Industrial excess heat for district heating

Comparison of potentials from top-down and bottom-up studies for energy-intensive process industries

Master of Science Thesis

MOA SWING GUSTAFSSON

Department of Energy and Environment
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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS

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MOA SWING GUSTAFSSON

SUPERVISOR:

Karin Pettersson

EXAMINER

Simon Harvey

Department of Energy and Environment
Division of Heat and Power Technology
CHALMERS UNIVERSITY OF TECHNOLOGY

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MOA SWING GUSTAFSSON

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

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ABSTRACT

The threat about increased global warming and the over-use of the Earth's resources makes it important to reduce fuel usage. One way to reduce fuel usage is to be more energy efficient and a way to be more energy efficient is to use industrial excess heat as a source of district heating.

District heating from excess heat is delivered by Swedish industrial plants today. There have been studies trying to evaluate the potential for further production of district heating from excess heat at a national level in Sweden. In one major study, ratios were calculated for different industrial sectors that propose estimates for excess heat delivery to district heating networks per unit of fuel usage at the industrial plant.

In this study five energy analyses of different energy-intensive industrial plants have been evaluated. The potential for producing district heating from excess heat using pinch analysis and the current potential for producing district heating based on heat flows in process stream coolers have been calculated. These results have been compared to each other and with the results using the ratios described above for specific industrial sectors.

In the pinch analysis, the impact of different values of the minimum temperature difference allowed in the heat exchangers (ΔT_{min}) on the potential for export of excess heat have been evaluated. An increase in ΔT_{min} results in an increase in the minimum cooling demand. Generally, one would expect that an increased cooling demand would increase the possibility to produce district heating. However, this is not the case for all of the industrial plants studied in this report. Two of the five studied industrial plants show an opposite behaviour. An increase in ΔT_{min} does increase the cooling demand but the potential for producing district heating is however decreased. This makes it difficult to define a minimum amount of excess heat for district heating, which could be regarded as "true" excess heat, for these plants. For the other plants studied, an increased value of ΔT_{min} leads to an increased potential for district heating delivery. These plants clearly illustrate the trade-off between increased energy efficiency at the plant, leading to decreased internal fuel usage, and delivery of excess heat as district heating. For these plants it would be possible to define a minimum amount of "true" excess heat for district heating. However, it should be noted that the theoretical potential for export of excess heat depends on the selected value of ΔT_{min}, thus it is difficult to provide a general definition of "true" excess heat.

The potentials estimated using GCC curves from pinch analysis, available heat in existing process coolers, as well as estimates based on plant fuel usage differ to different extents for the different plants, but are on the same order of magnitude. The results based on GCC curves and available heat in process coolers are in most cases very sensitive to the assumed value of district heating supply temperature.

Key words: excess heat, district heating, energy-intensive industry, pinch analysis

Industriell överskottsvärme för fjärrvärme
Jämförelse av potentialer från top-down och bottom-up studier för energiintensiv processindustri
Examensarbete på masternivå

MOA SWING GUSTAFSSON
Institutionen för Energi och Miljö
Avdelningen för Värmeteknik och maskinlära
Chalmers tekniska högskola

SAMMANFATTNING

Hotet om global uppvärmning och överanvändandet av jordens resurser gör minskad bränsleanvändning till en viktig fråga. Ett sätt att minska bränsleförbrukningen är att bli mer energieffektiv och ett sätt att vara mer energieffektiv är att använda industriell överskottsvärme som en källa till fjärrvärme.

Överskottsvärme levereras av svenska industrianläggningar idag i form av fjärrvärme. Det har gjorts studier på nationell nivå i Sverige för att utvärdera potentialen för ytterligare produktion av fjärrvärme från industriell överskottsvärme. I en av studierna togs nyckeltal fram för olika industrisektorer som beskriver levererad mängd fjärrvärme från överskottsvärme per bränsleåtgång.

I denna studie har fem energianalyser från olika energiintensiva industrianläggningar utvärderats. Potentialen för produktion av fjärrvärme från överskottsvärme har beräknats med hjälp av pinchanalys och potentialen för att producera fjärrvärme baserad på dagens kylbehov har beräknats med hjälp av uppgifter om industrianläggningens befintliga värmeväxlarnätverk. Dessa resultat har jämförts med varandra och med det resultat som erhålls genom användandet av nyckeltalet beskrivet i stycket ovan.

I pinchanalyserna har effekterna på fjärrvärmepotentialen utvärderats för olika värden på den minsta tillåtna temperaturskillnaden i värmeväxlarna (ΔT_{min}). En ökning av ΔT_{min} resulterar i en ökning av kylbehovet i processen. Generellt skulle man förvänta sig att ett ökat kylbehov ökar potentialen för att producera fjärrvärme. Detta är dock inte fallet för alla industrianläggningar som studerats i denna rapport. Två av de fem studerade anläggningarna visar ett motsatt beteende. En ökning av ΔT_{min} leder till ett ökat kylbehov men däremot minskar fjärrvärmepotentialen. Detta gör det svårt att definiera en minsta mängd överskottsvärme för produktion av fjärrvärme, vilket skulle kunna betraktas som "sann" överskottsvärme, för dessa anläggningar. För de resterande tre anläggningarna leder ett ökat värde på ΔT_{min} till en ökad fjärrvärmepotential. Dessa industrianläggningar illustrerar tydligt avvägningen mellan en ökad energieffektivitet i anläggningen, vilket leder till minskad intern bränsleförbrukningen, och leverans av överskottsvärme som fjärrvärme. För dessa anläggningar skulle det vara möjligt att definiera en minimal mängd av "sann" överskottsvärme för produktion av fjärrvärme. Det bör dock noteras att den teoretiska potentialen för export av överskottsvärme beror på det valda värdet av ΔT_{min}, därför är det svårt att ge en allmän definition av "sann" överskottsvärme.

De potentialer som uppskattats med hjälp av GCC-kurvor från pinchanalys, den befintliga värmen i processens kylare samt från bränsleanvändning skiljer olika mycket för olika industrianläggningar, men är all i samma storleksordning. Resultaten från GCC-kurvorna och tillgängligt värme i processens kylare är i de flesta fall mycket känsliga för det antagna värdet på fjärrvärmens framledningstemperatur.

Nyckelord: överskottsvärme, fjärrvärme, energiintensiv industri, pinchanalys

Contents

Notations

ΔT_{min}	Minimum temperature difference in heat exchanger
CC	Composite curve
GCC	Grand composite curve
GWh	Gigawatt-hour
PVC	Polyvinyl chloride
TWh	Terawatt-hour
VCM	Vinyl chloride

1 Introduction

1.1 Background

Reducing energy usage is an important issue today, both at a national and international level. The European Union has set a target to reduce energy use by 20% by the year 2020. The Energy Efficiency Directive was formulated during 2011 as a driver for achieving this goal. One way to increase energy efficiency is to use excess heat as a heat source for district heating systems. This can help to reduce overall fuel use.

In Sweden there are several industries that currently deliver excess heat to a local district heating grid, but a question that is raised is how much more there is to harness. This question is for example interesting in view of the current discussion about whether to open up the district heating grids and introduce a statutory third party access as opposed to today's situation where the owner of the district heating grid is the one who decides who is allowed to use the grid.

Previous studies have been done which attempt to evaluate the potential for excess heat for district heating on a national level. It has been shown that the potential for using excess heat for district heating is larger than what is used today. One of these studies was conducted in 2002 (Svensk Fjärrvärme, 2002) with an updating and complementary version in 2009 (Cronholm, et al., 2009). These studies have made use of a general relationship that is based on the current amount of excess heat that industries deliver to district heating grids. Data on how much excess heat industries supply to the district heating grid together with their fuel use has been collected from SCB (Statistiska Centralbyrån, Statistics Sweden). From these data a ratio has been calculated that describes delivered excess heat per fuel usage. This has been done for each industrial sector (based on the industry classification used in the Swedish SNI 2002). By collecting data on total fuel use in each industrial sector (even industrial plants that currently do not deliver excess heat to a district heating grid) a theoretical potential for excess heat was calculated by multiplying the fuel use with the ratio. The theoretical potential was then adjusted based on contacts with companies and other sources of today's excess heat supplies. The calculated theoretical potential for all industrial plants in Sweden is 6.3 TWh/yr and the adjusted potential is 6.2 to 7.9 TWh/yr. The total amount of excess heat that is currently delivered is 4.1 TWh/yr. Energy-intensive industry accounts for 70% of the calculated theoretical potential and is the focus of this thesis project.

A more accurate way to estimate the excess heat potential would be to make a so called bottom-up energy analysis. In this way one can determine the current amount of excess heat at the industrial plant and how much that can be used to produce district heating. Pinch analysis is a tool that can be used to determine the theoretical amount of excess heat available for delivery of district heating from an industrial plant. By performing pinch analysis of all industrial plants in a country, a potential at the national level could be calculated. Performing energy analyses and pinch analyses are however time consuming processes and resources are lacking to conduct them for every plant.

1.2 Aim

The aim of this master's thesis project is to compare the amount of estimated excess heat for district heating from different industrial plants calculated with the ratio provided by Cronholm et al. with the resulting theoretical and current amount of excess heat for district heating from a selection of energy studies based on pinch analyses. This could potentially provide improvements in the general methodology used and thereby get a more reliable result about how much excess heat there is available from industries that could be used for district heating. Furthermore, the current potential for district heating will be compared to the theoretical potential for district heating provided by pinch analysis.

1.3 Scope

This thesis will focus on the excess heat from energy intensive industries; pulp and paper, steel and metal production and chemical industries. The pinch analysis studies that are used are based on previously conducted studies, mostly other master's thesis project reports. The scope of these studies was adopted as a limit of what can be taken into account and not, i.e. no additional data was collected. Five different pinch analysis studies are used: three from the pulp and paper industry (one chemical pulp and paperboard mill, one chemical pulp mill and one mechanical pulp and paper mill), one from a steel industry and one from a chemical industry. The refined petroleum products sector was not studied even though it's an energy intensive industry because of lack of comparable data in the comparing study by Cronholm et al. (2009), due to confidentiality reasons.

1.4 Objectives

The objective of this work is to quantify the theoretical potential for delivering excess heat in the form of district heating for five industrial plants, as well as the amount of excess heat that could be used to produce district heating given the current energy system configuration of these plants. These values will be compared to each other as well as with the estimated values obtained using the method in the study by Cronholm et al. (2009)

1.5 Method

The thesis will consist of three parts; calculation of district heating potential using excess heat from five different industrial plants using pinch analysis, identification of comparable values in the study by Cronholm et al. (2009) and finally comparison of these values with each other in order to suggest possible methodology improvements. Pinch analysis is described in Section 0 and the study by Cronholm et al. (2009) is explained in more detail in Section 0.

Collecting data and doing the calculations for a large industrial plant is a time consuming task and is not done in this thesis. This has already been done in the existing pinch analysis studies from the various industries that are investigated, and data is taken from these reports. All the values needed in this thesis are not reported in the existing pinch analysis studies, so additional calculations are performed. However, the basic data needed from the industrial plants to conduct pinch calculations is taken from the existing reports. Depending on what the existing pinch analyses were studying, different complementary calculations must be done. The pinch calculations were conducted in an Excel-based program called PRO_PI2, which is a program designed for pinch technology studies.

In this thesis the existing and theoretical amount of excess heat that can be used for district heating will be calculated. In order for excess heat to be used for district heating it has to have a high enough temperature. The supply temperature in district heating grids varies from country to country and over the course of the year. In Sweden, most older grids are designed for a maximum supply temperature of 120°C. Lower supply temperatures lead to reduced heat losses as well as opportunities for higher efficiency of cogeneration steam turbine units, but require larger water flows in order to deliver the same amount of heat. As a result, most of the new systems built in Sweden are designed for a maximum supply temperature of 100°C according to Werner et al. (2011). Since the report by Cronholm et al. (2009) includes all industrial plants in Sweden, there are different supply and return temperatures for the different industrial plants delivering district heating. Consequently, it is impossible to take the same values in order to make a comparison. Therefore, typical values of the return and supply temperatures of 55°C and 95°C respectively are assumed in this thesis. However, a sensitivity analysis is performed using different supply temperatures in the range of 85°C to 105°C.

The existing amount of excess heat from an industrial plant is its existing cooling demand. The theoretical amount of excess heat is the cooling demand that corresponds to a heat exchanger network designed for maximum heat recovery with a minimum allowable temperature difference (ΔT_{min}) of 0 K for all heat exchangers. This is of course not possible in practice since it implies heat exchangers with infinite areas (and thereby also infinite investment costs). In practice, the ΔT_{min} value used when designing a heat exchanger network results from a trade-off between heat exchanger area investment costs and hot (and cold) utility supply costs. The economic optimum value for ΔT_{min} is often between 5 and 10°C for grass root designs of new processes. However, for existing industrial plants it is seldom profitable to retrofit the heat exchanger network to achieve the degree of heat recovery corresponding to values of ΔT_{min} in this interval, even if a lower value of ΔT_{min} is accepted in some specific individual heat exchangers. In most cases, the optimal degree of heat recovery for a retrofitted network corresponds to a higher value of ΔT_{min} for the network. For the reasons listed above, the value of ΔT_{min} was varied between 0°C and 15°C in this study.

Section 0, Case study 1, presents a more detailed explanation of the methodology used whereas sections 0 to 0 (Case study 2 to 5) present the results for the different cases. A summary and discussion of the results for all the different case studies is presented in Section 0 which is followed by the conclusions in Section 0.

2 Earlier studies estimating the potential for industrial excess heat for district heating in Sweden

As mentioned in Section 1.1, two earlier studies have attempted to evaluate the potential for district heating production from excess heat at a national level, one in 2002 and the updated version in 2009. The updated version is the version this report is based on. The biggest difference between the 2002 and the 2009 report is the approach used to calculate the ratio between fuel usage at the industrial plant and the amount of heat that can be exported to a district heating network. In the first study the ratio was calculated individually for each industrial plant and the mean of ratios in each industrial sector was thereafter adopted as the indicative ratio for the sector. In the update in 2009 it was recognized that the ratios for each individual plant were weighted equally which had the effect that plants that differed a lot from the other plants in that particular sector had a major impact on the overall ratio. Therefore, the calculation was changed so that the ratio for each sector was calculated from the total delivered excess heat and fuel use in that sector, without using a mean value.

