bar. A summary of the steam producers and their contribution is presented in *Table 4.1.* (Iggesund, 2011a)

Table 4.1: Stream producers 2010 (Iggseund 2010a)

	MW	**% of total**
SP3 + SP4	155.4	64
P11	13.9	6
P12	71.4	29
GP	2.3	1
Total	*243.9*	*100*

The two recovery boilers are fuelled with thick black liquor but also use a small amount of oil. Also P12 mix the solid biofuel, mostly bark and saw mill residue, with some oil.

The produced 60 bar steam is reduced into 13, 9 and 4 bar steam using two back pressure turbines, generating 230 GWh of electricity per year.

Temperate water used within the pulp production is produced using an internal secondary heating system and is used mainly in the bleach plants and for the cooking of pulp. Temperate water is produced at three levels: medium hot water, MW, at 40°C, warm water, WW, at 65°C and hot water, HW, at 85°C. During normal production conditions no steam is needed for the production as presented in the balance by Carlsson and Nygaard (2008). When installing the new recovery boiler there will also be changes made in the secondary heating system.

5 Methodology

A major part of this thesis work has been devoted to collecting data and analysing the mill. After visiting the mill to gain an overview of the processes and collecting data on site, streams of interest were identified and used in the pinch analysis as well as for the evaluation. The work includes a literature study in order to understand the process of papermaking and pinch theory. Together with a review of the mill itself and earlier work at the mill, with energy related questions it made up the foundation for the rest of the work.

Printouts from the controller screens, connected to the mills info and control system, together with the process flow charts have been used to understand the process and identify streams and heat exchangers of interest for the pinch analysis.

5.1 Collection of data

An annual average case was chosen as base for this study, since the new boiler is designed for a medium production case[2], and the secondary heat balance provided by Åf (Carlsson A-M. and Nygaard J., 2008) exists for a summer and a winter case. Thereby an average case is suitable.

Iggesund uses a continuous process for the production of pulp and process data is continually measured and stored. In the info systems information is stored for a period of two years and information from the control system is stored for a period of seven days. The major part of data in this thesis originates from measuring equipment within the process, stored in any of the two systems mentioned above. If possible the data have been taken from the info systems and an annual average has been calculated from stored data between 28th of April 2009 and 27th of April 2011.

Previous energy studies have also been an important information source. The energy investigation by Åf (Johansson M.H., 2005) has been useful in order to identify unused energy and together with the secondary heat balance (Carlsson A-M. and Nygaard J., 2008) provide a foundation for assumptions made. Also the pre-study by Fortum (Sjökvist L., 2010) has been used to develop a description of the future production situation with the new boiler in place.

A limitation and source of error with the procedure, is that no measurements on site have been carried out to fill information gaps. More information in Appendix A1 listing identified heat exchangers and Appendix A2 listing the streams included in this pinch analysis.

5.2 Selection of included process parts

As said in section 1.4, this pinch analysis focuses on the pulp parts of the mill. The hardwood bleach plant, BL3, is manually controlled making it hard to identify reliable values for temperatures and flows over time and harder to integrate with other processes. Only the effluent streams from the D0 and D1 bleach stages are therefore taken into account and the rest of the streams are excluded from the analysis. Also the lime kiln process, as it is today, is excluded from this pinch study. The existing heat exchangers within this process are either small, used in safety systems or there is a lack of information since measurement equipment is missing. Cooking of tall oil is

[2] The medium production case is based on permitted pulp and paper production levels.

steam consuming, as well as the gas and condensate systems but this will also release heat. These processes should be included in the analysis but are to a large extent omitted due to lack of information. Both the evaporation lines are integrated and only the end condenses i.e. surface condensers are of interest. A detailed list of identified heat exchangers and comments on whether they are included or excluded is available in Appendix A1.

5.2.1 The district heating system

The mill is currently connected to the local district heating network in Iggesund and supplies a nearby saw mill with heat. From start the district heat will not be included as an existing heat demand. So when designing the heat exchanger network, all existing heat exchangers connected to the district heating system are removed. Later on, when designing the new network, the possibility for district heat production from excess of heat is evaluated. By designing it from scratch it will be easier to think beyond existing routines, giving a possibility for reducing the amount of primary heat needed and for releasing excess heat at higher temperatures usable in other parts of the process.

5.3 Evaluation and representation of data

In a pinch analysis the streams need to be represented with start temperature, target temperature and energy content. Heat loads in different streams have been calculated using data from existing heat exchangers. As far as possible the flows and temperatures for both sides of the heat exchanger were identified. In the case of non-consistency in transferred energy, one of the values was chosen based on a judgement of reliability and previous experience. Missing values where calculated using mass and heat balances.

5.3.1 Stream representation

The included streams and corresponding information can be found in Appendix A2.

Streams passing through more than one heat exchanger are lumped together into one. The stream start and target temperatures can be classified as either hard or soft. The hard targets are required by the process while the soft can be changed in order to reach maximum energy output. Soft targets are assigned to the effluent streams and some of the water streams

The inlet temperature for freshwater, FW, and mechanically cleaned water, MCW, has been set to 18°C if no other information has been available. This since MCW usually have a higher temperature then FW and provided info on specific streams indicates that 18°C is a reasonable annual average. The standard value for FW is between 4°C and 25°C for FW. Information gaps for the medium temperature water, MW, will be given a target of 40°C, since it is the design temperature. The warm water, WW, will have a target of 65°C and the hot water, HW, of 85°C.

The sewage treatment handling the effluent streams sent to drain don not have any specific temperature request so the temperature for all effluent streams are set to a soft target of 37°C.

In order to distinguish the direct steam users from the steam heating demand, all steam users within the analysed part of the process were identified and analysed. When steam was used for heating purpose, and theoretically could be replaced with process heat exchanging, the heat demand was represented by the cold stream at its start and target temperatures. The streams where steam cannot be replaced, since it is direct steam or needed by the equipment, are represented as cold streams at the steam condensing temperature.

Another important value needed for the pinch analysis is the minimum temperature difference, ΔT_{min}, as stated in section 1.3. Values were chosen from the studies by E. Axelsson (2008) and are presented in *Table 5.1*. For stream classes not listed in the table a $\Delta T_{min}/2$ of 5 was used.

Table 5.1: Minimum temperature difference for different fluids used in the analysis

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

5.3.1.1 Existing network

For the representation of the existing network the water streams were kept separate and soft targets where only used to fill information gaps. Energy saving opportunities were identified by studying the GCC and CC, since these show the minimum utility demand. Then, today's heat exchanging network was constructed and pinch violations identified.

5.3.1.2 The Future network, with projected changes

As already indicated a new recovery boiler is being built. The new boiler will be equipped with flue gas cooling which increases the possible heat deliveries. Fortum suggests that heat from the flue gas cooling should be used to preheat feed water or for the production of district heat (Sjökvist L., 2010). In this analysis the heat load was included but the specific usage left open until the final analysis. Furthermore, Fortum suggests to also include the installation of a flue gas cooler on the lime kiln and installing a new condenser on KM2 (paperboard machine 2).

Here it is suggested that the heat from the condenser should used elsewhere in the process, and must therefore be compensated. It is suggested to be done by letting the water be heated by the today unused filtrate from the bleach plant instead of the flash steam. This will free energy at a higher temperature level then today's effluent temperature of 65°C. In total, all these changes will increase the amount of heat available in the system. (Sjökvist L., 2010) A GCC for this system is created and compared to the existing networks GCC. In the modelling both hot flue gas streams were represented as hot water streams, since in available information (Sjökvist L., 2010) the hot flue gases are first exchanged with a water stream and then with the rest of the process, and only the heating potential is of interest here.

5.3.2 Analysis

The pinch temperatures are identified, at the point where the minimum temperature difference appears. Transferring heat down through the pinch is a pinch violation as well as cooling above and heating below.

Heat exchanger networks were created and the pinch violations are analysed. For the future situation two main uses for excess heat were evaluated. One with the goal to reduce the steam usage and one with the goal to increase the production of district heat and also function as a comparison with the suggestion from Fortum (Sjökvist L., 2010). No economic evaluation was performed.

6 The present and future energy situation

In this section the present energy situation and the situation after the installation of the new recovery boiler will be presented. Focus will be on the system with the new boiler in place since it is already under construction. First the current production situation is presented and the utility demand today and in the future is analysed. Finally pinch violations, i.e. the non-optimal energy usages are listed.

6.1 Current production

Iggesund produces pulp in two continuously production lines. The softwood line has more production hours each year and the total number of production hours is around 8700 h.

As presented in section 5.1 an annual average is used for the calculations. The average pulp production rate for the main period of time used can be seen in *Table 6.1*.

Table 6.1: Average pulp production rate 28th of April 2009 to 27th of April 2011

	ton/h
Hardwood, line 3	19
Softwood, line 4	22

Temperate water used within the pulp production is produced using an internal secondary heating system and used mainly in the bleach plants and for the cooking of pulp. Many of the streams in the pinch analysis are part of this system as either heat deliverers to the water streams or as the actual water streams. At normal production conditions no steam is needed for the production of hot and warm water as presented in the balance by Carlsson and Nygaard (2008).

When installing the new recovery boiler there will also be changes made in the secondary heating system.

6.2 Heating and cooling demand today and in the future

The heating and cooling system at a pulp mill is complex, involving a large number of heat exchangers and utility streams. In this work gathered information is converted to heating and cooling demand, represented by hot and cold streams, see Appendix A2.

When streams are assigned the individual ΔT_{min} the pinch temperature and minimum utility demands can be identified. The values for today's process and the future process are summarised in *Table 6.2*.

Table 6.2: Pinch results

	Today's network without effluents[1]	**Today's network**	**Future network**
Pinch temperature [°C]	62	69	113
Minimum hot utility [kW]	85 900	85 500	74 000
Minimum cold utility [kW]	1 720	31 800	29 300

[1] Today most of the effluent is sent to drain without any cooling

Effluent streams from the bleach plants, stream H9 and H44 to H47 in Appendix A2, are today sent to the drain without any cooling at a temperature over 60°C. Since the task is to identify measures in order to increase the energy efficiency, these streams should be included as potential heat sources. As can be seen in *Table 6.2* the need for cooling is much lower than when the effluent streams are included since it is a fictive cooling demand that today is not utilised.

The information from *Table 6.2* can be graphically seen in the composite curves, CC, *Figure 6.1* for today's network and *Figure 6.2* for the future, as a comparison today's network without effluents is available in Appendix A3. In the figure we have a hot CC, in red, resenting all the hot streams and a cold CC, in blue, resenting all the cold streams. The pinch is located where the distance between the two curves are the smallest, representing the minimum temperature difference.