In the report by Cronholm et al (2009), as well as in this thesis, the term excess heat is used to denote primary heat content of liquid and gas streams that could be used to deliver heat to a district heating network without requiring use of a heat pump to raise the temperature. The fuel usage in the report by Cronholm et al. (2009) is the fuel usage excluding electricity which has a high impact on the ratio for electricity-intensive industries.

Since the calculations in this thesis are done for energy-intensive industries, only the results concerning those industrial sectors are presented here. For a sector breakdown of the energy-intensive industries, see *Table 2.1.* The big difference for “manufacture of coke, refined petroleum and nuclear fuels as well as manufacture of chemicals and chemical products” in terms of the calculated theoretical potential and the adjusted theoretical potential is because the adjusted potential includes the manufacturing of coke, refined petroleum and nuclear fuels, whereas information about these manufacturing processes are missing in the calculated value because of confidentiality reasons. This also explains why the supply is less than the estimated potential. (Cronholm, et al., 2009)

Table 2.1 Sector breakdown of delivered excess heat, theoretical potential and adjusted theoretical potential for energy intensive industries (Cronholm, et al., 2009)

Sector	Delivered excess heat 2007 [GWh/year]	Theoretical potential (original estimation) [GWh/year]	Theoretical potential (Adjusted value) [GWh/year]
Pulp-, paper production and publishing	1392	2015	2000-2500
Manufacturing of coke, refined petroleum and nuclear fuels as well as manufacturing of chemicals and chemical products	1908	1849	2500-3000
Steel- and metal production	502	678	900-1300

The calculated theoretical potential in the report by Cronholm et al. (2009) differs from the theoretical potential calculated in the case studies presented in this report. In the calculations done in this thesis, "theoretical potential" is the potential for producing district heating (for different temperatures of the district heating) using excess heat only assuming that the ΔT_{min} is set to 0 K for all heat exchangers. Since this leads to unacceptably large heat exchangers, the theoretical potential is thus not economically realistic. In the report by Cronholm et al. (2009), however, the theoretical potential is defined as the potential calculated using the adopted ratio for delivered excess heat per unit of fuel usage. It is therefore a potential based on the current deliveries of excess heat from industries and not a theoretical value calculated as described above.

The adjusted potentials presented in Cronholm et al. (2009) are based on different facts and experience depending on industrial sector. For the pulp and paper production and publishing sector, the adjusted potential is higher than the potential initially estimated in the original work. The most frequently used source for excess heat is the effluent streams. An additional source that has begun to be used in the pulping industry during recent years is heat recovery from a flue gas condensation unit mounted in the exhaust gas section of the recovery boiler. There are however difficulties implementing flue gas condensation, thus there is a significant potential for this technology to be used to a greater extent than it is today. This is the reason why Cronholm et al. (2009) revised the value of estimated potential for heat delivery from this sector.

The reason why the adjusted value for manufacture of coke, refined petroleum and nuclear fuels as well as manufacture of chemicals and chemical products is higher than the originally proposed value is explained above.

Through discussions with the energy coordinator at one of the industries in the steel and metal sector it was concluded that they had around 500 GWh of excess heat available each year for production of district heating, that they are not selling today.

This is the main reason why Cronholm et al. (2009) increased the value for district heat export potential for the steel- and metal production sector. The authors also comment that the adjusted value for this sector might still be an underestimation.

Table 2.2 shows the calculated ratios for separate industrial sub-sectors used in the original estimation. The ratios are not available for the adjusted values of the potential and it is not possible to calculate backwards since the adjusted values aren't available for the different sub-sectors. However the difference between the calculated potentials from the ratios and adjusted values should be kept in mind when using the ratios for calculating the potentials for single industrial plants.

Table 2.2 The calculated ratios for industrial sub-sectors calculated for the year 2007. The ratio describes delivered excess heat per fuel use per year.

Sector	**Ratio – Percentage of excess heat delivered per unit of fuel usage [%]**
Pulp industry	2.8
Paper industry	3.2
Chemicals and chemical products	24.3
Steel- and metal production (production of iron, steel and ferro-alloys, manufacture of iron- and steel pipes and other primary processing of iron and steel)	2.5

3 Pinch technology

Pinch technology was developed by Professor Bodo Linnhoff at Manchester Institute of Science and Technology and was introduced in the late 70-ties. It has since then been developed further in order to use it in more areas. It is useful when analyzing complex industrial processes in order to save energy (and money). This theory about pinch technology is based on course material from the course “Industrial energy systems” at Chalmers University of Technology written by Harvey (2011) if nothing else is said.

Pinch analysis is a systematic method that determines the minimum heating and cooling demand of a process. Before starting pinch calculations one have to collect data on all the streams in the process that require cooling or heating. The streams that require cooling is called a hot stream and streams that require heating is called a cold stream. Note that the names hot and cold stream has nothing to do with the temperatures of the streams, only their need for cooling/heating. The data needed are the start and target temperatures of the streams, their flow and the specific heat capacity.

In order to display the streams a composite curve (CC) can be drawn. The CC is a temperature – enthalpy diagram with one curve for the hot streams and one curve for the cold streams. For an example of a CC, see *Figure 3.1*.

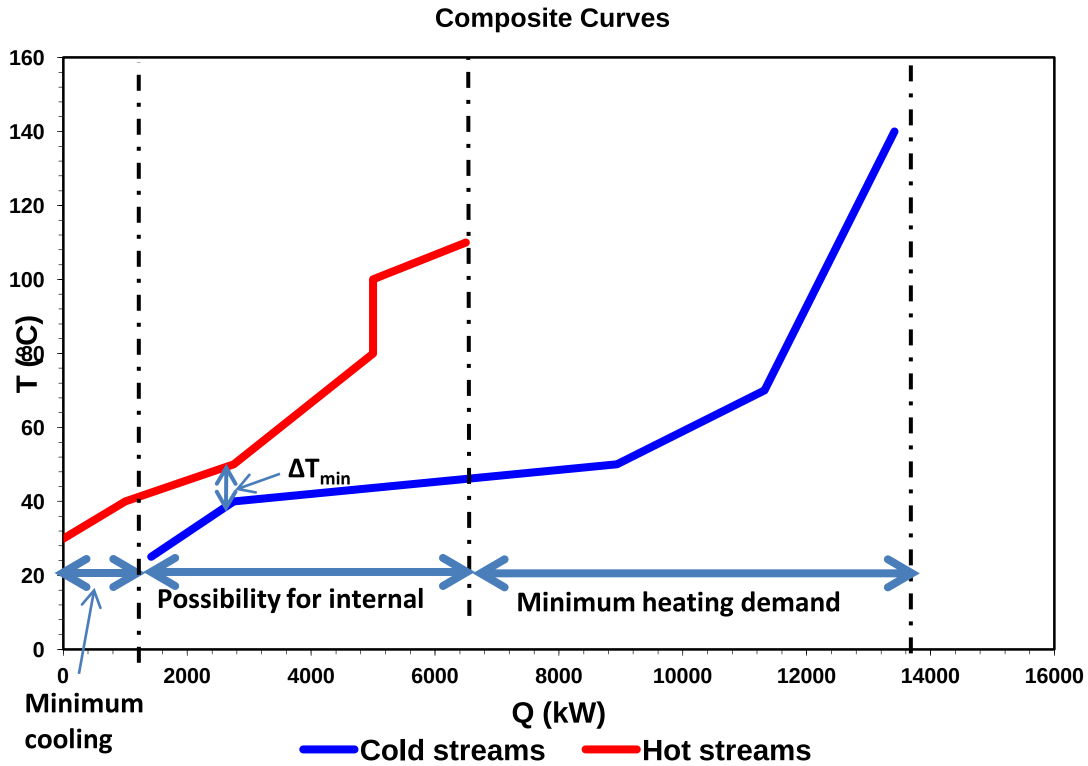

Figure 3.1 *An example of a CC with cold and hot streams and a minimum temperature difference (ΔT_{min}) of 10°C. The minimum cooling demand is 1400 kW, the minimum heating demand is 6900 kW and the pinch temperature is 40°C for the cold streams, and 50°C for the hot streams.*

In the figure above you can see the minimum cooling and heating demand for the process and the possibility for internal heat exchanging between the streams. The minimum temperature difference, ΔT_{min}, is the lowest allowable temperature difference between two streams exchanging heat. In the example above ΔT_{min} is set to 10°C. The point where ΔT_{min} occurs is called the pinch. Changing ΔT_{min} changes the minimum heating and cooling demand, an increase in ΔT_{min} increases the minimum heating and cooling demand. However a decrease in ΔT_{min} increases the heat exchanger area. This means that the value of ΔT_{min} is set by a trade-off between heat exchanger area investment costs and hot (and cold) utility supply costs.

Combining the hot streams and the cold streams results in a grand composite curve (GCC) which can be seen in *Figure 3.2*. The minimum temperature differences can be set individually for each stream or a global temperature difference can be used for all streams. In this example, same as the CC above, a global temperature difference of 10°C has been used. The temperatures of the hot streams in the GCC are lowered by $\Delta T_{min}/2$ and the temperatures of the cold streams in the GCC are lifted by $\Delta T_{min}/2$.

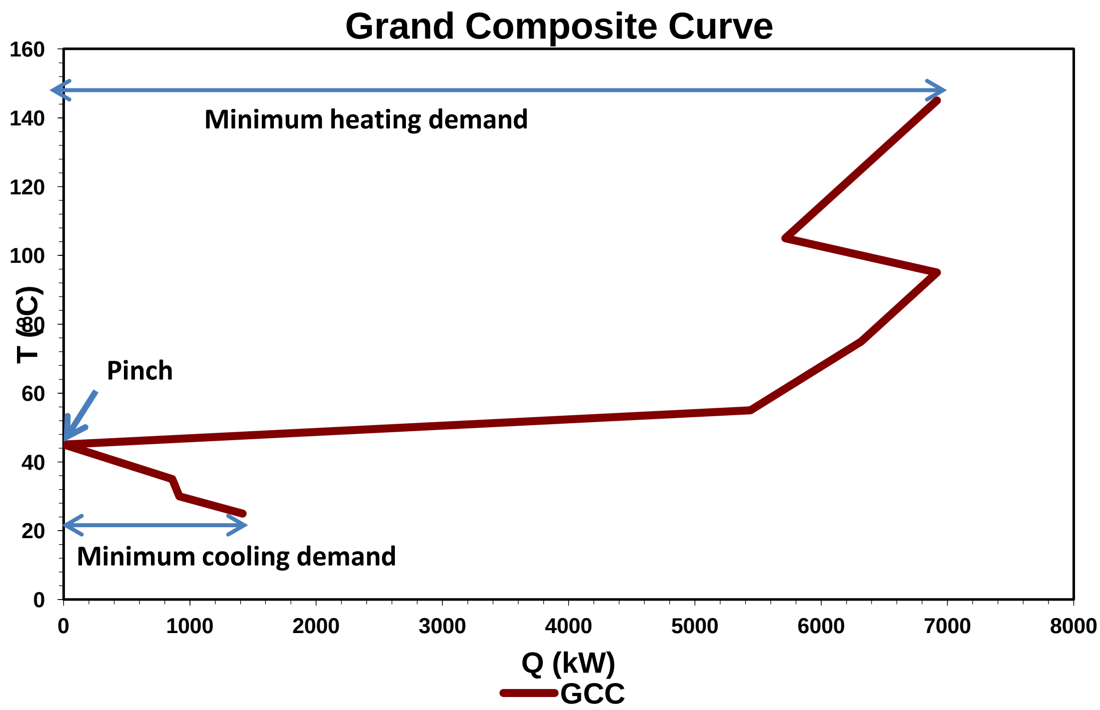

Figure 3.2 An example of a GCC with a minimum cooling demand of 1400 kW, a minimum heating demand of 6900 kW and a pinch temperature of 45°C. The global minimum temperature difference is 10°C.

The pinch point occurs at the pinch temperature, which is a very important temperature within pinch technology. Above the pinch temperature the streams have a deficit of heat and a heating source is required. Below the pinch temperature the streams have a surplus of heat and a cooling utility is needed. The pinch temperature shows the highest temperature where cooling can occur, and thereby also the highest temperature for district heating produced from excess heat. Remember that the temperatures are shifted. In the example above with a pinch temperature of 45°C and a global minimum temperature difference of 10°C, the pinch temperature for the cold stream is 40°C and the pinch temperature for the hot stream is 50°C.

The GCC shows what's possible in theory and not what is practical. In order for a process to recover as much heat as possible, and thereby reaching the minimum cooling and heating demand, there are three "golden rules" that must be followed. These are as follows:

- Do not transfer heat from a stream above the pinch temperature to a stream below the pinch temperature
- Do not cool a stream above the pinch temperature with cold utility
- Do not heat a stream below the pinch temperature with hot utility

Existing processes rarely follow these golden rules, i.e. their heating and cooling demands are greater than the minimum values. By identifying violations of these rules, one can find ways to reduce cooling and heating demands in a process.

The cold and hot utility demand for different heat exchanger networks at an industrial plant corresponds to different global temperature differences. A demand curve can be drawn showing how the hot- and cold utility demand changes with changing global temperature difference. The demand curves for the example above can be seen in *Figure 3.3*. The demand curve shows what was said above, an increased global temperature difference increases the heat demand as well as the cooling demand.

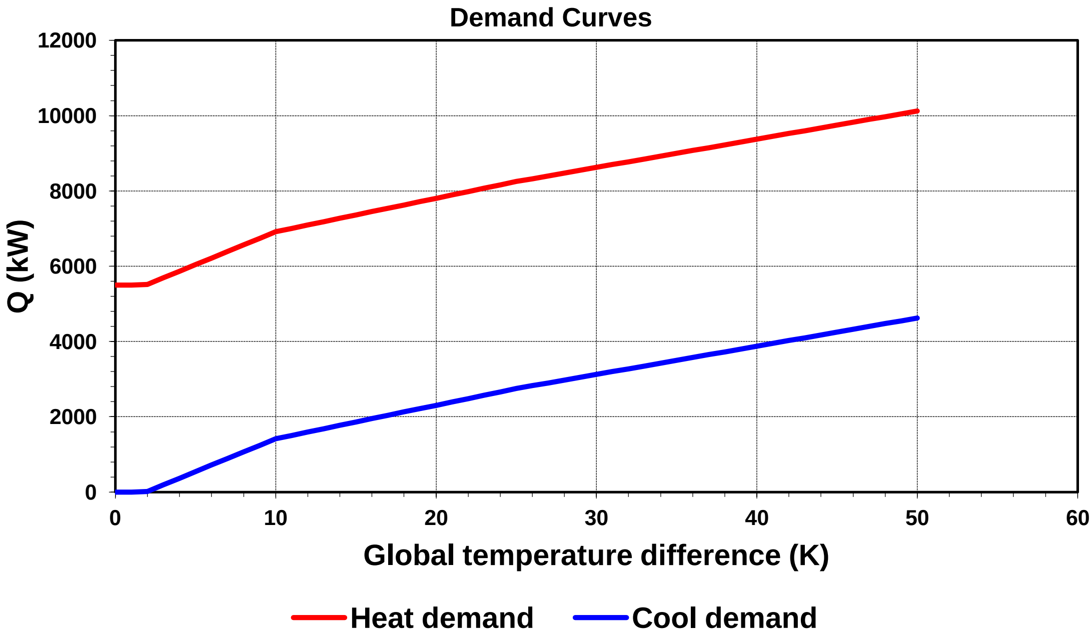

Figure 3.3 The demand curves showing different heat- and cool demand depending on the global temperature difference of the process.

Since the heat exchanger network isn't revealed in the GCC, a set of "advanced composite curves" have been further developed by Nordman (2005). One of the aims with these advanced curves is to identify temperature levels where usable excess heat can be extracted. The advanced curves consist of four curves above the pinch and four curves below the pinch. The curves above the pinch are hot utility curve (HUC), theoretical heat load curve (THLC), actual heat load curve (AHLC) and extreme heat load curve (EHLC), and the curves below the pinch are cold utility curve (CUC), theoretical cooling load curve (TCLC), actual cooling load curve (ACLC) and extreme cooling load curve (ECLC). Most of these curves are explained by their names. The hot/cold utility curve is a composite curve of the utility streams in the existing heaters/coolers. The actual heat/cooling load curve is a composite curve of the process streams in the existing heaters/coolers. For the same total heat demand as the AHLC streams the EHLC shows the temperatures where heat could be supplied if it were to be supplied at the highest possible temperature. For that same heat demand the THLC shows the lowest possible temperatures where heat can be supplied. The corresponding curves below the pinch, ECLC and TCLC, show the temperatures where heat could be removed at the lowest temperature and highest temperature respectively.

If there is information about the whole heat exchanger network at the plant all of the advanced curves can be constructed. This is done in PRO_PI2 with the actual demand streams and utility streams as input together with the whole process included in the GCC. For an example, see *Figure 3.4* (the extreme curves are of no interest in this study and are not included in the example).

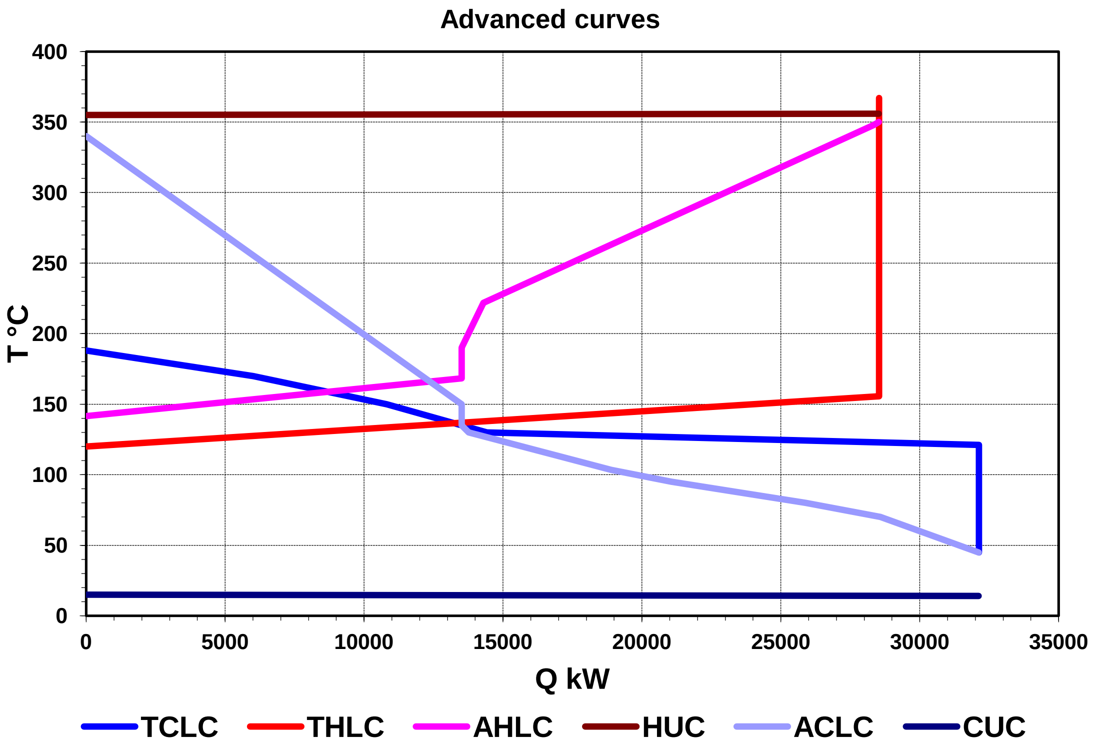

Figure 3.4 An example of the advanced curves TCLC, THLC, AHLC, HUC, ACLC and CUC.

Looking at the AHLC and THLC one can see that the heating at the plant could theoretically occur at a lower temperature than that achieved in the current utility system design. The TCLC (theoretical cooling) shows the maximum temperature where cooling can occur without breaking any pinch rules. It is however to a large extent at a lower temperature than the ACLC (actual cooling). Since the actual cooling is violating the pinch rules there are hot/cold utility savings that can be done if the heat exchanger network is constructed as the TCLC and THLC suggests. The maximum utility savings that can be made (for this amount of actual heating and cooling) is the amount up to where the TCLC and THLC are ΔT degrees from intersecting. The value of ΔT is the minimum temperature difference one decides to have in the heat exchangers between a hot stream and a cold stream. If the ΔT is set to 10°C this occurs at around 12000 kW in the example above in *Figure 3.4*. Up to this point the streams in the TCLC can be used to heat the streams in the THLC. The amount of heat, 12000 kW, that is saved by internal heat exchanging between the TCLC and THLC can be saved by using less hot utility. Or the same amount of hot utility can be used to produce district heating. Looking at the ACLC and AHLC they do intersect as well and hot utility could be saved if these were to be heat exchanged, however not as much as if one were to heat exchange the theoretical curves.

If one chooses to use the saved hot utility instead of producing/buying less, the theoretical cooling curve that can be used to produce for example district heating has the temperature of the utility up to the point where the TCLC and THLC are ΔT degrees from intersecting, and then it has the shape of the original TCLC for the temperatures below that point.

In the example above, the temperatures of TCLC and ACLC are both much higher than what is needed to produce district heating. The limiting factor for the potential of producing district heating would in this case be the return temperature. So in this example the potential for producing district heating wouldn't change much if you were to use the TCLC streams, the ACLC streams or the saved utility to produce the district heating. However, if you were to use the TCLC to heat the THLC and produce/buy less hot utility (i.e. not using the saved utility) the potential would decrease by the same amount of heat that is saved.

4 Case study 1 – Chemical pulp and paperboard mill

4.1 Description of the mill

The first mill studied is an integrated kraft pulp and paperboard mill, which means that both pulp and paperboard is produced. The end product of the mill is virgin fiber-based paperboard of which they are one of the largest producers in Europe with a production capacity of 330 000 ton/yr. (Iggesund Paperboard AB, 2010)

The mill is today connected to the local district heating grid as well as a saw mill nearby which they deliver heat to. Excess heat is used on site in an internal secondary heating system producing medium hot water at 40°C, warm water at 65°C and hot water at 85°C which is used in the mill. (Glader, 2011)

A schematic picture of the process can be seen in *Figure 4.1*.

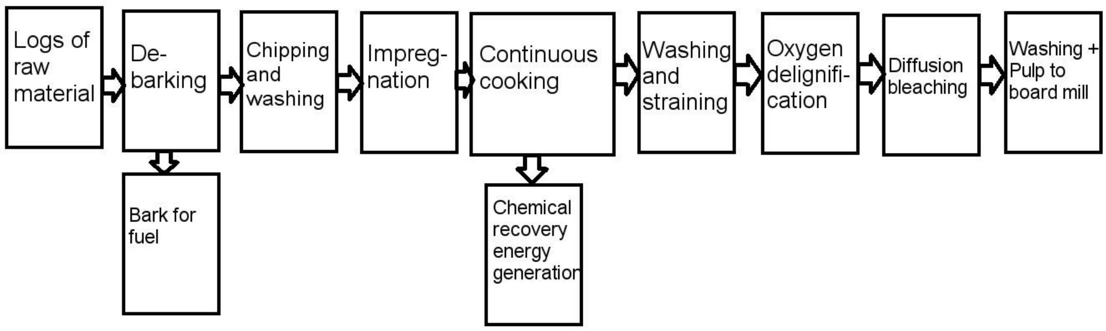

Figure 4.1 A schematic picture of the chemical pulp mill process.

The raw material (timber) is firstly debarked and chipped into smaller pieces. The wooden chips are then impregnated with white liquor in order to have an even distribution of the white liquor among the chips before the digestion step where continuous cooking is done. The wood chips consists mainly of cellulose fibers (which is what's needed for the pulp and paper making) that are being held together with lignin. During the cooking the main part of the lignin is dissolved in the white liquor, creating a liquid called black liquor (the wood also consist of hemicelluloses which partly end up in the pulp and partly in the black liquor). The cooking is a continuous process where 80-90 % of the lignin is dissolved. The black liquor is a part of the recovery cycle which recovers the white liquor as well as the energy contained in the lignin. This part is the one that makes it possible for chemical pulp mills to be self-sufficient in terms of energy and will be described more in detail below. (Iggesund Paperboard AB, 2010)

After the cooking follows some steps which wash away cooking chemical residues, bleaches the pulp and dries it if it's supposed to be shipped away to some other user. However, only a small portion of the pulp produced in this specific mill is dried since most of it is used directly in the paperboard mill. (Iggesund Paperboard AB, 2010)

The paperboard mill takes most of its pulp from the pulp mill on site. However, bought pulp bales are also used. The pulp is first mixed with water to a water content of 99 %. After that follows several steps that prepares the pulp before entering the paperboard machine. These steps can for example be to add additives that increases the whiteness of the fibers or additives that increase water repellency of the fibers. (Iggesund Paperboard AB, 2010)

The pulp- and water mixture is then formed in layers on a moving wire or plastic mesh. The water content is reduced using vacuum assistance but most of the water content is reduced in the two following steps, the pressing and drying. In the pressing, the pulp is pressed between rollers reducing the water content to 60-65 %. In the drying step the pulp is dried over steam heated steel cylinders reducing the water content to 5-10 %. (Iggesund Paperboard AB, 2010)

The last steps in the paperboard mill are steps that improve the paperboard in different ways. Starch solution can be applied to increase the strength of the paperboard, the thickness and smoothness can be increase and different coatings and brushings can be used depending on the final usage of the paperboard.

4.1.1 Recovery cycle and steam production

The recovery cycle is as mentioned above the part in a chemical mill that makes it possible for the mill to be self sufficient in terms of energy. It also recovers the white liquor. For a schematic picture of the recovery cycle see *Figure 4.2*.

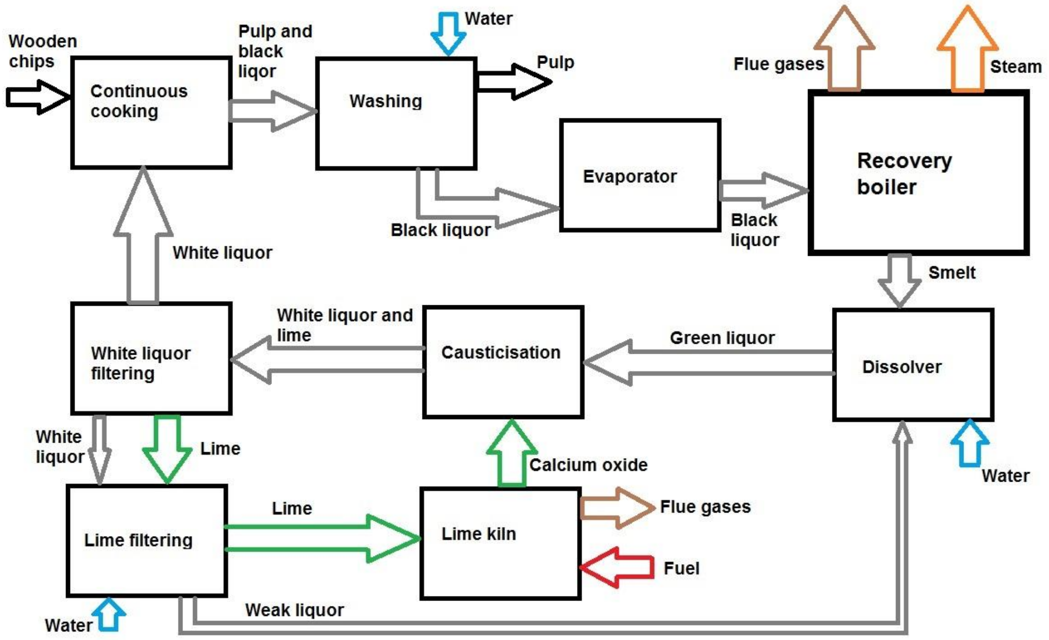

Figure 4.2 A schematic picture of the recovery cycle.

The black liquor contains a lot of different chemicals but to the most part it’s white liquor and lignin. The black liquor has high water content and is firstly evaporated until the dry solid content is around 70-80 %. Thereafter it is burned in the recovery boiler where high pressure steam is produced. The black liquor will form a smelt at the bottom of the recovery boiler when burnt. The smelt is dissolved in order to create green liquor which is regenerated into white liquor by a reaction with calcium hydroxide. In the reaction lime is produced as a by-product. The lime and the white liquor is separated and the white liquor is recycled to the cooking The lime is burned in the lime kiln and forms carbon dioxide and calcium oxide which dissolved in water forms calcium hydroxide.