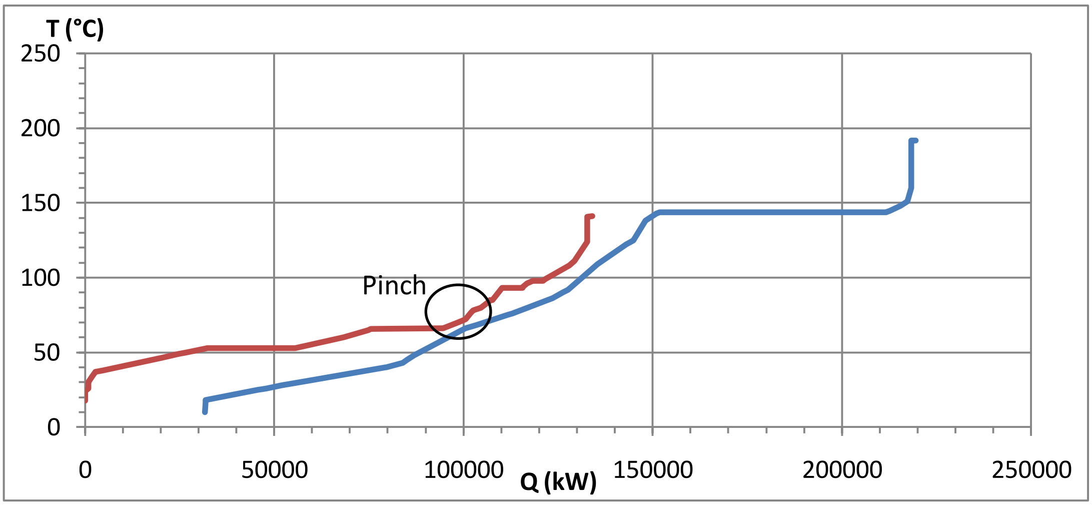

Figure 6.1: Composite Curve for today's network

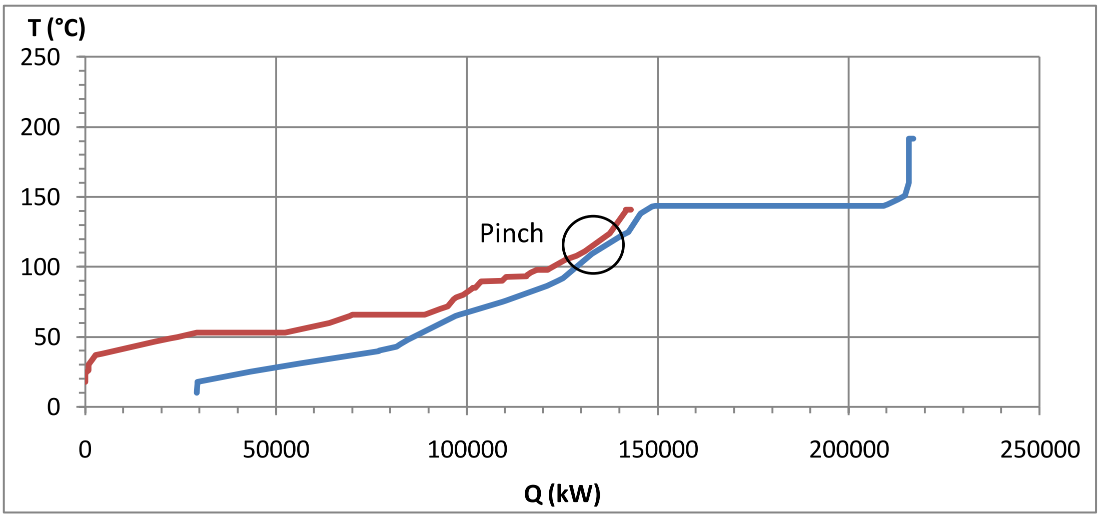

Figure 6.2: Composite Curve for the future network

The overlap between the two curves indicates the theoretical maximum internal heat recovery, thus the process covers its own heating and cooling demand within this area. The long horizontal line represents the 4 bar steam demand and the small line at around 190°C is the 13 bar steam demand.

As can be seen above, the two systems do not have the same pinch temperature. The introduction of the hot streams from the flue gas cooling will increase the amount of available heat in the temperature interval 140°C to 105°C. The difference between the two networks can more clearly be seen from the GCC in *Figure 6.3*. A GCC comparing today's network without and with effluents can be seen in Appendix A3.

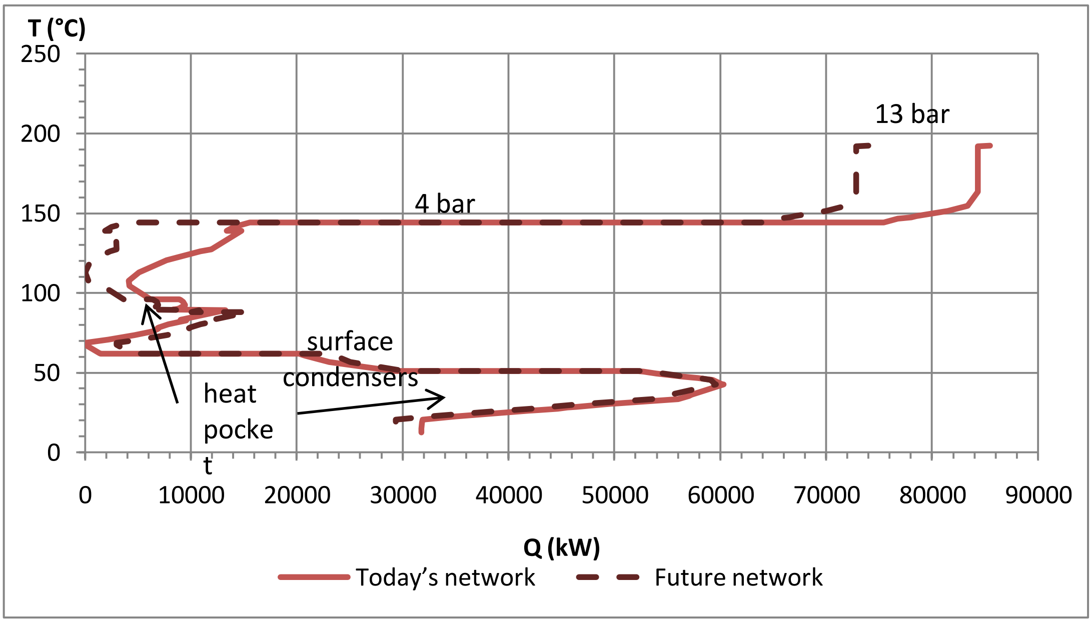

Figure 6.3: Grand Composite Curve for Today's and the future network

A GGC shows at which maximum and minimum temperatures where heating and cooling can occur. The effluent streams are, as described in section 5.3.1 assigned soft targets. When using soft targets there will be an overestimation in utility demand since the utility presented is the one needed to reach the soft target. The extra amount of cooling is around 30 MW, of which around 16 MW is over 50°C, and should, as said above, be regarded as potential future heat sources.

Both GCCs have two noses surrounding a heat pocket, in which the streams could be heat integrated. The introduction of the two flue gas coolers and the new KM2 condenser shift the pinch since the shape of this pocket will be changed. A GCC can be sensitive to included streams, like above where the introduction of three new streams drastically changes the pinch temperature and thereby the optimal running conditions, from a pinch perspective. An increase in pinch temperature will release heat with a higher temperature levels and thereby increase the possibilities for process integration and district heat delivery.

There is also a pocket around 35°C, with possible internal heat exchange, necessary to us in order to reach the minimum hot utility demand, and the two horizontal lines under the pinch are the surface condensers at evaporation line 3 and 4. After the heat exchangers preheating the BFW with incoming BFW condensate, the surface condensers are the biggest exchangers with a load of 18.8 MW and 22.8 MW respectively.

6.2.1 Existing heat exchanger network

The current heat exchanger network, composed of streams selected for this analysis, includes one cooler, seven steam heaters and 18 process-to-process heat exchangers. There are also 9 streams representing direct process steam. After the installation of the flue gas cooler on SP5 and on the lime kiln as well as new KM2 condenser there will be an addition of three units. The existing and future heat exchanger network can be seen in Appendix A4 and A5.

6.3 Potential for improvements, pinch violations

In an optimal world, a process would only use the minimum utility demand. In pinch this is usually called MER, "maximum energy recovery" (or "minimum energy requirement"). Due to the so called pinch violations, presented in section 3.1 the process cannot recover the theoretical maximum of heat. The amount of pinch violations can be seen in *Table 6.3* and is the difference between current steam demand and the minimum hot utility demand.

Table 6.3: *Theoretical saving potential*

	Today's network	Future network
Present steam demand [kW]	92 290	92 290
Minimum hot utility demand [kW]	85 501	73 998
Pinch temperature [°C]	69	113
Pinch violations [kW]	6 789	18 292

Since the network of today and the future network have different pinch temperatures there will be a difference between the identified pinch violations, as can be seen in *Table 6.4* and *Table 6.5*. The pinch violations are heating below, cooling above and transferring heat down through the pinch.

Table 6.4: Identified pinch violations in today's network

#	**Name hot stream**	#	**Name cold stream**	**Reason**	**Q [kW]**
1	turpentine vapour line3	2	water - turpentine condenser line3	through pinch	635
15	black liquor from flash	16	water - black liquor cooing (HX:3210=2064)	through pinch	140
18	black liquor (HX:3210=2081)	17	water - black liquor cooing (HX:3210=2081)	through pinch	1 150
22	weak liquor line 4	23	water - weak liquor cooling line 4	through pinch	92
29	evaporation vapour effect 3:5	CW	Cold Water	cooling above	788
31	stripper gas through intermediate condenser	30	water - intermediate condenser	through pinch	2 734
37	green liquor cooling	38	water - green liquor cooling	through pinch	579
43	boiler feed water condensate	42	boiler feed water	through pinch	670

Table 6.5: Identified pinch violations in the future network

#	Name hot stream	#	Name cold stream	Reason	Q [kW]
LP	Steam 3bar	6	boiler feed water preheating	heating below	6 605
LP	Steam 3bar	21	HX D2-D1	heating below	2 683
43	boiler feed water condensate	42	boiler feed water	through pinch	1 973
LP	Steam 3bar	42	boiler feed water	heating below	654
56	flue gas SP5		To atmosphere[1]	cooling above	4 251
57	flue gas lime kiln		To atmosphere[1]	cooling above	2 126

[1]Before identifying the stream used for condensing the flue gases the heat will be released above the pinch to the atmosphere.

Since the flue gas cooler on SP5 will be installed from start and it is a big possibility for the introduction of the lime kiln flue gas cooler and the rebuilding of KM2 during the period of 2013 to 2017, only the future network will be included in the retrofit analysis. If all pinch violations are solved the new network will be a MER network. But in this thesis there will be no construction of a MER network since it will have a large investment cost generating and unacceptable payback time.

So in the next chapter options for retrofits to reduce pinch violations and save steam will be suggested. Thus from the pinch violations in *Table 6.5*, an elimination of HX D2-D1 pre heating with steam, integration of flue gas cooling and a better preheating of the BFW, will be the violations of most interest to solve.

7 Retrofit suggestions

In this section two retrofit networks will be suggested and evaluated. Both networks will have the ambition of solving as many pinch violations as possible, but will have different needs for investments. As mentioned in previous chapters the introduction of the two flue gas coolers and rebuilding of the condenser at KM2 will add more high temperature heat to the system and here the goal is to reduce the steam usage.

One of this thesis' objectives has also been to reduce the proportion of primary heat in the district heating, DH, network with increased heat exchanging. Therefore a suggestion to maximize the production of district heat without increasing the steam demand is also evaluated together with the ideas from Fortum (Sjökvist L., 2010).

All existing steam heaters could theoretically be substituted with process-to-process heat exchangers if process heat at the right temperature is available, but the minimum hot utility demand of 74 MW cannot be covered. Above the pinch temperature there are streams around the two digesters being heated with steam, which is okay in a pinch view.

The secondary heating system at a mill, i.e. the water system delivering temperate process water to different operations, is usually complex and sensitive to changes. With the introduction of SP5 there will be changes in the existing system and no secondary heat balance for the new system is already available. Hence, as a limitation of the workload no changes affecting this system will be suggested to these streams included in the retrofit designs.