The high pressure steam that is produced in the recovery boiler is used in a back-pressure steam turbine to create electricity. Different steam levels are taken out in order to satisfy the demand of the process. The recovery boiler produces more energy than what is used in the pulping part of the mill. But since this mill is an integrated pulp and paper mill more steam is needed. In order to fulfill all the steam demands there is another boiler running as well, a bark boiler. The bark boiler uses bark from the debarking as well as bought bark and sawdust from sawmills. Some oil is used as well.

The two boilers produce a “surplus” of steam in order to use the steam for producing district heating.

4.2 Earlier study of the mill

An earlier study by Karin Glader (2011) has been made on the mill with the purpose of mapping and analyzing the current energy situation in order to identify where and how the energy situation could be improved. Pinch analysis was the tool used by Glader to evaluate the mill.

At the time when the study was done the building of a new recovery boiler with a new flue gas condensing system had already started but was not yet finished. However, the author adapted the situation and the calculations to the future conditions with the new boiler and flue gas condensing system in place. This means that some data are approximate.

The study was focused on the pulp production and didn’t include the paperboard part. However, since most of the heat surplus is in the pulp production part and this thesis is about using excess heat as district heating the study is still relevant.

4.2.1 Data collection and current situation

Some of the data on the mill is stored for 7 days and some of it is stored for 2 years. If possible an annual average has been used between April 2010 and April 2011.

Some of the streams have been omitted due to lack of information or due to technical issues which makes the stream non-integrable. An example of omitted streams is some streams in one of the bleaching plants since it is controlled manually which makes it hard to get reliable data and to integrate the streams with other streams. However, the effluent streams from the plant are included. The effluent streams have a so called “soft” target temperature since they don’t need to be cooled, but can be cooled in order to utilize the heat. The “soft” target is set to 37 °C. This also applies to other effluent streams from the mill and not only the streams from the bleaching plant mentioned above.

Table 4.1 The energy situation for the streams in the current network and in the future one, which is one of the results from Glader's report. Individual temperature differences have been used for the different streams. (Glader, 2011)

	Today's network without effluents	**Today's network**	**Future network[1]**
Pinch temperature [°C]	62	69	113
Min. hot utility [MW]	85.9	85.5	74.0
Min. cold utility [MW]	1.7	31.8	29.3

[1] With the new recovery boiler and flue gas condensing system

The energy situation for the streams in today's network as well as in the future network can be seen in *Table 4.1* above. Individual minimum temperature differences have been used for different fluids in the process. Clean water has a minimum temperature difference of 5°C, contaminated water 7°C, air 16°C, live steam 1°C, contaminated steam 4°C and steam with non-condensable gases 8°C. The present steam demand is 92.3 MW (for both today's network and the future one since no production changes will be made in the future one) so there is a possibility to decrease the hot utility used today. The new streams added in the future network (for example flue gas cooling from both the recovery boiler and the lime kiln) has a great impact on the pinch temperature which in this case mean that heat at a higher temperature can be utilized below the pinch. However, the minimum cold utility also decreases with the future network which is the theoretical amount of heat that can be used for other purposes. Bear in mind that the heat amount above (cold utility) can't all be used for district heating since it also includes cooling at a lower temperature then what is needed for heating district heating. Also most of the minimum cold utility needed is because of the effluent streams with "soft" targets, compare today's network without effluents with today's network. From the difference between today's network with effluents and without one can see that the extra amount of cooling because of the soft targets is around 30 MW. Around half of this amount is above 50°C and should, as Glader puts it, "be regarded as potential future heat sources".

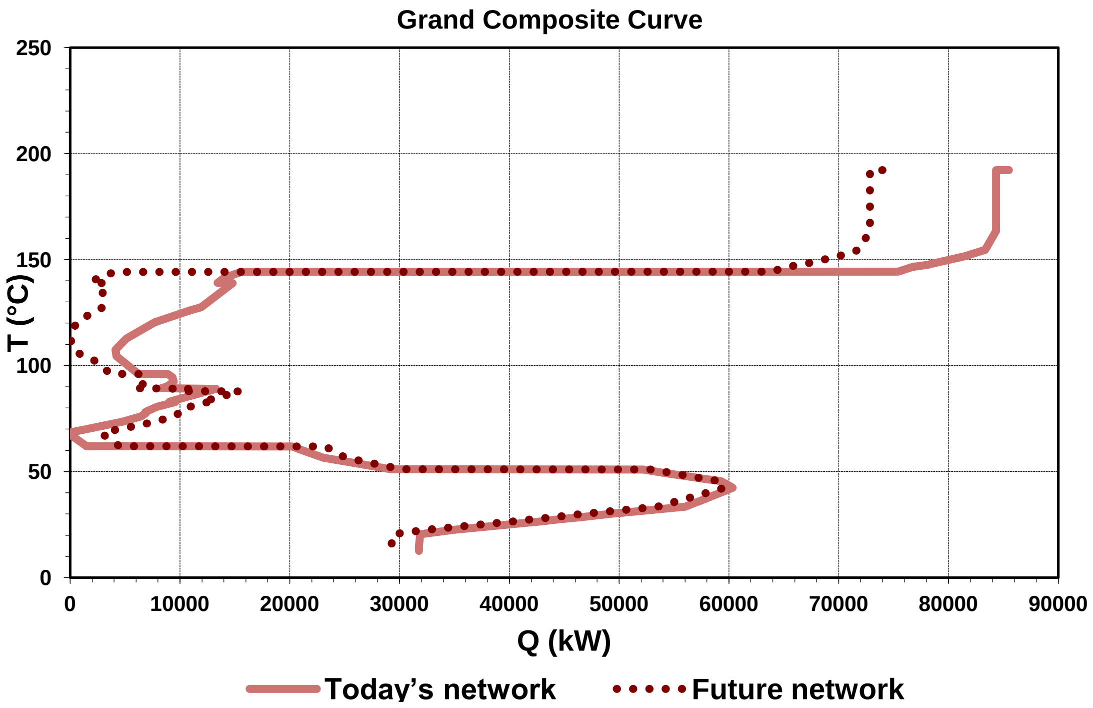

Figure 4.3 *The GCCs for the streams in todays network as well as in the future network with individual temperature differences.*

Figure 4.3 above shows the GCC's for the two different networks. The GCCs for the two different networks have almost the same shape except that the two "noses" around 70°C and 110°C changes place when new streams are included in the future network. The shape of the GCCs is the reason why the pinch temperature changes so drastically with only a few new streams included. Looking at the GCCs there are two distinct pockets, one around 40°C and one around 85°C, where there is a possibility to heat exchange internally between streams and thereby reducing the hot utility demand.

4.2.2 Retrofit results from the study

Glader has done three retrofits of the future network in order to solve pinch violations and therefore get closer to the minimum hot utility demand of 74.0 MW, compared to the present steam demand of 92.3 MW. The difference is 18.3 MW and consists of pinch violations in the mill. The internal secondary heat system is not included in the retrofits since the system is complex and sensitive to changes. The potential for producing district heating has also been calculated by Glader at two different supply temperatures of the district heating, 85°C and 110°C. The return temperature for the district heating is set to 50°C for both cases.

The first retrofit suggestion requires three new (or rebuilt) heat exchangers and will result in a steam saving of 7.9 MW. The potential for district heating is 6.8 MW at 110°C and 12 MW at 85°C.

The second retrofit is a more extended retrofit which requires five new (or rebuilt) heat exchangers but will save 13.0 MW of steam. The potential for district heating is however a bit lower here. 5.5 MW could potentially be delivered at 110°C and 11 MW at 85°C.

The third retrofit is focused on increasing the possibilities of delivering district heating. The process steam savings are not as high as the two previous retrofits, it's only 0.4 MW. However the steam used for producing district heating today is also eliminated, which is around 0.8 MW. This will, however, make it possible to produce 22 MW of district heating at 110°C. The author points out, however, that you have to make sure that the cooling of the process is covered even during seasons when the demand for district heating is low.

For all three retrofits it should be noted that the production of district heating is done using flue gases with temperatures above the pinch, i.e. the production is partly a pinch violation. Glader points this out in the report with the argument that ventilating the flue gases to the atmosphere is a pinch violation as well but in this way it will reduce the amount of steam needed for producing the district heating.

4.3 Pinch analysis of the mill

Glader's study was a part of her supervisor Johan Isaksson's Ph.D. project and his updated data on the mill will form the basis for the pinch calculations done in this master's thesis Isaksson (2013). The data used can be seen in Appendix 1.

The potential for district heating has been calculated from GCCs with different global temperature differences. The temperature difference between the process and the district heating has been set in two different ways. Firstly the difference is varied in the same way as the global temperature difference of the process and secondly it is set to a value of 7°C regardless of the global temperature difference of the process. The end temperature of the district heating is varied between 85°C and 105°C but the start temperature is set to 55°C at all times. For an example of how the district heating potential is calculated from the GCC, see *Figure 4.4*. The lines corresponding to the district heating has been drawn below the pinch temperature as a tangent to the GCC without crossing any part of it. For a specific district heating temperature this results in the maximum amount that can be produced using only excess heat from the process and not violating any pinch rules. As can be seen in the figure, district heating of 105°C can't be produced for that specific global temperature difference since 105°C is above the pinch temperature.

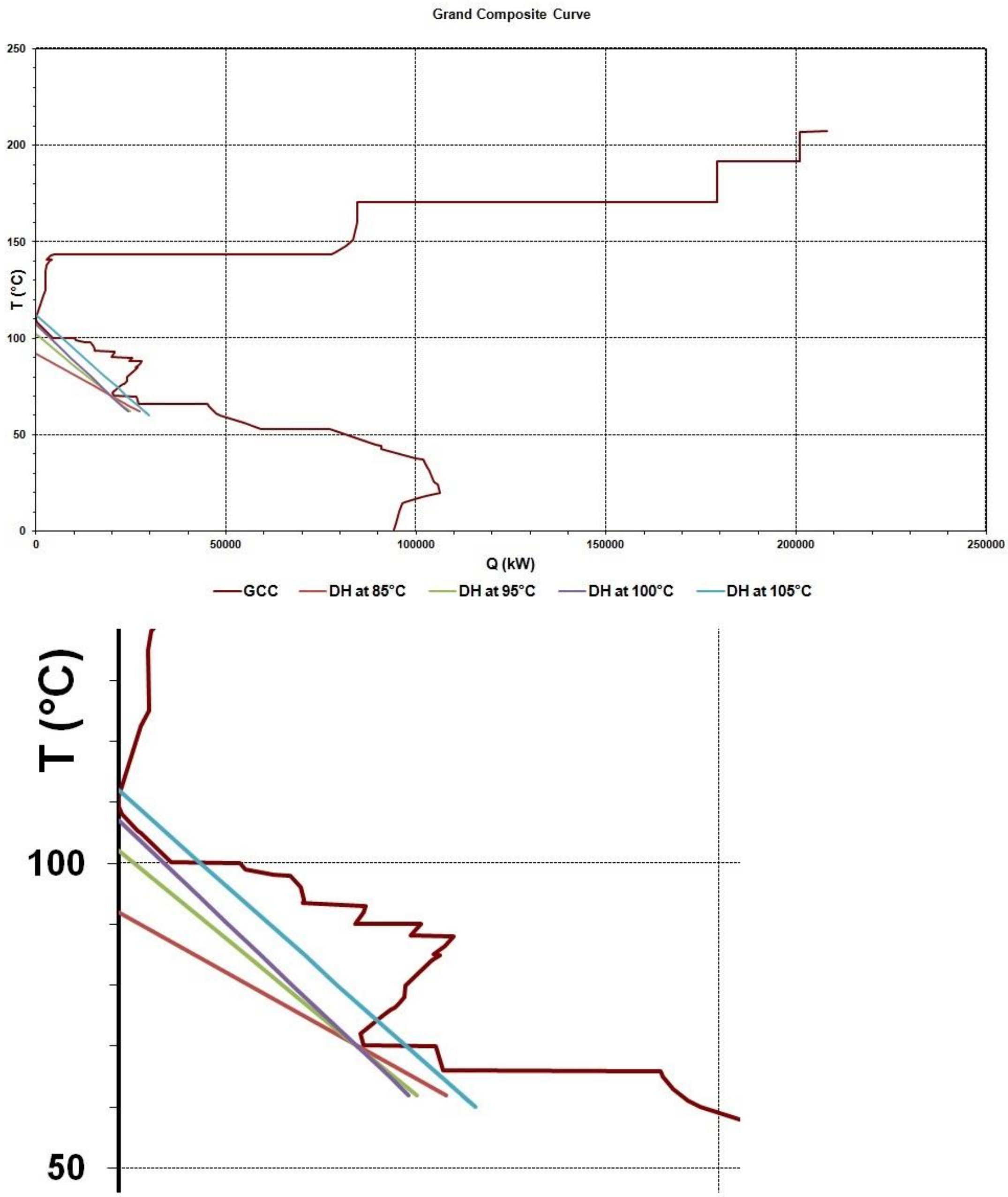

Figure 4.4 *An example of how the district heating potential is calculated from a GCC by drawing district heating lines that won't cross the GCC. The top picture is the whole GCC and the bottom one is zoomed in on the district heating lines where you can see that the blue line (DH at 105°C) lies above the pinch temperature.*

The results from all the different global temperature differences as well as the different variations in the temperature difference between the process and the district heating can be seen in *Table 4.2* and *Table 4.3*, where the second table shows the results with a set value of 7°C for the temperature difference between the process and the district heating.

Table 4.2 District heating potential (in MW) at different temperatures for different global temperature differences of the process and different temperature differences between the process and the district heating (same as the global temperature difference). The return temperature of the DH is set to 55°C for all cases.

Global temperature difference [°C]	**District heating supply temperature [°C]**				**Pinch temperature [°C]**
	85	95	100	105	
0	41.1	32.8	30.7	29.2	111.0
5	26.3	24.1	23.2	22.5	108.5
10	11.3	11.2	11.2	7.6	110.4

Table 4.3 District heating potential (in MW) at different temperatures for different global temperature differences of the process and a set temperature difference of 7°C between the process and the district heating. The return temperature of the DH is set to 55°C for all cases.