So not all of the streams in Appendix A5 are of interest for a retrofit, especially since no MER, maximum energy recovery, network will be designed. Main streams discussed in the sections below are presented in *Figure 7.1*.

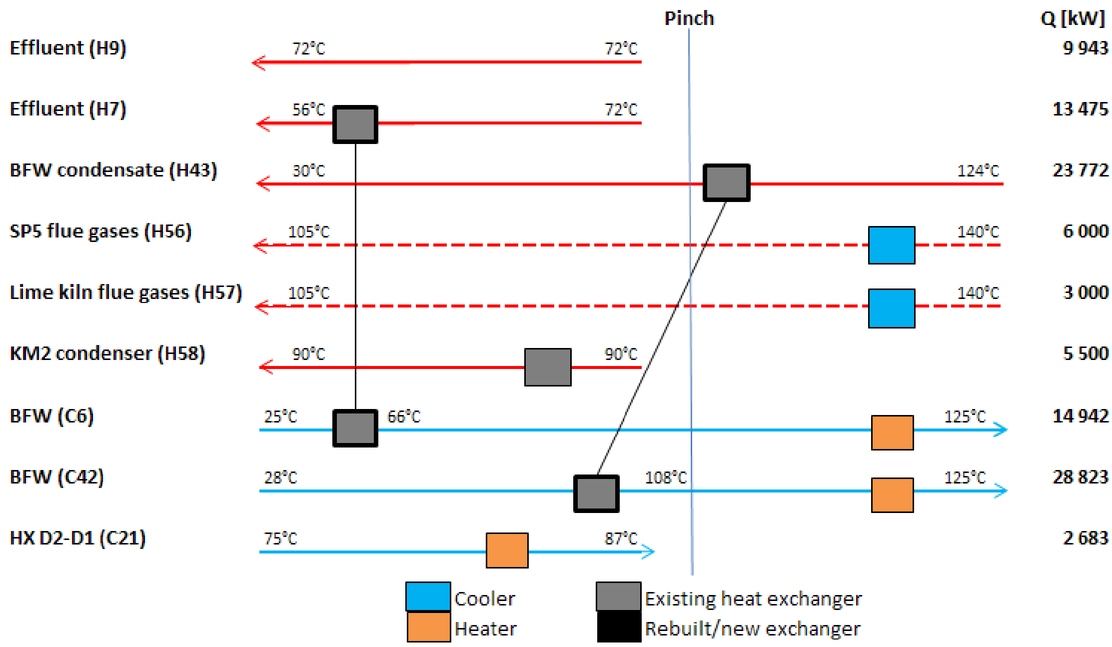

Figure 7.1: Future heat exchanger network before retrofits.
The heat exchanger on stream H58 is today connected to a water stream in the papermaking machine.

7.1 Decreasing the steam usage in the future network by solving of pinch violations

Two different retrofit suggestions with the purpose of decreasing the steam usage will be presented. They differ in percentage of pinch violations solved and changes needed.

7.1.1 Retrofit 1

Many of the identified pinch violations, see *Table 6.5*, are related to the preheating of the boiler feed water, BFW. There is also available heat from the two flue gas coolers. Suggested changes are presented in *Table 7.1*, and will be explained below.

Table 7.1: Changes in the steam saving suggestion retrofit 1

Hot stream		**Cold stream**		**Steam saved [kW]**
#	**Name**	**#**	**Name**	
H7	effluent from 3141=2034	C6	boiler feed water preheating	450
H58	flash steam through condenser at KM2	C6	boiler feed water preheating	2 390
H56	flue gas SP5	C42	boiler feed water	5 050
Total saving				7 890

If the heat exchanger that today preheats the BFW with effluent from the bleach plant, stream C6 and H7, is replaced with a new one, the temperature on the BFW can be increased while the flow of condensate can be reduced. This since the existing heat exchangers do not utilise all heat available and all the cooled off heat is not picked up by the cold stream. The total steam saving would not be that large in this modification alone, but it will reduce the needed bleach effluent flow from tank (3141=2034) with 169 m^3/h, which thus can be used to heat other parts of the process. The released energy from H7 has been allocated to stream H9 in the presented network by increasing its flow, since the two streams originates from the same effluent tank.

Combining the modified heat exchanger with further heating of stream C6, by exchanging it through the new condenser at KM2, more steam is saved (see *Table 7.1*). In total the reduction of needed steam will be 2 840 kW.

Existing heat exchanger between the BFW condensate, H43, and the BFW in stream C42 will be kept thus having a pinch violation of almost 2 MW. The returning BFW condensate needs to be cooled to at least 50°C before entering an ion exchange and it is suitable to heat exchange these two streams due to location within the process.

Furthermore, it is suggested that the heat from the new flue gas cooler on SP5 will be used to heat up the BFW in stream C42 and thereby eliminating all the need for steam heating up to 125°C. The potential of heat exchanging the BFW with the flue gases is good since the streams are located in the same production facilities. The old steam heaters will be kept on BFW stream C42 as a backup system and the load of the steam heater on BFW stream C6 is reduced but can be increased if necessary.

In *Figure 7.2* the heat exchanger network with the three new/changed exchangers, as black connected boxes, is presented. Only the streams relevant for the retrofit are included.

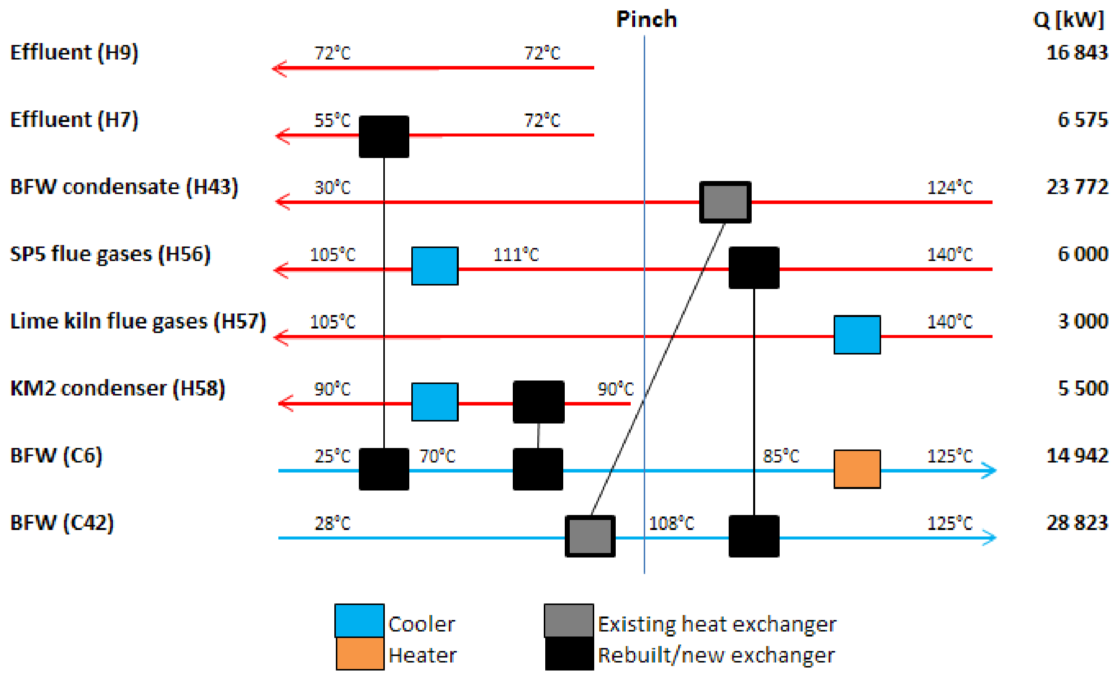

Figure 7.2: Heat exchanger network after retrofit 1

Studying the change in pinch violations for this suggestion, it will lead to an elimination of one of them and a reduction of one more. In total, the pinch violations in the fibre lines will be reduced with 43% and the steam demand with 7.9 MW, which represent 8.6% of the studied demand and 2.6%[3] of the mill's total demand. If the reduced steam is removed from the process through a decline of steam production, there will also be a reduced demand for BFW and less steam used for heating it until a new equilibrium is reached. However this change will be small compared to the other ones presented here and the increase in steam savings would only be marginally larger than stated here.

After introducing the modifications above, there is still a lot of excess heat below the pinch in the system. The heat in the effluent stream from tank 3141=2034, H9, is at 72°C and can be used for preheating incoming district heat from 50°C or within the secondary heat system to heat water. Today H9 is already used for this purpose to preheat incoming district heat return to 69.5˚C, but the increase of available flow due to the changes above, increase the energy content and it is therefore possible to increase the heat delivery to the district heat. The flue gas cooler on the lime kiln is not specifically connected to any stream, and could be used for reducing the steam demand within the district heat system. Fortum suggests two different opportunities where district heat production is one and BFW preheating is the other (Sjökvist, L, 2010). In Figure 7.3 the potential for district production is presented in form of a GCC, grand composite curve.

[3] Total steam demand for Iggesund mill is 298 MW

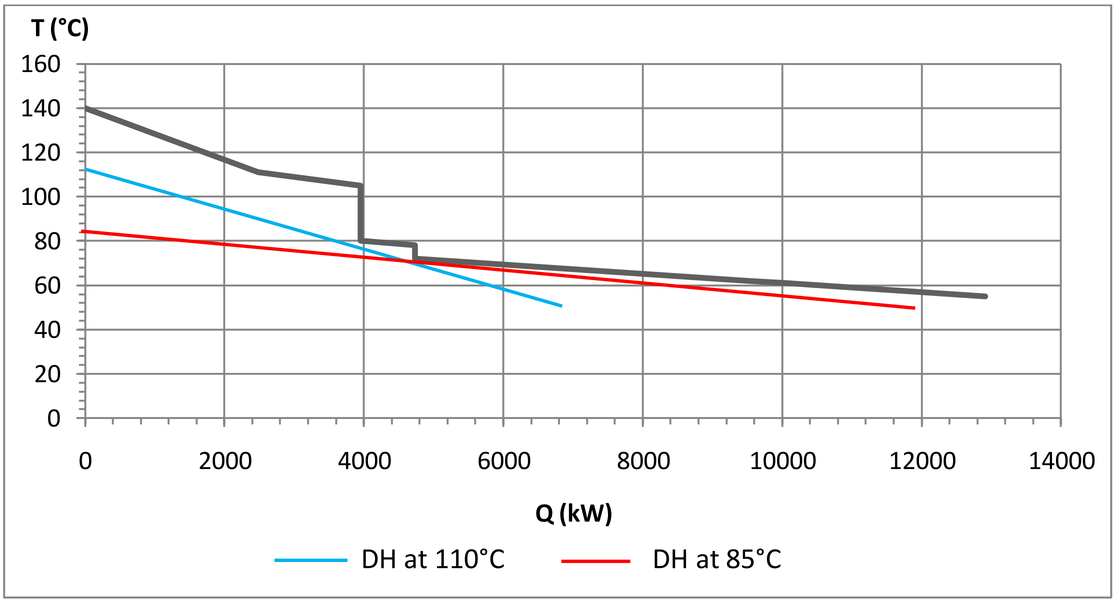

Figure 7.3: Potential for production of district heat in retrofit 1

If the suggested changes are built the energy surplus will be enough for generating 6.8 MW of district heat at 110°C, which is 54% of the needed peak load. Off peak around 12 MW can be produced at 85°C. It should be noted that heating district heat with the flue gases above pinch still is a pinch violation, as ventilating it to the atmosphere, but there will be a further reduction of the total steam demand since the pinch violation now is connected to a useful purpose.