Global temperature difference [°C]	**District heating supply temperature [°C]**				**Pinch temperature [°C]**
	85	95	100	105	
0	28.0	25.6	24.9	-[1]	111.0
5	24.2	22.6	21.9	-[1]	108.5
10	12.6	12.1	12.0	11,9	110.4

[1] The temperature of the district heating is above the pinch temperature and can therefore not be produced without violating the pinch rules.

The potential for producing district heating varies a lot depending on the temperature of the district heating as well as the global temperature difference of the process. It also varies depending on the temperature difference between the process and the district heating. Looking at the tables above it ranges from 7.6 MW (0 MW including the temperature where no district heating can be produced) to the theoretically maximum 41.1 MW. However, the global temperature difference of 0°C is not possible in practice.

One could say that the different global temperature differences represents different heat exchanger networks for the process which has the same hot utility demand as the minimum hot utility demand from the GCC for that specific global temperature difference. Since the affect on the potential for producing district heating when the heat exchanger networks are changed in a process is studied, the temperature difference between the process and the district heating is set to a set value. In this case the value is set to 7°C and is the value used in the rest of the report as well. The values from *Table 4.3* are therefore the values further discussed in this section.

It is however true that the value of the temperature difference between the process and the district heating affect the result. Comparing the same global temperature difference for the two tables one can see the difference between different temperature differences between the process and the district heating. For a global temperature difference of 5°C and 10°C the potential differs slightly depending on the temperature difference between the process and the district heating, except for a supply temperature of 105°C. The supply temperature of 105°C is close to the pinch and is therefore affected more depending on the temperature difference between the process and the district heating. Since the temperature difference between the process and the district heating has the same value as the global temperature difference in *Table 4.2*, the global temperature difference of 0°C differs more than the global temperature differences of 5°C and 10°C since they are closer to the 7°C used in *Table 4.3*. Even if the value of the temperature difference between the process and the district heating affect the result it is not varied in this study any further in order not to get too many results.

Increasing the global temperature difference increases the minimum cold utility needed as well. For the global temperatures 0°C, 5°C and 10°C the minimum cold utility needed are 94.1 MW, 95.8 MW and 97.1 MW respectively. Looking at *Table 4.3* again one can see that the potential for district heating is, however, decreasing when the global temperature difference is increased. The district heating with a temperature of 105° is an exception which is because it's such a high temperature that it lies above the pinch temperature until the global temperature difference is higher than the temperature difference between the DH and the process (which is 7°C).

The other district heating temperatures can be explained looking at *Figure 4.5* and *Figure 4.6*. *Figure 4.5* is the GCC for the global temperature difference of 2°C and *Figure 4.6* is the GCC for the global temperature difference of 10°C. Looking closely one can see that the minimum cold utility is increased for the higher global temperature difference. However, it's the shape of the GCC that explains why the potential for district heating is decreased. The "nose" at around 60°C to 70°C is positioned at a lower energy content (more to the left) for the higher global temperature difference which means that the lines for the district heating gets a steeper slope which in turn leads to a lower energy content for the district heating, i.e. lower potential.

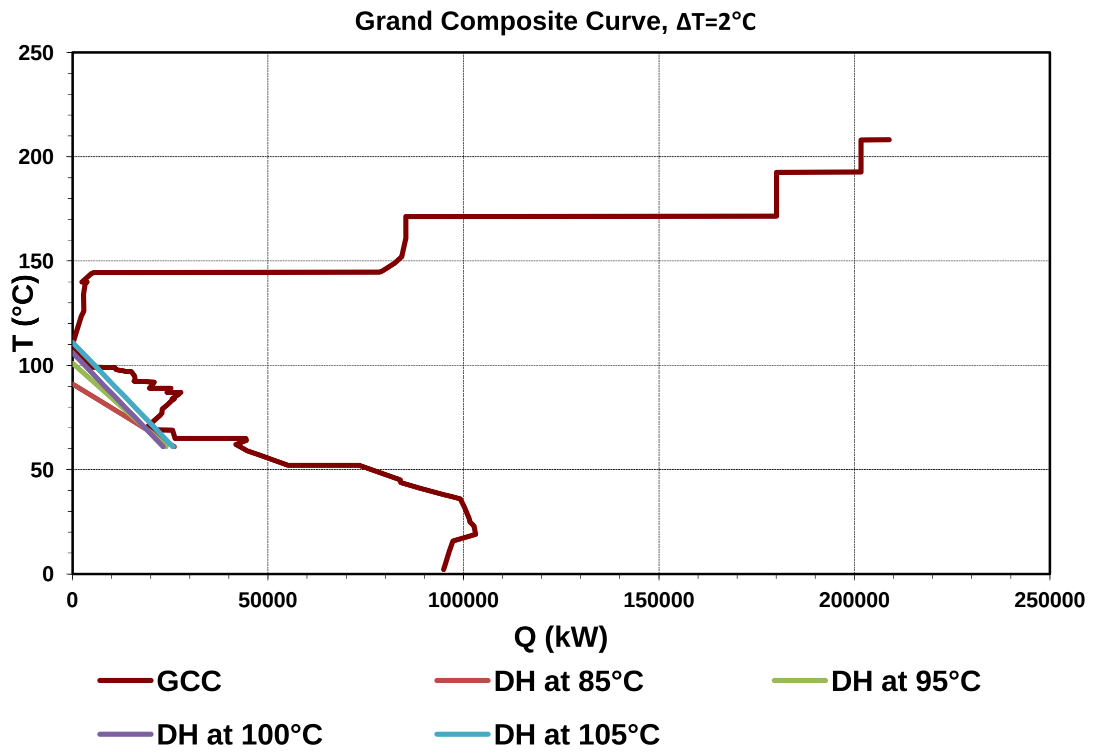

Figure 4.5 The grand composite curve for a global temperature difference of 2°C.

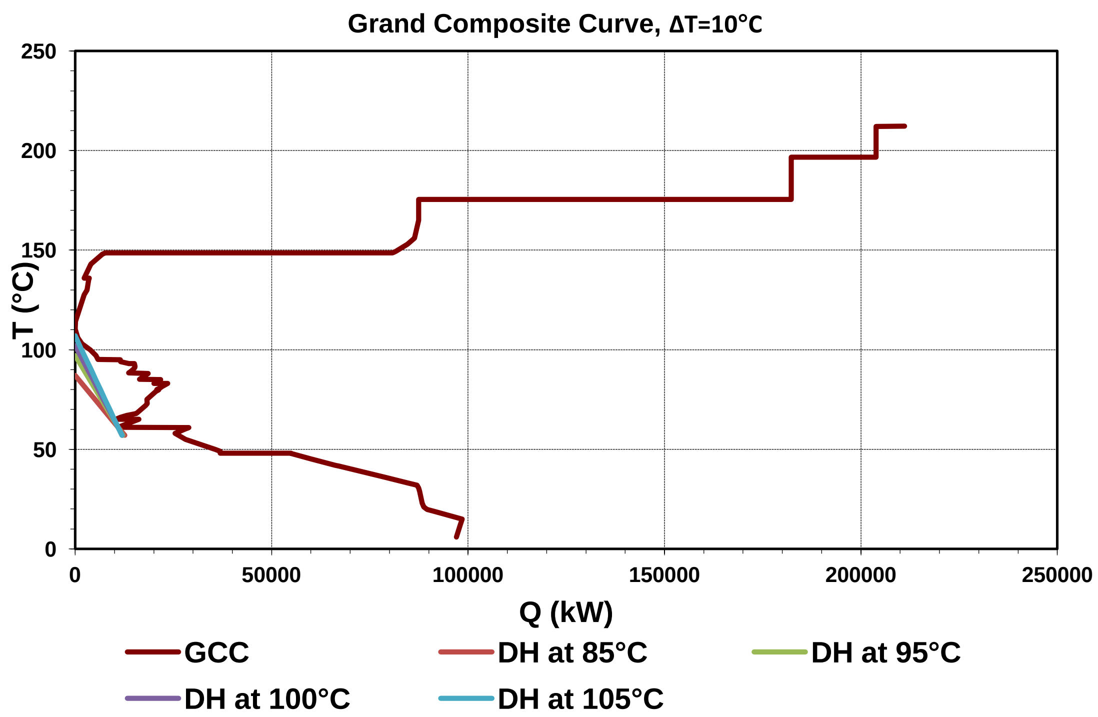

Figure 4.6 The grand composite curve for a global temperature difference of 10°C.

The shape of the GCC is why it's not possible to produce any district heating at a global temperature difference of 15°C or higher, and why in this thesis the global temperature difference of this process is varied between 0°C and 10°C. At a global temperature difference on 15°C the “nose” has moved even further to the left and produced a process with a double pinch. Since the “nose’s” position is only a few degrees above 55°C (the return temperature of the DH in this thesis) it would be no point in producing DH.

The actual possibility to deliver district heating is the process’s actual cooling demand. In this case, however, the actual cooling demand consists of streams with “soft” targets explained earlier. Since the streams with “soft” targets are included in the pinch analysis they have to be accounted for when calculating the actual cooling demand as well in order to make a comparison. The actual cooling demand for this process is 115.6 MW. A lot of that cooling demand is however below 55°C and can’t be used for producing district heating. Calculating the possibility for producing district heating from the actual cooling demand is done in the same way as in *Figure 4.4*. A graph is made containing the streams needing cooling and the district heating lines are drawn as tangents without crossing the actual cooling demand curve. This is done in *Figure 4.7*. The temperature difference between the cooling demand curve and the district heating is set to 7°C. The resulting possibility for producing district heating varies from 11 MW to 14 MW depending on the temperature of the district heating.

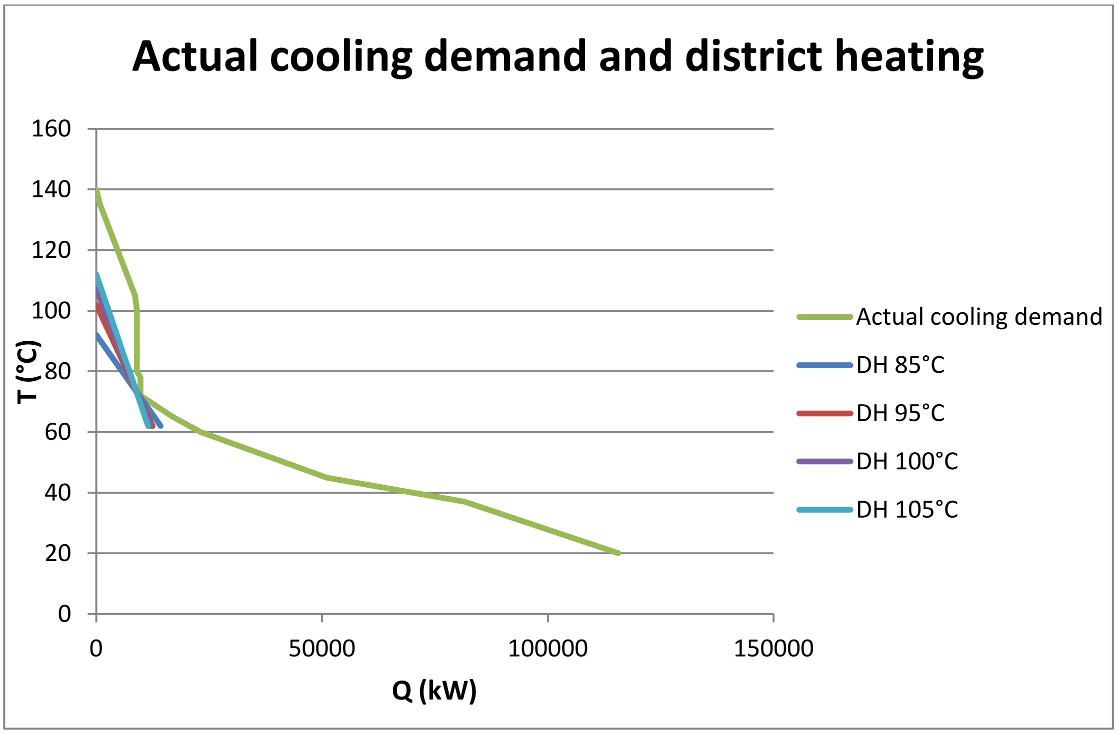

Figure 4.7 *The actual cooling demand curve with the district heating potentials drawn as tangents to the curve.*

The actual cooling demand of 115.6 MW corresponds to a global temperature difference between 22°C and 23°C. The actual heating demand of the process is 216.0 MW and corresponds to a global temperature difference between 16°C and 17°C. The actual heating demand and the actual cooling demand should correspond to the same global temperature difference. The reason why it’s not in this study might be because the actual cooling demand includes cooling of the flue gases from the new boiler which is currently not connected to any heat exchanger. The actual heating demand could be based on that the old recovery boiler uses a heat exchanger connected to the flue gases. If the flue gases from the old recovery boiler is connected to a heat exchanger the amount of heat extracted should be subtracted from the amount of heat in the flue gases from the new recovery boiler. The "actual" cooling demand is then lowered which would correspond to a lower global temperature difference. Even though the corresponding global temperature difference should be lower for the actual cooling demand it is not lower than the global temperature difference for the actual heating demand, which means it is still above 15°C where the process has a double pinch and it's not possible to produce any district heating without violating pinch rules.

Because the system doesn't add up (the actual cooling demand and the actual heating demand doesn't correspond to the same global temperature difference) it means that the heat exchanger network for the process isn't complete. Therefore the advanced curves aren't constructed for this case study.

4.4 Calculated potential with the ratios from Cronholm's report

In order to calculate the potential from the ratio in Cronholm's report the fuel usage of the mill has to be known or estimated. Since it is not known in this case it will be estimated from the steam production. An energy balance has been done over the mill where the high pressure steam production in the recovery boiler is calculated to 212.1 MW and the high pressure steam production in the bark boiler is calculated to 79.6 MW (Isaksson, 2013). This adds up to 291.7 MW. An efficiency of 85% is assumed for both boilers which results in a fuel usage of 343.2 MW. In addition, the mill uses fuel in the lime kiln. The fuel usage in the lime kiln is calculated to 14 MW based on Delin et al. (2005). In total the mill uses 357.2 MW of fuel.

It is unsure whether this integrated pulp and paper mill is counted as a pulp industry or a paper industry. Since that's the only two sub sectors under pulp and paper production used by Statistics Sweden (where the data in Cronholm's report are from) both ratios are used for calculation the potential for district heating.

The ratios are found in *Table 2.2* and are 2.8 % for pulp industry and 3.2% for paper industry. Multiplying these with the fuel usage gives a potential of 10.0 MW if it counts as a pulp industry and 11.4 MW if it counts as a paper industry.

4.5 Comparison

10.0 MW and 11.4 MW are lower than the calculated potential from the GCCs. However, for the GCCs with a global temperature difference of 10°C it's only slightly lower (see *Table 4.2* and *Table 4.3*). A global temperature difference of 10°C is much more realistic than 2°C or 5°C for an existing mill therefore one could say that the two methods give the same result.

This is, however, not completely true. The method where the potential has been calculated from GCCs gives the result with the requirement that only excess heat is used in the production of the district heating and that no pinch rules are violated. This means that no extra fuel has to be used in the process in order to deliver district heating. The GCC method also assumes that there is a way to construct a heat exchanger network that maximizes the use of the excess heat from the process. This is very seldom practical so the results from the GCCs should be lower in practice.

The potential calculated from the ratio most certainty assumes that fuel, steam or other heat above the pinch is used in the production of the district heating since that's the way it's done at some industrial plants today and is therefore included in the ratio. Then the potential requires more fuel usage and is not "true" excess heat. A longer discussion about "true" excess heat will be held in Section 0.

If you would however compare the result from the ratio calculation with the potential for producing district heating from the actual cooling (including the flue gases above the pinch) they are almost the same, 10.0-11.4 MW for the ratio calculation and 11-14 MW for the actual cooling depending on the supply temperature. The ratio calculations most certainty includes "excess" heat above the pinch but so does the actual cooling demand since the flue gases are included.

The results from Glader's three retrofits, 6.8 MW to 12 MW, 5.5 MW to 11 MW and 22 MW respectively, are in the same magnitude as the results from the GCC calculations done in this report and the results from the calculations with the ratios from Cronholm's report. Glader's retrofit does reduce the pinch violations and the steam demand but some of the district heating production is still a pinch violation and is therefore not "true" excess heat either. It should also be noted that the calculations in this report is done with an updated version of the data in Glader's report which includes some more streams as well as updated temperatures and energy content of the streams.

5 Case study 2 – Chemical pulp mill

5.1 Description of the mill

The second mill studied is also a kraft pulp mill. The difference between the mill in the first case study and this mill is that this mill is a pure pulp mill, called market pulp mill, and the one in the first case study is an integrated pulp and paper mill. This does however mean that the description of the pulp part of the mill and the recovery cycle in Section 4.1 above applies to this mill as well.

This mill produces 425 000 ton of pulp each year. It is located close to a saw mill and excess heat from the mill is transported to the saw mill in order to dry the wood. In return the saw mill delivers bark and wood chips. The mill is also connected to the local district heating grid where they deliver 120 GWh/yr, which covers 50 % of the heat demand in that community. The delivered district heating is produced mainly from excess heat in the process but is pitched with low pressure steam when needed. 99 % of the produced electricity and steam at the mill comes from biomass. (Södra Cell Värö, 2010)

5.2 Earlier study of the mill

In 2013 a study was done by Bood et al. (2013) where an energy analysis was performed for different possibilities to convert the mill to a dissolving pulp plant. The production of dissolving pulp is done by extracting the hemicelluloses before the digestion step. The current kraft pulp plant was also analyzed in terms of energy. The result shows that the proposed conversion to a dissolving pulp mill enables higher production of electricity and excess steam than today's kraft mill. It should be noted that since the hemicelluloses is removed from the pulp the pulp yield is lowered. In order to compensate for that and still have the same amount of pulp production the wood intake is increased. For a comparison of the GCC's for the current plant and the future possible dissolving plant, see *Figure 5.1*. The two GCC's has been constructed with the same individual temperature differences for the different streams. The individual temperature differences can be seen in *Table 5.1*. It can be seen that the dissolving plant actually has a lower minimum cooling demand, but the "nose" is moved further to the right which makes the potential for producing district heating higher for the dissolving plant. The reason to why the "nose" is moved is because the stream representing the horizontal line at around 100°C is increased in the dissolving plant, moving the GCC to the right. (Bood, et al., 2013)

Table 5.1 The individual temperature differences for different type of streams. The temperature difference is for that specific side of the heat exchanger, for example a water-water heat exchanger would have a temperature difference of 5°C (2.5+2.5) and a water-steam heat exchanger would have a temperature difference of 3°C (2.5+0.5)

Stream	Temperature difference [°C]
Water	2.5
Other liquid	3.5
Steam	0.5
Flash steam	2
Gases	8

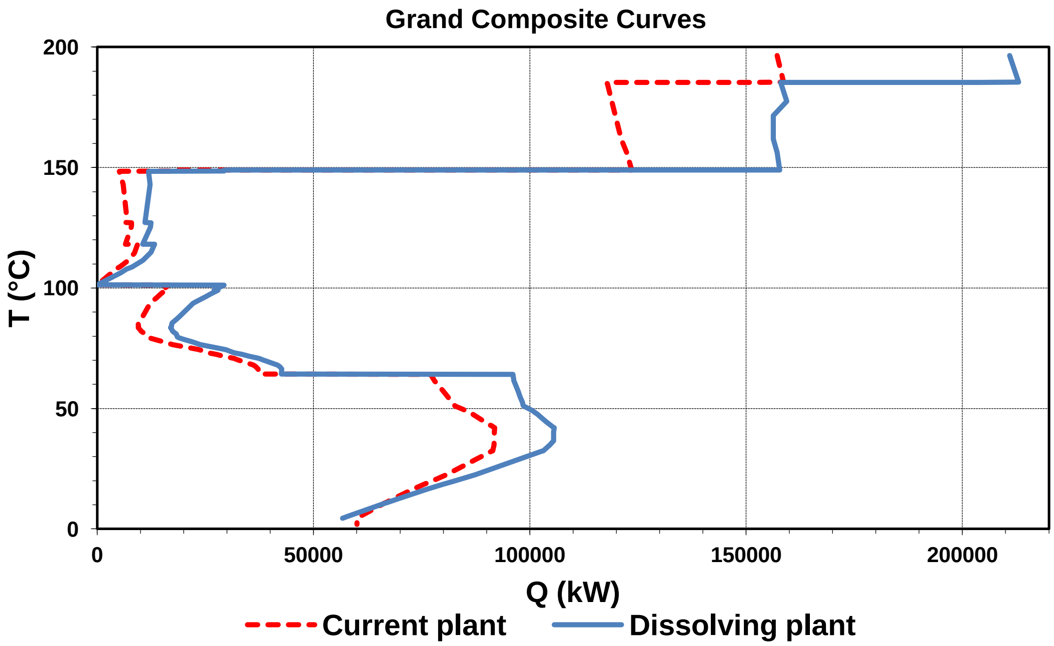

Figure 5.1 A comparison of the GCC's for the current pulp plant and a future possible dissolving pulp plant, both with the same individual temperature differences.

The data used in the report was gathered in the middle of January in 2012 when the production was stable. The weather conditions was deemed representable for a year round production and contact people at the plant made sure the values gathered were representative. Some of the temperatures and flows are however approximated and some of the data weren't available for January and data from November in 2012 were taken instead. (Bood, et al., 2013)

For the dissolving mill the potential for producing district heating with a return temperature of 43°C and a supply temperature of 95°C has been calculated to be 54.3 MW, see *Figure 5.2*. Individual temperature differences have been used for the different streams in the interval of 1°C to 16°C depending on the stream. The temperature difference between the process streams and the district heating is set to 2.5°C on the district heating side. The total temperature difference between the process and the district heating is dependent on the individual temperature differences for the streams heat exchanged with the district heating.

The production of 54.3 MW of district heating from excess heat without violating any pinch rules requires a heat exchanger network that maximizes the energy recovery in the process. This isn't reasonable in an existing plant and therefore the aim for Bood and Nilsson was to show that the current amount of delivered district heating from the mill is possible to be produced with only excess heat (see the red line in *Figure 5.2* below), as opposed to today where low pressure steam is used for part of the district heating production.

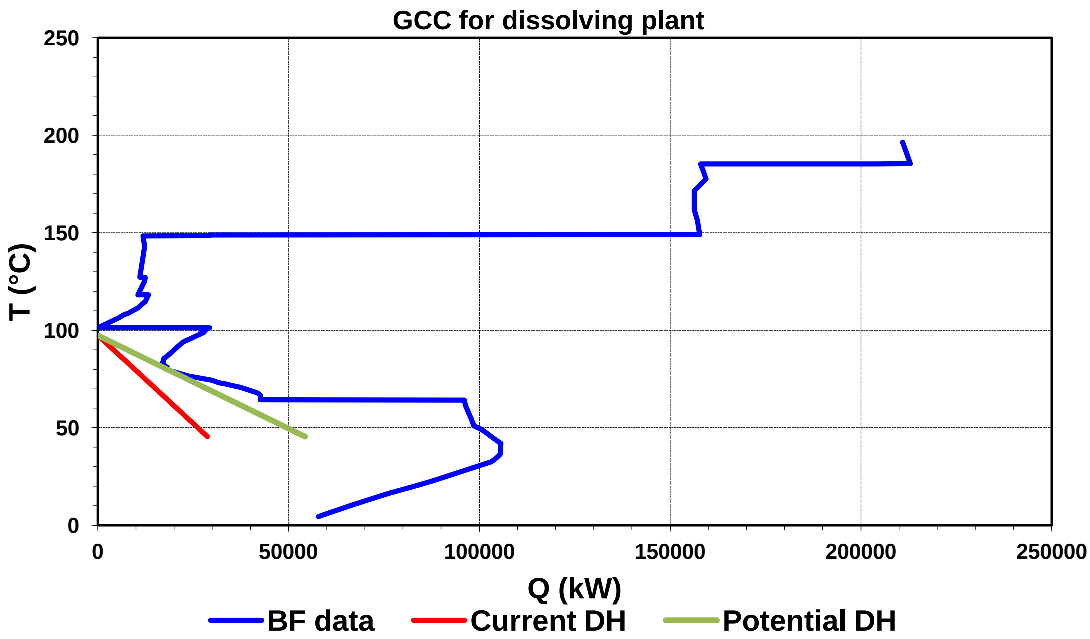

Figure 5.2 *The current amount of delivered DH and the potential amount at the same temperature levels (43°C return temperature and 95°C supply temperature)*

5.3 Pinch analysis

For the pinch analysis the streams from from the report by Bood et al. (2013) are used. The case studied is the existing mill and not one of the alternatives for hemicellulose extraction which was studied in the report by Bood et al. (2013). See Appendix 2 for a table of the streams used.

The potentials for producing district heating can be seen in *Table 5.2*. It can be seen that the pinch temperature of the process is too low to produce any district heating with a supply temperature of 100°C or above in order to have a temperature difference between the district heating and the process of 7°C.

The minimum cold utility demand is increasing with an increased global temperature difference and therefore the potential for producing district heating is also increased since the pinch point is around the same temperature for all of the different global temperature differences.

Table 5.2 *The potential for producing district heating for district heating supply temperatures at 85°C to 105°C and a global temperature difference for the process between 0°C and 15°C, with a temperature difference between the process and the district heating of 7°C.*

Global temperature difference [°C]	**District heating supply temperature [°C]**				**Pinch temperature [°C]**
	85	95	100	105	
0	38.2	23.7	-	-	103
5	42.2	26.4	-	-	101
10	45.5	28.4	-	-	98
15	48.9	30.4	-	-	96

The potential is decreasing for a higher supply temperature and the reason is the "nose" at around 80°C which can be seen in *Figure 5.3* below. The figure is for a global temperature difference of 10°C but the shape of the GCC is the same for 0°C, 5°C and 15°C as well.

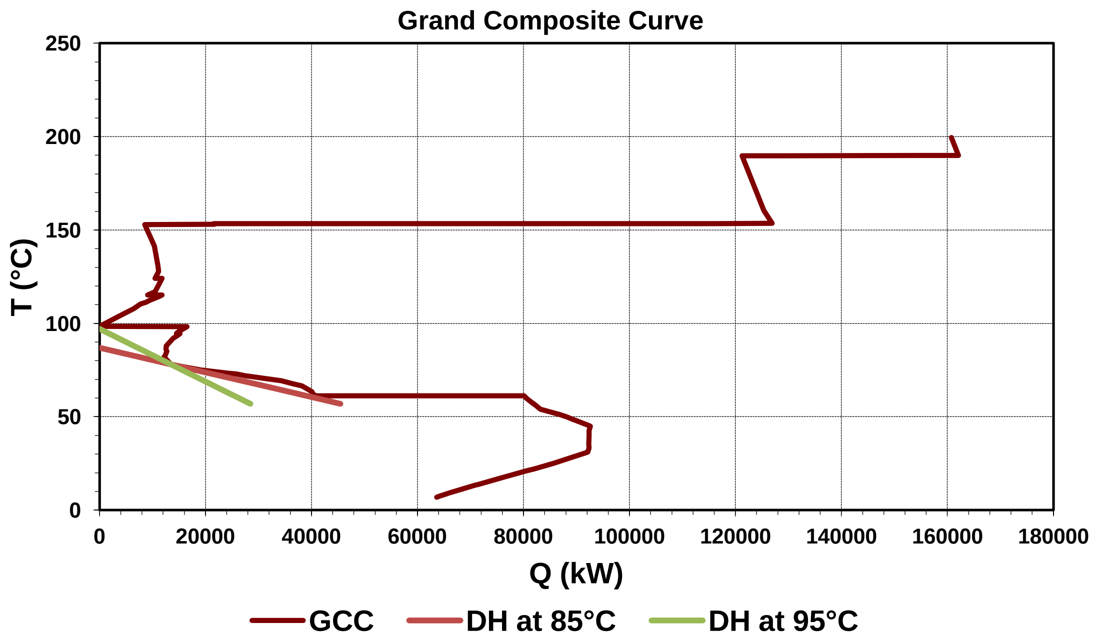

Figure 5.3 *The grand composite curve for a global temperature difference of 10°C with the district heating lines corresponding to supply temperatures of 85°C and 95°C. The pinch temperature is 98.3°C.*

According to Nilsson there are hardly any streams cooled with cold utility. There are some effluent streams that are sent out being cooled in the atmosphere as well as some air streams that are cooled to the atmosphere. All of these streams are however not included in the analysis done by Bood et al. (2013). The streams in the analysis cooled with “cold utility” are two effluent streams cooled with cooling towers to the atmosphere before being sent to the biological cleaning, and one effluent stream currently heat exchanged with the delivered district heating. These streams have starting temperatures of 65°C, 54°C and 77°C and can’t be used to produce district heating without heat from other sources with higher temperatures as well. This means that their actual cooling can’t be used to produce district heating.