Replacing the heat exchanger between stream C6 and H7, will probably not be of interest if only the steam saving should be regarded as gain. Thus the new use for the saved energy from the effluent is of importance. Heat exchanging BFW with flue gases is a common construction and should not need too large investments regarding piping. Heat exchanging between the BFW and the KM2 condenser on the other hand will need longer piping due to the distance between the units. The suggested potential for district heat production will also need a more complex piping construction and it may not be possible to utilise all the heat presented in *Figure 7.3*.

7.1.2 Retrofit 2 – Extended retrofit

Retrofit 1 does not solve all the pinch violations, so there is a possibility for further improvement of the heat exchanging. In *Table 7.2* a more extensive retrofit is presented.

Table 7.2: Changes in the steam saving suggestion retrofit 2

Hot stream		**Cold stream**		**Steam saved [kW]**
#	**Name**	**#**	**Name**	
H7	effluent from 3141=2034	C6	boiler feed water preheating	450
H57	flue gas lime kiln	C6	boiler feed water preheating	860
H56	flue gas SP5	C6	boiler feed water preheating	3970
H57	flue gas lime kiln	C42	boiler feed water	5 050
H58	flash steam through condenser at KM2	C21	HX D2-D1	2 680
Total saving				13 010

In this retrofit the same changes as in retrofit 1 is made to the heat exchanger between the BFW stream C6 and the effluent stream H7, and also here resulting in an increasing energy load in effluent stream H9. C6 is then further heated through heat exchanging with the flue gases from the lime kiln and SP5. It will still be a need for heating C6 with steam but the load will be reduced. The reduction in steam demand for heating of the BFW in C6 will in total be 5 280 kW. To further heat the other BFW stream, C42, in this case the flue gas cooler on the lime kiln is used; stream H57, which also in this retrofit eliminates all need for further steam heating of C42.
In *Figure 7.4* the extended heat exchanger network, retrofit 2, is presented with all changes. Only the streams relevant for the retrofit are included.

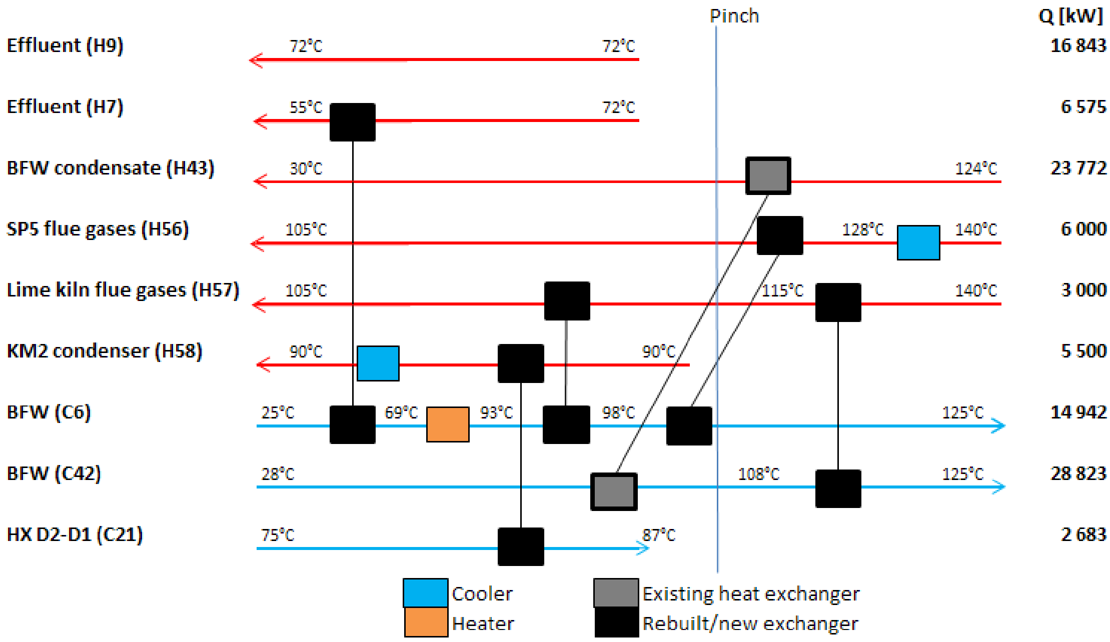

Figure 7.4: Heat exchanger network after retrofit 2

Retrofit 2 is more extensive then retrofit 1 and will lead to elimination of two of the pinch violations and reduction of one more. On the other hand it requires more heat exchanger arranged in a more complex network. In total the pinch violations will be reduced with 55% and the steam demand with 13 MW, which represent 14% of the studied demand and 4.4%[4] of the mill's total demand.

If rebuilding according to retrofit 2 there will also here be excess heat available but not to the same extent as in retrofit 1. The heat in the effluent stream from tank 3141=2034, H9, is still unused and there is a possibility for further cooling of the SP5 flue gases and the condenser in KM2. In *Figure 7.5* the potential for district heat production is presented in form of a GCC.

[4] Total steam demand for Iggesund mill is 298 MW

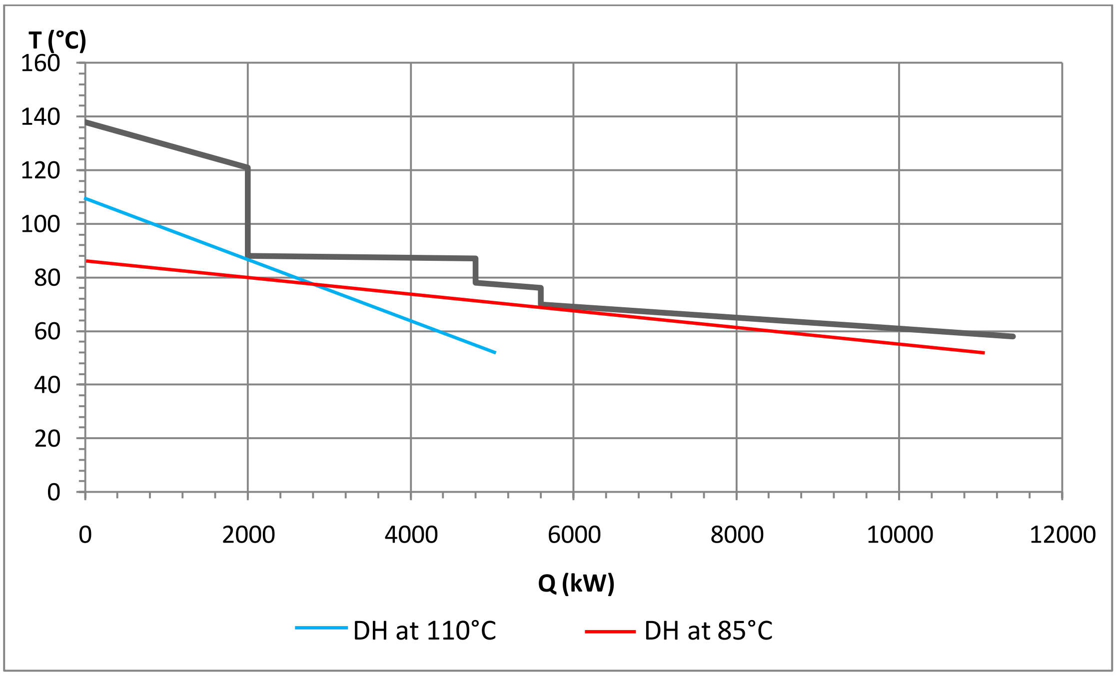

Figure 7.5: Potential for production of district heat in retrofit 2

The surplus energy will be enough to produce 5.5 MW of district heat at 110°C, which is 44% of the needed peak load, and around 11 MW at 85°C off peak.

As said before, retrofit 2 is more extensive and will have higher investment costs. Heat exchanging stream C21 in the bleach plant with the condensate from KM2, stream H58, may not be feasible due to the distance between the two facilities. The BFW in stream C6, which is the smaller stream, is exchanged with both the flue gases from the lime kiln and SP5 needing more advance piping than in retrofit 1. The BFW in stream C42 is also heated with flue gases from the lime kiln, needing more extensive piping then in retrofit 1. Also here the suggested potential for district heat production will need a complex piping construction.

7.1.3 Summery retrofit 1 and 2

Results from retrofit 1 and 2 are compiled in *Table 7.3*.

Table 7.3: Results from the two retrofit suggestions

	Retrofit 1	**Retrofit 2**
Steam saving in process		
Steam saving [MW]	7.9	13
Steam saving of total demand	2.6%	4.4%
Reduced pinch violations	43%	55%
District heat production and steam savings		
DH at 110°C [MW]	6.8	5.5
DH at 85°C [MW]	12.0	11.0
Steam saving in DH production	30%	14%

An investment in retrofit 2 will generate a larger steam saving during the whole year but requires lager investments. Including the steam saving from the production of district heat the possible annual steam saving from retrofit 1 and 2 will be slightly larger.

7.2 Increased district heat production in the future network

Among the projects Iggesund considers for the future is from the analysis by at Fortum, regarding the possibilities for district heat production from secondary heat (Lars Sjökvist 2010). The analysis is an ambitious three step plan from which the suggestions to change the condenser at KM2 and installing a flue gas cooler on the lime kiln have been adopted in this analyse but their usage has been kept open.

Different suggestions to increase the district heat production from secondary heat and thus minimize the steam have been analysed. Only the most relevant one, case 5, will be presented here and for other possibilities see Appendix A6.

The calculations are based on a district heat flow of 180 m^3/h needed to be heated to 110°C equal to 12.6 MW, which is a high temperature, but used since the case then can be compared with the ideas from Fortum. If the flow is 180 m^3/h and needs to be heated from 50 to 110°C the system needs 8 284kW of steam, which is higher than the average use, since the temperature needed off peak is lower.

Streams used are presented in *Table 3.1.* The figures used here are calculated from the high usage, peak, season. It is also when steam is needed in the district heat system.

Table 7.4: Temperatures for the district heat production in Case 5

#	Hot stream	Temperatures of the district heat	
		Tstart	**Ttarget**
H9	effluent from 3141=2034	50	70
H56[1]	flue gas SP5	70	110
H58[1]	flash steam through condenser at KM2	70	87
H57[1]	flue gas lime kiln	87	110

[1] The district heat stream is split after being exchanged with H9. Half is heated by H56 and half with H58+57.

The heat exchanger between stream H7, with BFW in and C6, bleach plant effluent from tank (3141=2034), are changed as in the steam reduction retrofit. This will reduce the heating demand below the pinch and release energy from H7 which is moved to stream H9, also from tank (3141=2034). As mentioned previously in section 7.1.1 a preheater for incoming district heat return is already in place on stream H9, but it can increase its capacity letting more flow pass through it.

In this case, the district heating stream is spitted into two and heat exchanged in different parts of the process. This will give the possibility for both reaching the temperature target and increasing the flow of district heat without the need for steam heating, since the KM2 condenser and the two flue gas coolers all need to remove more energy from the streams i.e. get cooler. The layout for the case 5 exchangers can be seen in *Figure 7.6*

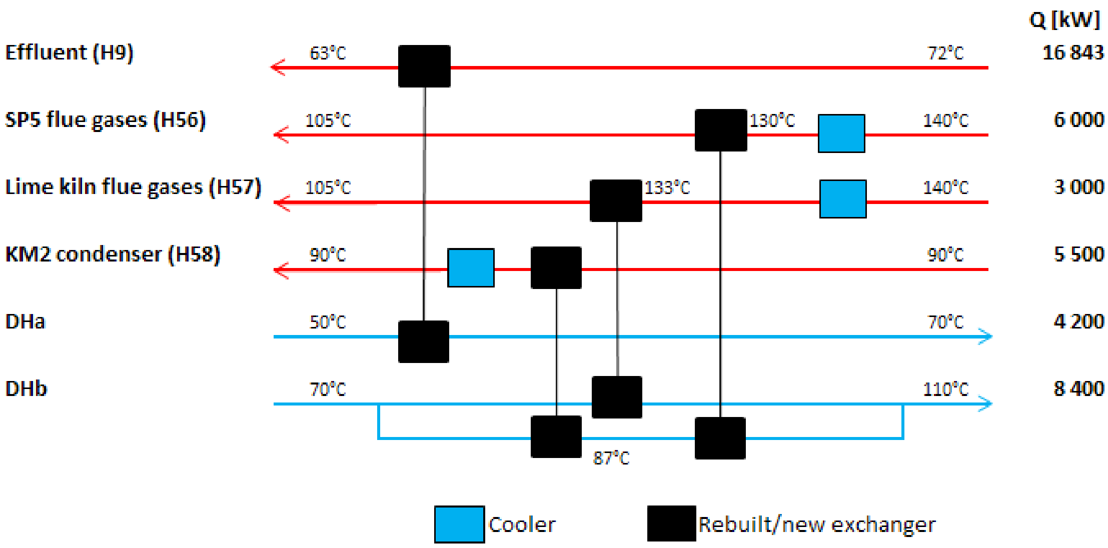

Figure 7.6: Heat exchanger network for case 5-stream splitting

Case 5 will have a pinch violation of 5.7 MW and almost 6.1 MW of surplus heat over 90°C, which can be used for e.g. preheating of BFW. Another option is to further increase the flow of district heat resulting in a maximum production of 22MW district heat at 110°C. If lower temperature is acceptable even more district heat could be produced or more surplus heat available. An increase of the district heat production can in the future be of interest if Fortum continues with the plans for connecting the district heat network in Iggesund with the one in Hudiksvall (Sjökvist L., 2010).

The process steam saving from this retrofit will be the 448 kW, equal to 3.9 TJ[5], from the new heat exchanger between H7 and H6. There will also be an elimination of the steam today use for producing district heat that is 816 kW equal to 26.7 TJ[6]. Since the steam demand changes with season but the total annual steam demand for district heat production will be eliminated, the total steam reduction is presented in TJ. So in total the stem reduction will be 30.6 TJ. Implementation of case 5 needs a lot of piping and it will be towards creation of the internal district heat system as Lars Sjökvist (2010) suggests that Iggesund should invest in. If investing in an internal network for district heat there will be a need to make sure that the real cooling of the process will be sufficient even during the low usage periods.

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[5] If the production time8700 h/year

[6] From the annual demand is 816 kW which is equal ton 26. TJ (Iggesund 2010a) but the daily use changes with season

7.3 Other possibilities for energy efficiency

In all the presented suggestions above there is still excess heat in the system but not at useful temperature levels, for solving more pinch violations or reducing the steam consumption. The effluents from the bleach plant can heat streams up to 60°C which is too low for more than pre heating the district heating water, but there are other possible usages. There could be a possibility for redesigning the secondary heat system, and utilize the effluent streams for heating water, and thereby releasing heat in process parts outside the scope of this thesis.

As mention in Section 1.4, there is an ongoing PhD project studying the possibility of investing in biomass gasification. To improve the efficiency and have a good gasification process, the biomass first needs to be dried. Drying can be performed in many different types of dryers and at pulp mills it could be interesting to look into the concept of low temperature drying. The effluent streams have temperatures below 65°C and can be used for preheating of the drying air in combination with steam. (Ahtila, P. and Holmberg, H., 2004)

With the presented change to the KM2 condenser, heat with a higher temperature is replaced with heat with a lower temperature, since the water stream heated by the condenser only needs to be 60˚C and the condensation is taking place just below 90˚C. Therefore the hot condensate is replaced by an effluent stream from the bleach plant so that the condensate is free for other uses. Fortum (Sjökvist L., 2010) suggests that a similar process change can be done at KM1 as well. Today the paper machines have their own secondary heat system. It can be useful to investigate if further integration is possible and if the energy in effluents can be of use.

8 Energy usage compared to a reference mill

This comparison is based on the R&D work "Future resource adapted pulp mill-FRAM", which was a Swedish national research program (FRAM, 2005)

In order to get a view of how the Iggesund mill performs in an energy perspective compared to other mills, the energy demands are compared to one of the FRAM mills. The most appropriate mill within the project to compare with, is the "Bleached market kraft pulp mill" since it is only the pulp production that has been included in this thesis and the mill pulps both hardwood and softwood in campaigns. The report presents a reference mill, representing the best available, commercially proven Nordic technology and a typical Nordic mill, type mill. It includes the whole line from wood to fully bleached and dried pulp.

When comparing the Iggesund mill with the two mills in the FRAM report some factors need to be taken into consideration. Firstly, this is not an exact match but can give indications. The two FRAM mills are market pulp producers and the steam demand is entirely covered by the recovery boiler, except for the type mill hardwood pulping. The mills have almost the same feedstock, kappa number and product. The FRAM mills have feed stock with softwood, in a mix of 50/50 pine and spruce, and hardwood, which is at least 90% birch. Pulp is assumed to be produced in campaigns, compared to Iggesund that has a simultaneous production in two separate lines.

The type mill has about the same annual pulp production as Iggesund but the reference mill is much larger, since it is built to give the lowest possible specific capital cost. In *Table 8.1*and *Table 8.2* the main consumption and production of steam is compared.

Table 8.1: Steam consumptions in GJ/ADt

	Reference mill	**Type mill**	**Iggesund mill[1]**	**Future Iggesund mill[2]**
Woodyard	*0*	*0.26*	0.41	
Digester softwood	*1.50*	*2.57*	2.38	2.37
Digester hardwood	*1.19*	*2.07*	2.12	1.74
Bleaching softwood	*1.07*	*0.70*	0.89	0.76
Bleaching hardwood	*1.08*	*0.76*	0.21	0.51
Evaporation	*4.13*	*4.73*	3.92	4.01
Recovery boiler	*1.81*	*3.08*	1.80	no record
Chemical preparation	*0.2*	*0.2*	0.09	no record
Other, losses	0.70	2.16	1.58	no record
TM	2.19	2.9	4.30[3]	4.19[3]
KM	not integrated	not integrated	9.00[3]	9.00[3]

[1]According to budget (Iggesund 2010a)
[2]According to design for the new recovery boiler (Åf Energi, 2010)
[3]GJ/t machine-produced

Table 8.2: Steam production in GJ/ADt

	Reference mill	Type mill	Iggesund mill[1]	Future Iggesund mill[2]
Recovery boiler	32.74	30.56	23.85[3]	29.09[3]
Bark boiler	0.00	0.45	10.95	9.96
Other	1.04	0.87	2.49	2.26
Total production	*33.78*	*31.87*	*37.29*	*41.31*

[1]According to budget (Iggesund 2010a)
[2]According to design for the new recovery boiler (Åf Energi, 2010)
[3]From combustion of black liquor and oil

This comparison is a very general one and only provides guidelines. Especially the specific steam productions are hard to compare, since Iggesund is an integrated mill, and therefore produces a lot more steam used for the paperboard production. In *Table 8*.2 it can be seen in the large production of steam in the bark boiler. Other things that can increase the steam consumptions in a real mill, compared to models, are frequent stops, quality changes and fluctuating operations without buffers.

Comparing the figures in *Table 8.1* it seems like the best possibilities for savings is from reducing the steam usage at the woodyard. Water used for defrost and cleaning the logs don not need to be heated over 60°C and therefore in a energy perspective heating of water with steam should be replaced with secondary heat. There are also possibilities for savings within the cooking plants, but this will probably need new process equipment and cannot be solved with process integration. The main saving potential is listed in *Table 8.3*. From the FRAM report (2005) it can also be said that the heating of hot water should not need steam and today steam is only used to cover peaks or process disturbances at Iggesund.

Table 8.3: Saving potential in GJ/ADt

	Saving potential compared to Reference mill		Saving potential compared to Type mill	
	GJ/ADt	*%*	*GJ/ADt*	*%*
Woodyard	*0.41*	*100*	*0.15*	*37*
Digester softwood	*0.88*	*37*	*none*	*-*
Digester hardwood	*0.93*	*42*	*0.05*	*2*

9 Discussion

Iggesund mill is in many aspects a modern mill with many processes built in the 21th century, and the oldest process being the pulp dryer from 1960. Hence one could easily be misled to believe that the energy situation cannot be improved that much. But this thesis, together with other reports, has identified that much still can be done to become even more efficient.

From the composite curve, CC, and grand composite curve, GCC, it is clear that the process can cover almost all of its cooling demand above 10°C, trough heat exchanging with process streams or district heat, and the heating demand under 113°C. A maximum energy recovery, MER, network would reach the minimum heating and cooling demand but a MER network is usually not feasible due to economic reasons and one is not performed in this thesis. However, improvements are possible.

9.1 Observations regarding the mill

The comparison of Iggesund and the two presented FRAM mills suggest that the largest saving potential for the pulping process is at the woodyard and in the digesters. Saving potential for the woodyard is 37 to 100%, and in the digester theoretically up to 40% can be saved, see *Table 8.3*. As told in chapter 0, savings within the digester sections will probably need a change of process equipment, which lies outside the purpose of this thesis. On the other hand, the situation for the woodyard is different. One option for reducing the steam demand in the woodyard is by utilising the heat in the bleach plant effluents holding around 60˚C. The drawback could be the distance between these two facilities, which needs to be handled.

One idea could be to use medium temperature water, MW, and warm water, WW, from the existing secondary heat system and produce more MW and WW with the effluents. If the district heat production is increased, another option could be to let the stream pass by the woodyard and reroute a stream for this purpose or use the return. Since no surplus heat at the digester temperature level has been identified, process changes are needed to reduce the steam demand. In contrast, it could be mention that in some areas Iggesund mill is better than the two FRAM mills. Both the bleach plants and the evaporation lines consume less steam; *Table 8.1*, but since different process solutions are used it is hard to determine if the difference is due to more efficient production or specific production demands in the integrated Iggesund mill.

In the pinch analysis two other areas with improvement possibility have been analysed: the heating of boiler feed water and the production of district heat. The two retrofits suggested to decrease the steam usage, section 7.1, present two possible solutions to the first problem. With rather small changes, involving only one exchanger, besides the new SP5 flue gas coolers and the new KM2 coolers, the mill's total steam demand can be reduced by 2.6%, meanwhile having the capacity to produce 6.8 MW of 110°C district heat.

Since there is an excess of heat available for district heat production and un solved pinch violations there is also a possibility for further integration, as suggested in retrofit 2. This case involves four heat exchangers where two of them will be cooling the flue gases from the lime kiln indirect thorough the water circuit. This retrofit can reduce the total steam demand with 4.4% and still produce 5.5 MW of 110°C district heat.