The energy content of the three streams adds up to 37.4 MW. Comparing this value with the minimum cold utility from the GCC above in *Figure 5.3*, which is just above 60 MW, there should be more streams that currently are cooled. The warm and hot water demand from the secondary heating system is included in the GCC but the probable explanation is that there is a greater production of warm and hot water than what is needed today and this extra production is not included in the GCC. Since there is not enough information about the existing heat exchanger network including the secondary heating system in the study by Bood et al. (2013) the advanced curves can’t be constructed.

5.4 Calculated potential with the ratios from Cronholm’s report

The current amount of high pressure steam produced in the recovery boiler is 272.5 MW according to the analysis done by Bood et al. (2013). This is the amount of steam produced at normal operating mode. There is a bark boiler at the mill as well but it’s only used around 3 months per year to make up for seasonal variations as well as production variations. The capacity of the bark boiler is 30 MW and assuming it runs at full capacity one quarter of the year 7.5 MW is added to the total steam production. The total steam production is then 280 MW. Assuming an efficiency of 85 % for both boilers results in a fuel usage of 329.4 MW. 20 MW of fuel is assumed to be used in the lime kiln (calculated based on Delin et al. (2005)) which adds up to a total of 349.4 MW of fuel for the mill.

Since this is a pulp mill the ratio used from the report by Cronholm et al. (2009) is 2.8 %, see *Table 2.2*. The potential for producing district heating using the ratio from the report by Cronholm et al. (2009) is 9.8 MW.

5.5 Comparison

9.8 MW from the ratio calculation is much lower than the potentials from the calculations in this report which for a global temperature difference of 10°C and a supply temperature of 95°C is 28.4 MW. Since there are some uncertainties concerning the heat produced in the secondary heating system the potential might be a bit lower if there are more heat used than what is accounted for in the GCC. How much lower is hard to approximate without information about the secondary warm/hot water system.

In the calculations done in this report the highest supply temperature of the district heating that can be produced is 95°C (with a temperature difference between the process and the DH of 7°C) which means that there could be problems producing district heating during the winter when the load is increased and the supply temperatures is increased to overcome the losses in the system. When the majority of the district heating can be produced using excess heat one could however accept using low pressure steam to pitch the temperature during the winter and thus violating the pinch rules.

6 Case study 3 – Mechanical pulp and paper mill

6.1 Description of the mill

The third case study is also a mill in the pulp and paper industry. It’s an integrated pulp and paper mill like Case study 1, but the difference is that this mill produces mechanical pulp instead of chemical pulp. The capacity of the mill is 750 000 ton of paper per year. However, during the last four years the production has been just above 700 000 ton per year.

The different pulps produced at the mill are thermo mechanical pulp (TMP) and recycled pulp (de-inked pulp, DIP). The thermo mechanical pulp is made by heating the wooden chips, timber that has been debarked and chopped to chips, and then grinding them in a refiner. The heating is done to soften the lignin which will make it easier to separate the fibers. The grinding itself generates heat which softens the lignin and the individual fibers are separated from each other. The lignin is not separated from the pulp as is the case when producing chemical pulp. The pulp is screened and cleaned and sent off to the paper machines. The DIP is produced by dissolving the recycled paper in water. The DIP is then filtered and washed before mixed with other kinds of pulp. (Theliander, et al., 2002)

The heat obtained in the refiners is used to produce steam used in other parts of the mill, for example in the three paper machines.

The mill has a steam demand of 103 MW where 69 MW (67 %) of the steam demand is the demand in the three paper machines and 16 MW is the demand at the saw mill connected to the mill. Even though the pulp machines don’t require that much steam they do require energy in the form of electricity to run the refiners. The refiners do however produce steam. The amount of steam produced in the refiners are approximately 54.6 MW. (Isaksson, 2013)

6.2 Earlier study

Isaksson (2013) has already done an energy analysis of the mill where the focus was on increasing the energy efficiency of the mill and thereby lowering the heating demand. The result was that the total steam demand could theoretically be lowered by 7 %. By doing some changes including using effluent streams to preheat the water used in the paper machines the total steam demand could be lowered by 4 %. Pinch technology was the tool used in the analysis and a global temperature difference of 8°C was used.

The study did not include possibilities to make use of any excess heat from the process. Since the focus wasn’t on the excess heat, the heat from the flue gases weren’t included in the study. According to studies done by the mill itself the flue gases contain around 7.5 MW of heat, but at a lower temperature where they already have an excess of heat (around the same temperatures as the effluent streams).

6.3 Pinch analysis

Data from Isaksson’s energy analysis has been used in this report to calculate different potentials for producing district heating with different global temperature differences. Because of confidentiality the streams used are not presented in any appendix for this case study. As in the previous case studies the global temperature differences 0°C, 5°C, 10°C and 15°C has been used and a temperature difference between the process streams and the district heating of 7°C.

The mechanical pulp- and paper mills potential for producing district heating is very low, see *Table 6.1*.

Table 6.1 *The potential for producing district heating for district heating supply temperatures at 85°C to 105°C and a global temperature difference for the process between 0°C and 15°C, with a temperature difference between the process and the district heating of 7°C.*

Global temperature difference [°C]	**District heating supply temperature [°C]**				**Pinch temperature [°C]**
	85	95	100	105	
0	-[1] (5.1)[2]	-[1]	-[1]	-[1]	95.0
5	2.3	-[1]	-[1]	-[1]	97.5
10	-[1]	-[1]	-[1]	-[1]	55.9
15	-[1]	-[1]	-[1]	-[1]	53.4

[1] The temperature of the district heating is higher than the pinch temperature and heat can therefore not be extracted in order to not violate the pinch rules.

[2] The potential is for a district heating supply temperature of 83°C which is the highest possible with a temperature difference between the process and the district heating of 7°C.

The major reason to why the potential for producing district heating is low, or non-existent, is because the pinch temperature of the process is low. The GCC's for the global temperature differences 0°C, 5°C and 10°C can be seen in *Figure 6.1-Figure 6.3*. Comparing the first two figures, the pinch temperature changes by 2.5°C. The major difference between the first two is the "nose" that appears at around 60°C and the steeper slope for temperatures above the nose but below the pinch for the global temperature difference of 5°C. Looking at the third figure, *Figure 6.3,* one can see that the "nose" has become the new pinch point and there is no longer any possibility to produce any district heating at all without violating the pinch rules.

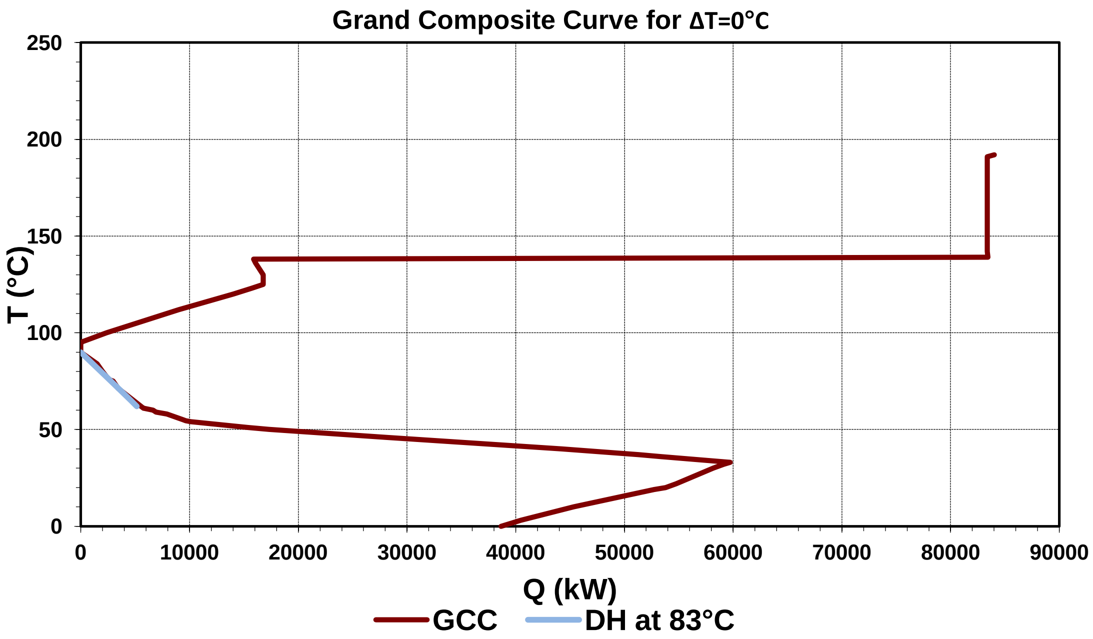

Figure 6.1 *The grand composite curve for a global temperature difference of 0°C. The pinch temperature is 95°C and the highest possible temperature where district heating can be produced without violating any pinch rules is at 83°C (the light blue line)*

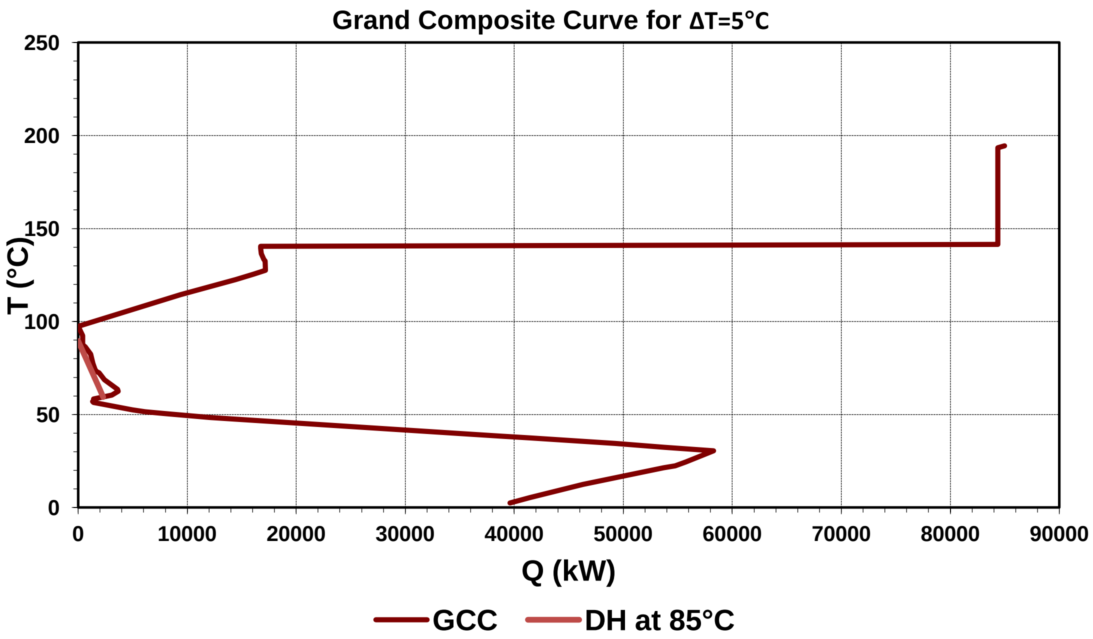

Figure 6.2 *The GCC for a global temperature difference of 5°C. The "nose" at around 60°C and the steeper slope for temperatures above the "nose" (but below the pinch) is the reason to why the potential for producing district heating is low.*

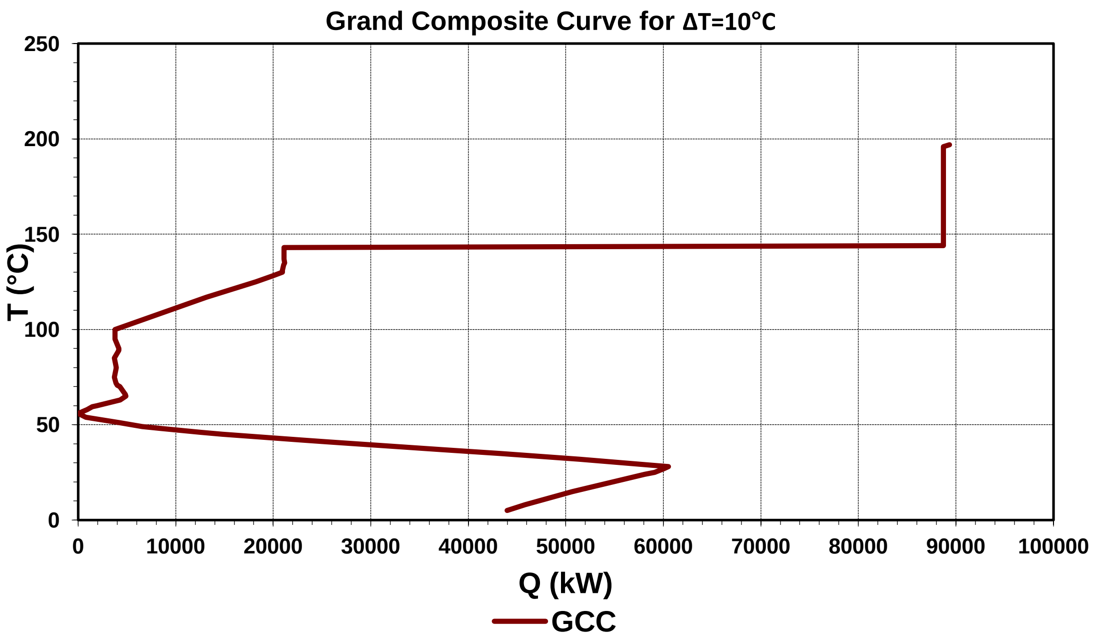

Figure 6.3 *The GCC for a global temperature difference of 10°C where the "nose" from the previous figure has become the new pinch point, with a pinch temperature of 55.9°C. The potential for producing district heating is non-existent.*

The actual cooling of the mill is around 46 MW. The streams included in the actual cooling are effluent streams with a soft target temperature of around 40°C and moist air from the drying machines with a soft target of around 30°C. These streams aren't actually cooled with a cold utility, they are sent out being cooled in the atmosphere. None of the streams being cooled in the atmosphere has a higher temperature than 55°C which means that no district heating can be produced from these streams.