Depending on which solutions that are applied, different amount of steam can be saved. The steam saving potential at the woodyard is between 0.4% and 1.05% of the mills total demand. Combining it with the saving potential for the retrofit 1 and 2, the total saving potential span from 3.1 to 5.4% and even a little more if the changes to the district heat production are included. Reducing the steam demand with 13 MW is equal to removing the oil boiler, P11 and even if the reduced steam is not removed from the process the use of P11 can be reduced since the new recovery boiler, SP5, will produce more steam then the two existing ones.

The second problem stated in the objective is approached with the maximum district heat retrofit. The potential for district heat production has already been discussed during the steam saving retrofits but here the goal was to analyse the maximum capacity without using any steam.

It is clear that steam can be saved but since the calculations are for the peak season, most of the steam savings will only accrue during this period. It should also be noted that the used outlet temperature of 110˚C is rather high and only needed for a short period of time during the winter, and a temperature of 85°C will be enough for most of the year. Investing in the increased district heat production retrofit, will produce the needed maximum load of 12.6 MW of 110˚C district heat. Meanwhile having potential for increasing the district heat production to 22 MW, without using any steam.

From the three retrofits it can be said that steam can be saved but to a different extent and in different part of the process. An increased processes integration, i.e. better internal heat exchanging, will reduce the capacity for district heat production. It could be good to reflect on the question to which extent Iggesund should deliver external district heat. Today there is a need for steam heating in the process, and it will be increased if they are interested in reducing the pinch violations from the boiler feed water pre heating. The main difference between saving steam in the process and from the production of district heat is that the process steam saving will last during the whole year. In section 7.3 there is also a short discussion on possibilities for biomass drying at Iggesund, to be used for gasification. If the drying should be performed with as low amount of steam as possible it can then be interesting to free energy at higher temperature, today suggested to be used for the production of heating district heat.

9.2 Sources of errors and uncertainties

A limitation in the thesis is that no measurements on site have been carried out by the writer to fill information gaps. Better organisation for collecting and storing information of flows and temperatures will most probably improve the efficiency at Iggesund and reduce the need for extra measurements.

The collected data used comes from many sources with different accuracy. It includes data spanning from annual averages to theoretically calculated estimations. Since annual averages are used within the pinch analysis, while some data comes from measurements in March, the annual average has had to be approximated for those values.

Within this study there has been a problem with linking information from the process flow charts with the information about process layout from the controller screens. In order to ease this kind of work, those sources must be up to date and in sync with each other.

As shown in *Figure 6.3* the shape of the GCC changes with the introduction of new streams and thus generating a new pinch temperature. Which processes are chosen for inclusion, will thereby affect the identified pinch violations. Nevertheless, pinch analysis is a good tool for energy evaluations since the main goal has been to find and remove steam users.

There are large parts of the mill excluded from this study, which can be useful to analyse. To start with, the pulp dryer and the paperboard machines KM1 and KM2 should be included in order to evaluate the total energy situation. These are processes that are large steam consumers but also release heat at lower temperatures.

10 Conclusions

There are possibilities for improving the heat recovery and reducing the steam usage. Comparing the mill to one with the best available technology shows that there are large improvement possibilities by eliminating the steam usage in the woodyard and reducing it within the cooking lines. If Iggesund mill instead is compared to a type mill, savings can mostly be done in the woodyard. The pinch analysis has identified a theoretical saving potential of 18.3 MW. If Iggesund decides to invest in the steam reducing retrofit network and make changes of the woodyard they have the possibility to save between 3.1 to 5.4% of the mill's total steam demand, equal to 9.2 to 19.1 MW. The fact that a higher saving the theoretical maximum can be archived is due to the fact that the wood yard steam us was not included in the pinch analysis.

This analysis is limited to the pulp production and recovery cycle, and therefore only covers parts of the energy users at the mill. Still this work can provide some guidelines or a frame for further work, but should be complemented with an economic evaluation.

11 Further work

In this thesis the potentials for increased energy efficiency have been presented, and an improvement potential has been identified. Some of the suggestions here should be further evaluated soon if they are considered interesting, since they can be included in the SP5 construction, which is schedule to be in operation June 2012. There is especially a need for economic evaluations.

There are large parts of the mill excluded from this study, which can be useful to include in future analysis. To start with the paperboard machines KM2 and KM2 should be included and at least integrated individually. The paper machine, TM4, is somewhat of the mills black sheep. It is the oldest process and information of energy flow is scarce. If Iggesund, as indicated, wants to keep it in use with some renovation, it would be good to further evaluate its energy use and integration possibilities, since there should be ample possibilities for this due to the age.

Finally, when building the new recovery boiler and changing the secondary heating system it could be a good time to reflect on where process measurement equipment should be placed in order to have the optimal process overview in an energy perspective, today and in the future.

12 References

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13 Appendix

Appendix A1-Identifyed heat exchangers within the process

In the table below all identified heat exchangers with it limitations are presented together with comments on whether they are included or excluded.

ID	**Identified in**	**Comments on if it is included or excluded from the analysis**
3120=2001	Cooking line3	Included
3120=2002	Cooking line3	Included
3120=253-17	Cooking line3	Included
3120=253-18	Cooking line3	Omitted since it is only used when3120=253-17 and 3120=253-19 are out of order
3120=253-19	Cooking line3	Included
3120=253-25	Cooking line3	Included
3141=2023	Bleach plant 3	All exchangers in bleach plant 3 is omitted since it is manually controlled
3141=2035	BFW	Included
3141=2036	BFW	Included
3141=263-28	Bleach plant 3	All exchangers in bleach plant 3 is omitted since it is manually controlled
3150=2003	Bleach plant 3	Omitted since used for district heat production
3150=2004	Bleach plant 3	Omitted since used for district heat production
3150=2005	Bleach plant 3	Omitted since used for district heat production
3210=2044	Cooking line 4	Included
3210=2047	Cooking line 4	Included
3210=2048	Cooking line 4	Included
3210=2060	Cooking line 4	Included
3210=2062	Cooking line 4	Omitted due to lack of information
3210=2064	Cooking line 4	Included
3210=2067	Cooking line 4	Omitted since it is no longer in used, according to the information from the measurement equipment.
3210=2081	Cooking line 4	Included
3213=2043	O_2 Bleach plant	Omitted due to lack of information
3214=2025	Bleach plant 4	Included
3214=2031	Bleach plant 4	Included
3214=2046	Bleach plant 4	Omitted since it is a help heater in the secondary heating system and only used if there is a heat deficit
3420=201	Methanol	Omitted since no information about the flow is available
3420=2015	Gas & cond.	Omitted since no information about the flow is available
3420=2016	Gas & cond.	Omitted since no information about the flow is available
3420=206	Methanol	Omitted since no information about the flow is available
3442=2009	Evaporation 4	Included
3442=2011	Evaporation 4	Omitted since it only used to recover the heat from the evaporated gas from the strong liquor cisterns

3443=210	Evaporation 3	Omitted since the evaporation is integrated
3443=216	Evaporation 3	Included, surface condenser
3443=217	Evaporation 3	Included, surface condenser
3443=218	Evaporation 3	Omitted since the evaporation is integrated
3443=219	Evaporation 3	Omitted since the evaporation is integrated
3443=220	Evaporation 3	Omitted since the evaporation is integrated
3443=235	Evaporation 3	Included
3443=237	Evaporation 3	Only the hot stream included. The cool stream is district heat.
3443=238	Evaporation 3	Only the hot stream included. The cool stream is district heat.
3443=247	Evaporation 3	Omitted since the evaporation is integrated
3443=248	Evaporation 3	Omitted since the evaporation is integrated
3443=249	Evaporation 3	Omitted since the evaporation is integrated
3443=256	Gas & cond.	Included
3444=2021	Evaporation 4	Omitted since the evaporation is integrated
3444=2022	Evaporation 4	Omitted since the evaporation is integrated
3444=2023	Evaporation 4	Included, surface condenser
3444=2024	Evaporation 4	Included, surface condenser
3444=2025	Evaporation 4	Included
3450=2025	Causticizing	Included
3460=2107	Lime kiln	Omitted since it is small
3460=2114	Lime kiln	Omitted since it is part of the lime kiln safety system
3460=2135	Lime kiln	Omitted since it is small
3460=2153	Lime kiln	Omitted since it is part of the lime kiln safety system
3480=2023	Tall oil	Omitted due to lack of information
3480=2024	Tall oil	Included
3480=2026	Tall oil	Omitted since it is small
3516=2116	Tall oil	Omitted due to lack of information
3573=2102	BFW	Included
3573=2103	BFW	Included

Appendix A2 – Streams included in the pinch analysis

In *Table 13.1* and *Table 13.2* the stream data used in this thesis is presented. Explanations to indexes can be found in the end.

Table 13.1: Stream data used in the pinch analysis

# SD	**Name**	**HX with**	**Heat exchanger**	**Tin**	**Tut**	***ρ***	**F**	***Cp***	***Δh***	***Q***
				°C	°C	*kg/m3*	kg/s	*kJ/kg*K*	*kJ/kg*	*kW*
Hot streams										
H01	turpentine vapour line3	C02	3120=2001& 2002	99.0 [B]	49.0 [B]		1.28 [B]			3 072.614
H07	effluent from 3141=2034 (to HX:3150=2035)	C06	3141=2035 & 2036	72.0 [C]	37.0 [I]	1000 [F]	91.67 [C]	4.20 [F]		13 475.000
H09	effluent from 3141=2034 (to HX:3150=2005)	DH[1]	3150=2005 & 2004	72.0 [C]	37.0 [I]	1000 [F]	67.64 [C]	4.20 [F]		9 942.917
H12	vapour from cyclone	C10	3210=2048	141.0 [B]	140.9 [B]		2.42 [B]		2 139.9 [G]	1 398.123
H13	turpentine vapour line4	C14	3210=2060	98.1 [F]	98.0 [F]		1.14 [B]		2 189.0 [G]	2 679.485
H15	black liquor from flash	C16	3210=2064	111.0 [C]	94.0 [A]	1090 [D]	57.53 [C]	3.87 [D]		3 784.753
H18	black liquor (HX:3210=2081)	C17	3210=2081	84.0 [C]	77.0 [C]	990 [D]	58.03 [C]	4.18 [D]		1 697.812
H20	pulp water	C19	3214=2025	70.0 [D]	38.0 [D]	1000 [F]		4.20 [F]		454.600
H22	weak liquor line 4	C23	3442=2009	108.0 [C]	96.0 [C]	1070 [D]	49.34 [C]	4.20 [D]		2 486.680
H24	evaporation vapour line 3	C26	3443=217 & 216	66.0 [B]	65.9 [B]		8.36 [J]		2 242.6 [G]	18 755.675
H25	sub cooling of evaporation vapour line 3	C26	3443=217 & 216	65.9 [B]	46.6 [B]	1082 [D]	8.36 [J]	4.178 [D]		674.387
H27	secondary condensate evp.3	C28	3443=235	26.0 [B]	24.0 [B]	1082 [D]		4.178 [D]		853.504
H29	evaporation vapour effect 3:5	DH[1]/CW	3443=237 & 238	80.0 [B]	78.0 [B]					788.077
H31	stripper gas through intermediate condenser	C30	3443=256	93.4 [A]	93.0 [B]				2 274.7 [G]	5 267.389
H32	evaporation vapour line 4	C33	3444=2023 & 2024	53.1 [B]	53.0 [B]		9.139 [J]		2 500.2 [G]	22 849.069
H34	sub cooling of evaporation vapour line 4	C33	3444=2023 & 2024	53.0 [B]	33.9 [B]	1082 [D]	10.02 [J]	4.178 [D]		799.655
H35	secondary condensate evp.4	C36	3444=2025	50.0 [B]	29.5 [A]	1082 [D]	0.94 [J]	4.178 [D]		80.810
H37	green liquor	C38	3450=2025	85.0 [F]	84.9 [A]				2 294.3 [G]	607.108
H40	tall oil	C41	3480=2024	65.8 [B]	17.6 [B]		0.58 [A]	4.20 [J]		118.090

H43	boiler feed water condensate	C42	3573=2102 & 2103	124.0 [J]	30.0 [C]	990 [F]	60.50 [A]	4.18 [F]		23 771.660
H44	effluent D0, line3	*	*	60.0 [C]	37.0 [I]	1000 [F]	50.00 [A]	4.20 [F]		4 830.000
H45	effluent D1, line3	*	*	60.0 [C]	37.0 [I]	1000 [F]	47.22 [C]	4.20 [F]		4 561.667
H46	effluent D0, line4	*	*	65.0 [C]	37.0 [I]	1000 [F]	55.56 [C]	4.20 [F]		1 033.333
H47	effluent EOP, line4	*	*	60.0 [C]	37.0 [I]	1000 [F]	47.22 [C]	4.20 [F]		4 561.667
H56	flue gas SP5	Atm	new	140.0 [C]	105.0 [C]					6 000.000
H57	flue gas lime kiln	Atm	new	140.0 [C]	105.0 [C]					3 000.000
H58	flash steam through condenser at KM2	MW	new	90.0 [C]	89.9 [C]					5 500.000
Cold Streams										
C02	water - turpentine condenser line3	H01	3120=2001& 2002	48.0 [C]	75.0 [A]	990 [F]	27.23 [C]	4.18 [F]		3 072.614
C03	cooking circulation counter current A5	MP	3120=253-17	138.0 [B]	144.0 [B]	917 [D]	78.96 [B]	4.256 [D]		2 016.422
C04	cooking circulation counter current A6	MP	3120=253-19	148.0 [B]	151.0 [B]	917 [D]	120.23 [B]	4.256 [D]		1 535.082
C05	cooking circulation counter current A8	MP	3120=253-25	109.2 [B]	144.5 [B]	917 [D]	32.10 [B]	4.256 [D]		4 821.850
C06	boiler feed water preheating	H07	3141=2035 & 2036	25.0 [C]	125.0 [H]	990 [F]	35.75 [A]	4.18 [F]		14 943.500
C10	washing circulation C44+C48	H12/MP	3210=2048 & 2044	122.5 [A]	160.0 [B]	982 [D]	27.41 [A]	4.08 [D]		4 194.368
C11	pre impregnation C47	LP	3210=2047	143.0 [B]	148.0 [B]	922 [D]	170.06 [B]	4.26 [D]		3 622.231
C14	water - turpentine condenser line4	H13	3210=2060	66.0 [C]	75.0 [C]	990 [F]	71.23 [A]	4.18 [F]		2 679.485
C16	water - black liquor cooing (HX:3210=2064)	H15	3210=2064	65.0 [C]	92.0 [A]	990 [F]		4.18 [F]		3 784.753
C17	water - black liquor cooing (HX:3210=2081)	H18	3210=2081	45.0 [B]	76.0 [B]	990 [F]		4.18 [F]		1 697.812
C19	chlorine dioxide	H20	3214=2025	10.0 [B]	31.0 [A]	997 [D]	5.18 [A]	4.18 [D]		454.600
C21	HX D2-D1	LP	3214=2031	75.0 [H]	86.5 [A]	1000 [F]	55.56 [A]	4.20 [J]		2 683.333
C23	water - weak liquor cooling line 4	H22	3442=2009	65.0 [C]	92.0 [C]	970 [F]		4.19 [F]		2 486.680
C26	water- evaporation vapour line 3	H24/25	3443=217 & 216	18.0 [H]	39.9 [B]	990 [F]	222.20 [B]	4.18 [F]		19 430.062
C28	water - cooling of 2nd condensate evp.3	H27	3443=235	18.0 [H]	25.5 [B]	990 [F]	27.23 [B]	4.18 [F]		853.504
C30	water - intermediate condenser	H31	3443=256	40.1 [B]	90.0 [B]	970 [F]	25.19 [B]	4.19 [F]		5 267.389
C33	water- evaporation vapour line 4	H32/34	3444=2023 & 2024	18.0 [A]	43.0 [A]	990 [F]	263.45 [E]	4.18 [F]		23 648.723

C36	water - cooling of 2nd condensate evp.4	H35	3444=2025	26.0 [B]	45.0 [H]	990 [F]	1.02 [A]	4.18 [F]		80.810
C38	water - green liquor cooling	H37	3450=2025	18.0 [H]	68.3 [B]	990 [F]	2.89 [B]	4.18 [F]		607.108
C41	water - tall oil	H40	3480=2024	16.4 [B]	65.0 [H]	990 [F]		4.18 [F]		118.090
C42	boiler feed water	H43	3573=2102 & 2103	28.0 [A]	125.0 [A]	99 [D]	71.09 [J]	4.18 [F]		28 823.138

[1] In the existing system district heat is heat exchanged with the stream.

Table 13.2: Process steam streams included in the pinch analysis

# SD	Namn	HX with	Tin [°C]	Tut [°C]	P[bar]	F [kg/s]	Δh[kJ/kg]	Q [kW]
C48	process steam for evap.3	*	143.6 [F]	143.7 [F]	4 [B, H]	9.17 [A]	2 132.0 [G]	19 543.752
C49	process steam for evap.4	*	143.6 [F]	143.7 [F]	4 [B, H]	8.89 [B]	2 134.8 [G]	22 849.069
C50	process steam for stripper column	*	143.6 [F]	143.7 [F]	4 [B, H]	2.43 [B]	2 132.0 [G]	5 182.056
C51	process steam for cocking line 3	*	143.6 [F]	143.7 [F]	4 [B, H]	1.28 [B]	2 132.0 [G]	2 724.281
C52	process steam for cocking line 4	*	143.6 [F]	143.7 [F]	4 [B, H]	1.31 [B]	2 132.0 [G]	2 783.504
C53	process steam for O2 reactor	*	191.6 [F]	191.7 [F]	13 [B, H]	0.44 [B]	1 973.4 [G]	877.077
C54	process steam for EOP reactor	*	191.6 [F]	191.7 [F]	13 [B, H]	0.14 [B]	1 973.4 [G]	274.087
C55	process steam for BFW 125->140°C	*	143.6 [F]	143.7 [F]	4 [B, H]	3.15 [J]	2 132.0 [G]	6 712.861

Explanations to the indexes, indicating where the values are taken from:

A. Values from the info system, based on an annual average between 28th of April 2009 to 27th of April 2011.
B. Values from the control systems. Annual averages have been estimated.
C. Values from the Fortum analysis (Lars Sjökvist 2010).
D. Values from the master thesis by Brantebäck (1994)
E. Values from the secondary heat balance (Carlsson A-M. and Nygaard J., 2008)
F. Values from steam tables (Mörstedt & Hellsetn, 2003)
G. Values from steam table based on IFC-67 available at Heat and power Technology
H. Design values
I. Soft target values
J. Calculated values or estimated

Appendix A3 – CC and GCC for Today's network without effluents

Figure 13.1 presents the composite curve, cc, for today's system without the extra cooling of the effluents, from which it can be seen that the minimum external cooling demand in the process is very low.

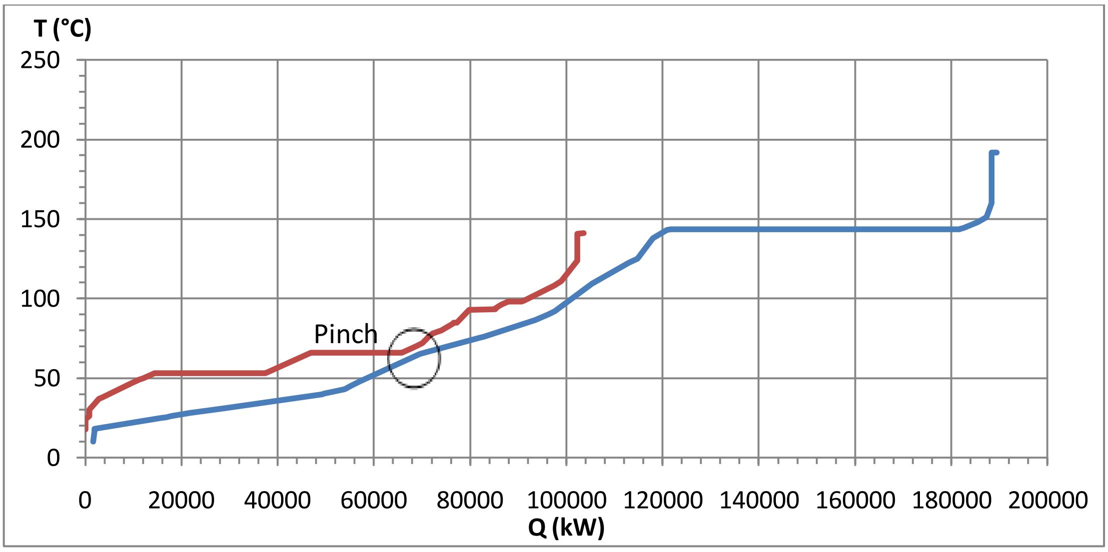


Figure 13.1: Composite Curve: Today's network without effluents

The difference in cooling demand can more clearly be analysed comparing the grand composite curve, GCC, between today's system with or without effluents (see *Figure 13.2)*

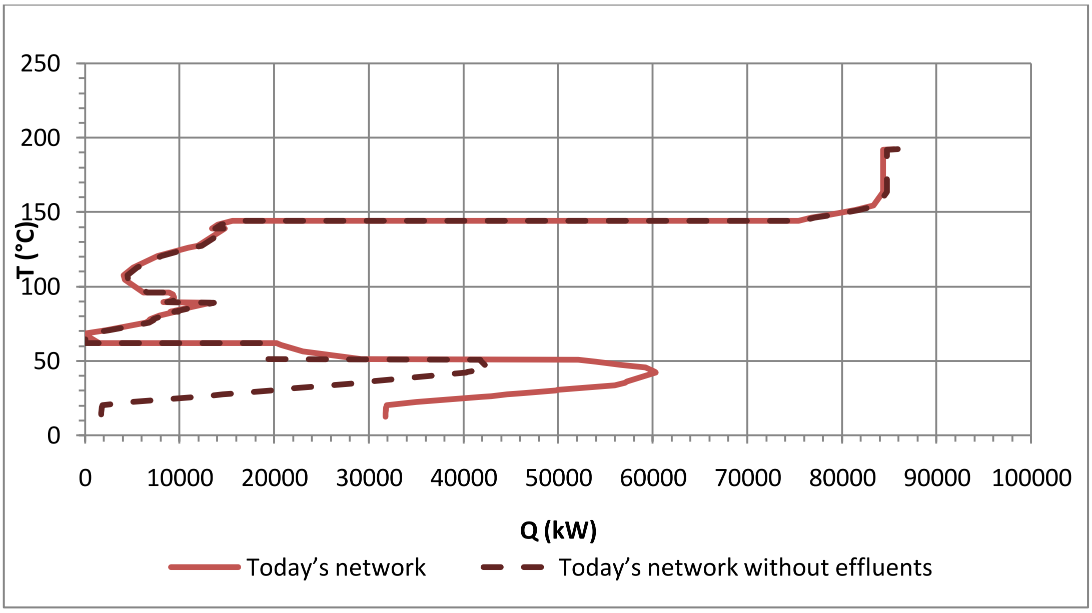
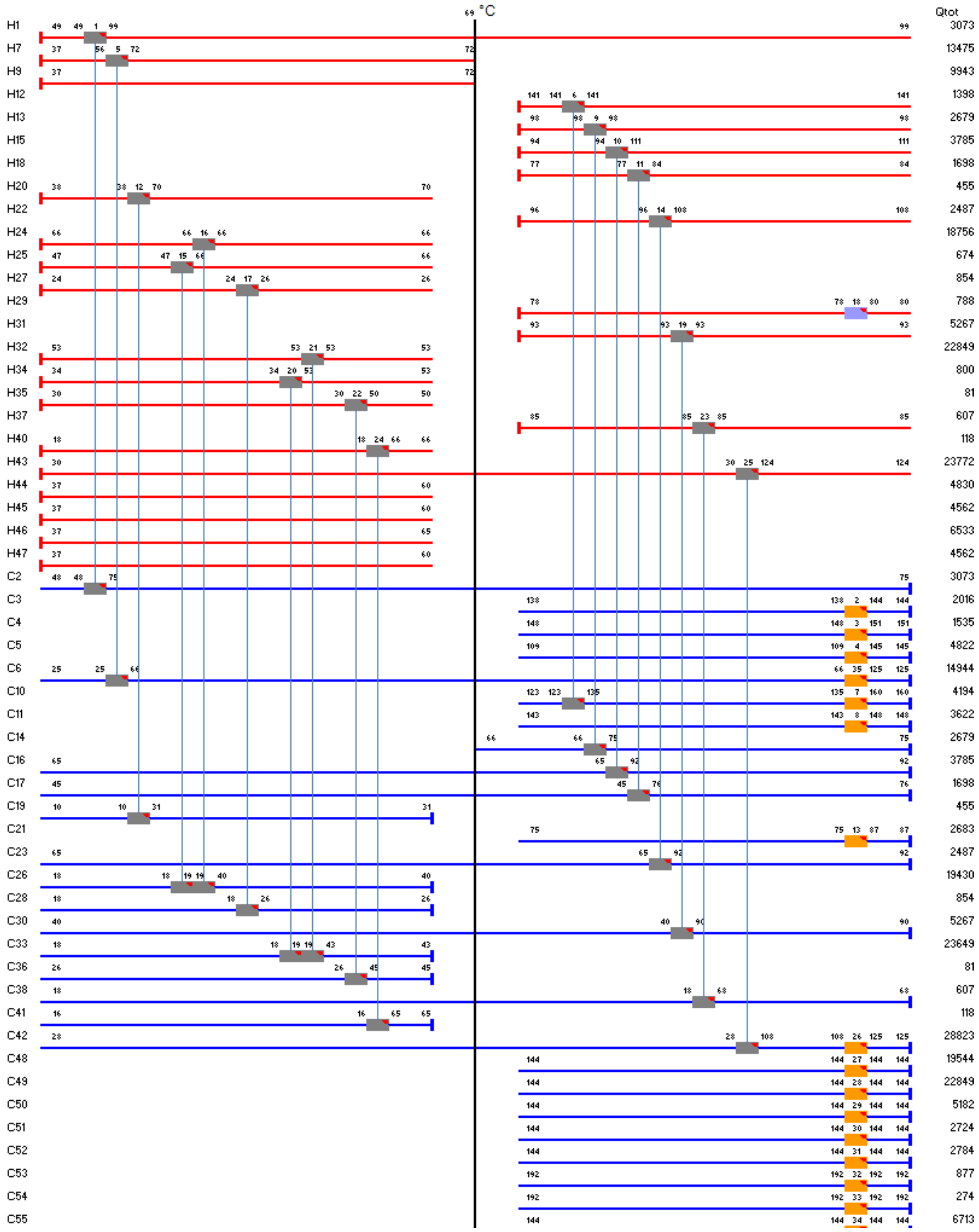


Figure 13.2: Grand Composite Curve for today's network without and with effluents

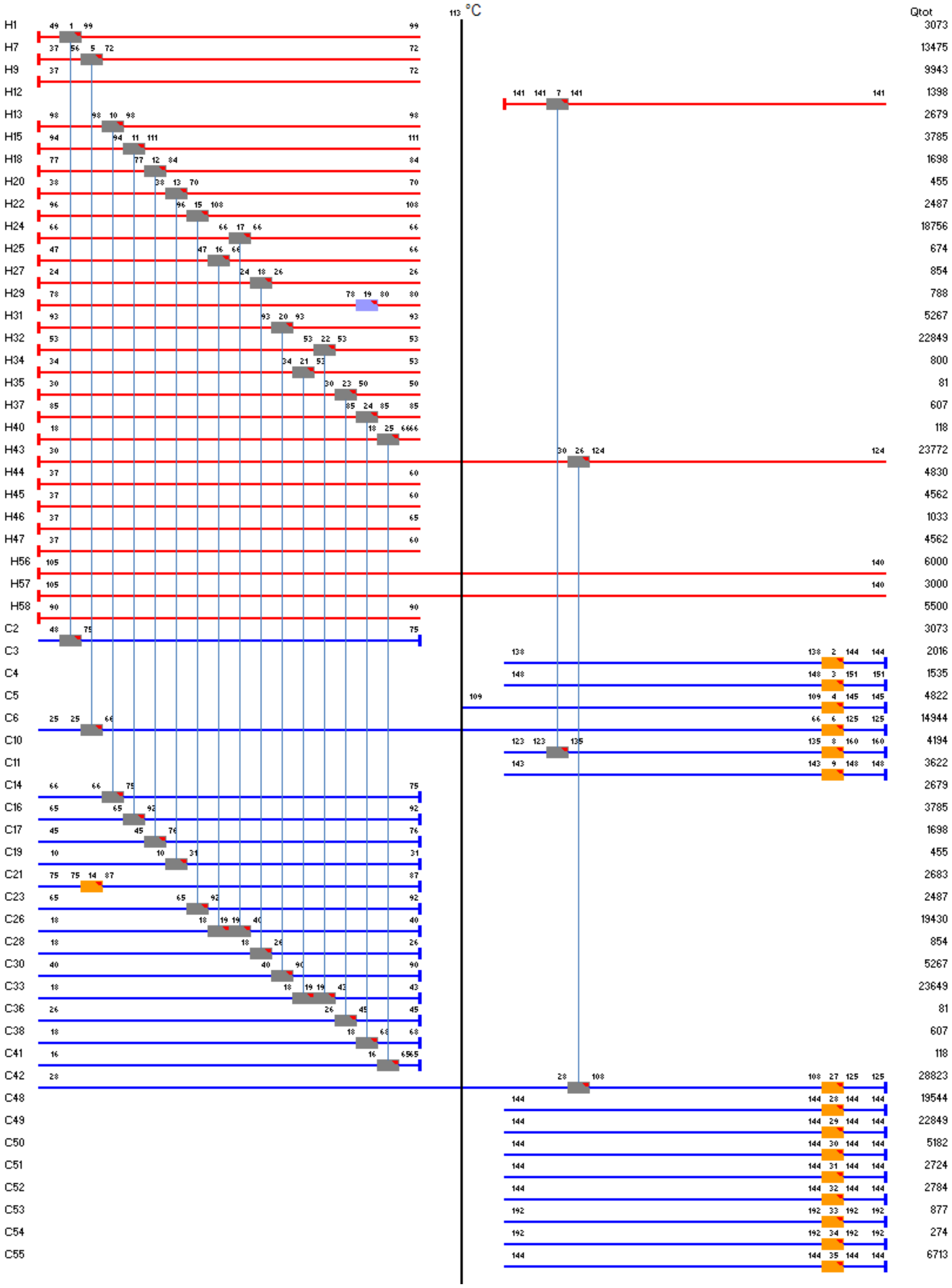
Appendix A4– Today's heat exchanger network

Blue boxes represent coolers, orange heaters, and grey connected are heat exchangers.



Appendix A5 – Future heat exchanger network

Blue boxes represent coolers, orange heaters, and grey connected are heat exchangers.



Appendix A6 – Suggestions for increased district heat production in the future network

In section 7.2 a possibility for increased production o district heat was presented. In this appendix the four other possibilities that were analysed are presented.

During the creation of case 5 four other suggestions was evaluated and they will be presented here. The goal is to increase the district heat production from secondary heat and thus minimize the steam usage. As said in section 7.2 the calculations are based on a district heat flow of 180 m^3/h needed to be heated to 110°C representing the high usage season. During the main part of the year a temperature of 85°C is enough. Five different production cases are presented in *Table 13.3,* whit their temperature in different stages and energy deficit.

Table 13.3: Cases for production of DH at 110°C, after different retrofits.

#	**Hot stream**	**Temperatures of the DH**		**kW steam to reach 110°C**
		Tstart	**Ttarget**	
Case 1				
H9	effluent from 3141=2034	50	70	
H57	flue gas lime kiln	70	84.3	
				5 397
Case 2				
H9	effluent from 3141=2034	50	70	
H56	flue gas SP5	70	98.6	
				2 394
Case 3				
H9	effluent from 3141=2034	50	70	
H58	lash steam through condenser at KM2	70	87	
H57	flue gas lime kiln	87	101	
				1 890
Case 4				
H9	effluent from 3141=2034	50	70	
H58	flash steam through condenser at KM2	70	87	
H56	flue gas SP5	87	110	
				0
Case 5-stream splitting				
H9	effluent from 3141=2034	50	70	
H56[1]	flue gas SP5	70	110	
H58[1]	flash steam through condenser at KM2	70	87	
H57[1]	flue gas lime kiln	87	110	
				0

[1] The district heat stream is split after being exchanged with H9. Half is heated by H56 and half with H58+57.

The heat exchanger between H7, BFW, and C6, bleach plant effluent from tank 3141=2034, is changed in all cases in *Table 13.3,* as in the steam reduction retrofit. Condensation of steam in KM2 is taking place at 90˚C and releases energy of 5 500 kW and the water side of the flue gas condensers needs to be cooled from 140˚C to 105˚C. If one of them is used for district heat production it is possible to further heat the district heat without using steam. The direct steam saving from this retrofit will be the 448 kW from the new heat exchanger between H7 and H6, but there will also be a reduction of the steam use for production district heat.

How the available heat is used will affect the amount of district heat produced. Analysing *Table 13.3*only case 4 and 5 will be able to produce district heat at 110°C without using steam. So if the goal is to produce district heat without using steam they are the only ones that can be used. The difference between case 4 and 5 is that the surplus energy in case 5 can be used to increase the production of district heat.

On the other hand if a lower temperature is acceptable both case 2 and 3 reaches a temperature over 95°C and the surplus energy can be used for process integration as in the retrofits presented in section 7.1.

In *Table 13.4* the effects on used steam is presented for the different cases, during the high usage season. Depending on how large investments the mill is prepared to do, different cases will be of most interest.

Table 13.4: Comparison of savings during peak load in the different cases

	Steam saving [kW]	**Steam saving %**
Case 1	2 887	35
Case 2	5 890	71
Case 3	6 394	77
Case 4	8284	100
Case 5	8284	100