The actual cooling demand corresponds to a global temperature difference of around 13°C and the actual heating demand of 103.3 MW corresponds to a global temperature difference of 28°C. The two demands should correspond to the same global temperature difference. The heating demand corresponding to the same global temperature difference as the actual cooling demand is 92 MW, and the cooling demand corresponding to the same global temperature difference as the actual heating demand is 58 MW. Either some streams are missing in the actual cooling demand or the heating demand has streams included that are not included in this analysis. Since there are uncertainties about the streams included in the analysis and since a heat exchanger network is missing the advanced curves aren't constructed for this case study.

6.4 Calculated potential with the ratios from Cronholm's report

According to Isaksson's report the current steam consumption for the mill is 103.3 MW. Some of the steam is produced in the refiners and the rest is produced in a boiler which uses bark as the main fuel input. 54.6 MW of the steam is produced in the refiners with electricity as fuel. Since electricity isn't defined as fuel in the report by Cronholm et al. (2009) that amount has to be withdrawn which leaves 48.7 MW of steam that has to be produced in the boilers. Assuming an efficiency of 85% for the boiler results in a fuel usage of 57.3 MW.

Since this is an integrated pulp and paper mill it is unclear if it counts as a pulp mill or a paper mill in the statistics used in the report by Cronholm et al. (2009). Therefore both ratios are used, same as the chemical pulp and paper mill in Section 0. The ratios are 2.8 % for a pulp mill and 3.2 % for a paper mill. The resulting potentials are 1.6 MW and 1.8 MW respectively.

6.5 Comparison

Even though the GCC calculations doesn’t show any potential at all for certain global temperature differences and supply temperatures of the district heating the calculation done with the ratio from the report by Cronholm et al. (2009) doesn’t show any big potential either. As said in Section 6.2 the heat in the flue gases isn’t included in the analysis. Even though they contain around 7.5 MW most of the heat is around effluent temperatures according to the report done. However some heat, maybe around 1 MW, could be at a high enough temperature for producing district heating and in that case the ratio calculation is in agreement with the reality if you were to violate the pinch rules and produce district heating with the flue gases.

One important thing to keep in mind is that the ratios from the report by Cronholm et al. (2009) apply to both chemical pulp and paper mills and mechanical pulp and paper mills. These two ways to produce pulp and paper are very different and depending on the industrial plants included in calculation to come up with the ratio it is more accurate to use it only for one of the ways. For example if there are mainly chemical pulp and paper mills included in the calculation to come up with the ratio it shouldn’t be applicable to mechanical mills.

Since chemical pulp mills can be self sufficient energy wise due to the recovery cycle it is not hard to believe that most of the pulp and paper mills in this country delivering excess heat in the form of district heating are chemical pulp and paper mills. Most mills use fuel (indirectly from steam production or directly) to pitch the delivered district heating. This is also a reason to why chemical pulp mills might be more willing to produce district heating since they have their own fuel (black liquor and bark from the debarking), which for most market pulp mills is more than enough to satisfy their demand. Even though mechanical pulp mills have the bark from the debarking as well, it is not enough to cover the demand and they might not be willing to buy more fuel in order to produce district heating. Then the ratio isn’t applicable to mechanical pulp and paper mills.

Even though the result from the ratio calculation from this mechanical pulp and paper mill only is 1.6-1.8 MW higher than the potential from the GCC calculations (which was zero for most cases), the pinch temperature for higher global temperature differences than 10°C is so much lower than what is needed to produce district heating that “only” 1.6-1.8 MW is still far from attainable.

7 Case study 4 – Steel mill

7.1 Description of the mill

The steel mill in this case study is a mill which produces steel slabs from iron ore. The general layout of the mill can be seen in *Figure 7.1*. In reality the coking plant is placed more than 2 km from the other parts of the plant.

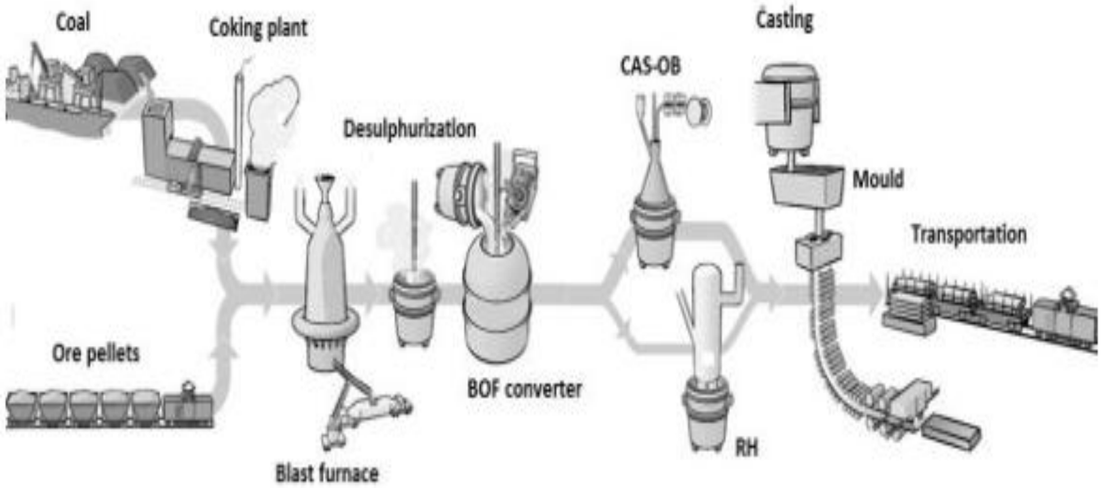

Figure 7.1 The general layout for the steel mill with the raw materials coal and ore pellets.

7.1.1 Coking plant

The first part of the process is the coking plant where coal is converted into coke. The battery in the coking plant consists of 54 ovens. The coal is heated up to 1100°C for around 18 h in order to convert it into coke. 50 % of the coke gas that is produced in the same process is recirculated and burned in the ovens. Before transporting the coke it is quenched using large amounts of water where one third is evaporated and let out in the atmosphere. The rest of the water is gathered and reused. (Isaksson, et al., 2010)

The coke gas that is produced in the coking contains contaminants that need to be removed before recirculating the gas. The contaminants include tar, naphthalene, benzene and sulphur which are removed in the gas cleaning site during different steps. The main source for excess heat in the coking plant is in the gas cleaning site. The flue gases from the battery are used to preheat the combustion air already and are left out (except for the residual heat after preheating of the combustion air) in the pinch study since it is unlikely that other usage would be more favourable. The main heat sources are therefore from the gas cooler, the naphthalene washer, the ammonia stripper, the sulphur stripper and the benzene washer. (Isaksson, et al., 2010)

7.1.2 Blast furnace and steel plant

Pig iron is produced in the blast furnace by reducing iron ore with coal and coke. In the blast furnace blast air is supplied at the bottom. The highest temperature in the blast furnace is at the bottom where the blast air is supplied and the temperature there is around 2200°C. Because of the high temperatures water is used to cool the equipment. The blast air is heated to just above 1000°C in stoves which use coke gas and blast furnace gas (which is obtained in the reduction process) as fuel. (Isaksson, et al., 2010)

The molten pig iron is extracted in the bottom of the blast furnace and is transported to the steel plant. The steel plant consists of four steps. The first step is a desulphurisation step. Calcium carbide and magnesium is added and reacts with the sulphur. The reactant is slag which floats up on the surface and can then be removed. The second step is where the pig iron is refined to steel. This is done by removing some of the carbon content which is removed in gas form. Some of this gas is reused as fuel. (SSAB, 2011)

The converters in the second step are of LD-type and at this plant there are two of these. This is a batch process where the converters are alternately loaded for 40min and then running for 20 min. The off gases from the converters are used to produce steam which reduces the temperature from 1600°C to around 1200°C. The steam is collected in steam domes in order to transfer it continuously to other parts of the process even though the production of the steam is not done continuously. A lot of cooling is needed in this part of the process, some of it is done directly and some is done in closed systems using cooling water on the other side of the heat exchanger. (Isaksson, et al., 2010)

The third step in the steel plant is where the steel is adjusted to the right temperature and quality depending on the usage. This is done by adding different alloys. Steel with even lower carbon content then normally can be created as well in this step. This is done by creating a vacuum which makes the remaining carbon to leave the steel. The vacuum is created using steam. (Isaksson, et al., 2010)

The fourth and final step in the steel plant is the casting. In order to cool the molten steel of 1600°C water is used. Four water-cooled plates gives the molten metal a solid crust and is then cut into slabs with some further cooling. However it’s only cooled to around 800°C with water and then the steel is piled up on cooling beds releasing the rest of the heat to the surroundings. The cooling water used in this step is in a closed system using sea water to cool it down.

7.1.3 Hot and cold utility used

The plant is situated close to a river in the north of Sweden so the cooling water used is taken from that river. The whole plant (coking plant, blast furnace and the steel plant) shares cooling water system.

The hot utility, steam, used in the coking plant is produced in their own steam boiler which uses coke oven gas as fuel.

Hot utility needed at the rest of the plant is produced in the second step at the steel plant. Some high pressure (15 bar) steam is also delivered from a company close to the plant. (Isaksson, et al., 2010)

7.2 Earlier study

A study done to evaluate possibilities to implement pinch analysis in the steel industry has been done on this particular plant by Isaksson et al. (2010). In the study several pinch analysis was done on the different parts of the plant.

7.2.1 Method

Since the coke plant is more than two kilometers away from the other parts of the plant Isaksson et al. (2010) decided to split the pinch analysis into two parts, one containing the coke plant and one containing the rest of the plant, since it's not practical to heat exchange streams that are that far away from each other.

The two different pinch analyses were conducted in three steps each. The first one was done based on the current situation. The second step included waste heat that is currently not being used and is therefore not connected to any heat exchanger, for example flue gases. The third and last step includes some process modifications which would increase the efficiency of the process.

Only streams which directly can make use of excess heat are taken into account in the analyses. This means that, as the author describes it, "diffuse" sources such as hot slag and heat from cooling beds are not included.

Isaksson et al. (2010) does not calculate the amount of possible district heating that could be produced. He does however make GCC:s and calculate the minimum cold utility needed for the different cases. In this study the focus is on the possibility for district heating production and that will be calculated from his GCC:s. So the results below are not directly from his study, it's calculations based on his GCC:s. Isaksson et al. (2010) assumed a global temperature difference of 10°C in his analyses. The flue gases in step 2 and 3 for the coke plant have a higher temperature difference since most of the heat used in the process is steam and in order to produce steam from the flue gases in an intermediate step the temperature difference is increased.

Most of the data is from control room screen shots and variations (seasonal) over the year are not taken into account in this analysis. For the blast furnace and steel plant part some cooling is needed to cool hot equipment. This cooling is represented as if heat is being removed from the cooling water since it's not possible to include hot equipment as a stream.

7.2.2 Results

The constructed district heating curves are done for district heating temperatures of 85°C, 95°C, 100°C and 105°C with a temperature difference between the process and the district heating of 7°C. The return temperature of the district heating is set to 55°C.

7.2.2.1 Coke plant

The potential for district heating production in the coke plant varies from 1.5 MW to 4.5 MW, see *Table 7.1*.

Table 7.1 The district heating potentials in MW in the coke plant for different supply temperatures for the three different steps. All of the different steps are for a global temperature difference of 10°C.

Different step	**District heating supply temperature [°C]**			
	85	95	100	105
Step 1	3.0	1.8	-[1]	-[1]
Step 2	4.5	2.9	2.6	1.7
Step 3	3.0	1.9	1.6	1.5

[1] The temperature of the district heating is higher than the pinch temperature and heat can therefore not be extracted in order to not violate the pinch rules.

Step 1 is as said the process with streams in existing heat exchangers which means that not all hot streams are included.

In step 2, however, hot streams that are available in the process but not connected to a heat exchanger today are included. There are two added streams. The first is extended cooling of the flue gases. The second stream added is washing water which cools the coke oven gas in order to minimize the risk for explosion and to remove some of the tar. Adding these two streams with a heat surplus with one of them being below the pinch is the reason why the potential for district heating is higher in step 2 than in step 1. The pinch temperature is also increased which means that district heating with a higher supply temperature can be produced for step 2 compared to step 1.

Step 3 includes process modifications. The process modifications done is to extract some heat from the coke oven gas at 700°C before it is washed (and cooled) with washing water at around 70°C in order to remove the tar. The coke oven gas is assumed to be cooled to 450°C in order to not have tar condensing in the heat exchanger. This means that the washing water that removes the tar used in step 2 will have a lower temperature lift.

The added hot streams in step 3 do not increase the potential for district heating since the extracted heat from the coke oven gas has a temperature above the pinch. The stream does therefore not contribute in increasing the cold utility demand, instead it decreases the hot utility demand (by 3.5 MW). The washing water to remove the tar has a temperature below the pinch temperature but since the temperature lift is lowered compared to step 2 the cooling demand is lowered. This is the reason why the district heating potential is lowered in step 3 compared to step 2.

7.2.2.2 Blast furnace and steel plant

For the rest of the plant, the blast furnace and the steel plant, the potential for district heating is a lot higher than for the coke plant. The potential varies from 3.3 MW to 23.6 MW, see *Table 7.2*. Looking at the GCC's in *Figure 7.2* one can see that above the pinch the three steps look almost the same, but below the pinch there are big differences in temperature of the excess heat.

Table 7.2 The district heating potential in MW in the blast furnace and the steel plant for different supply temperatures for the three different steps. All steps with a global temperature difference of 10°C.

Different step	District heating supply temperature [°C]			
	85°C	95°C	100°C	105°C
Step 1	3.7	3.4	3.4	3.3
Step 2	15.4	15.4	15.4	15.4
Step 3	23.6	23.6	23.6	23.6

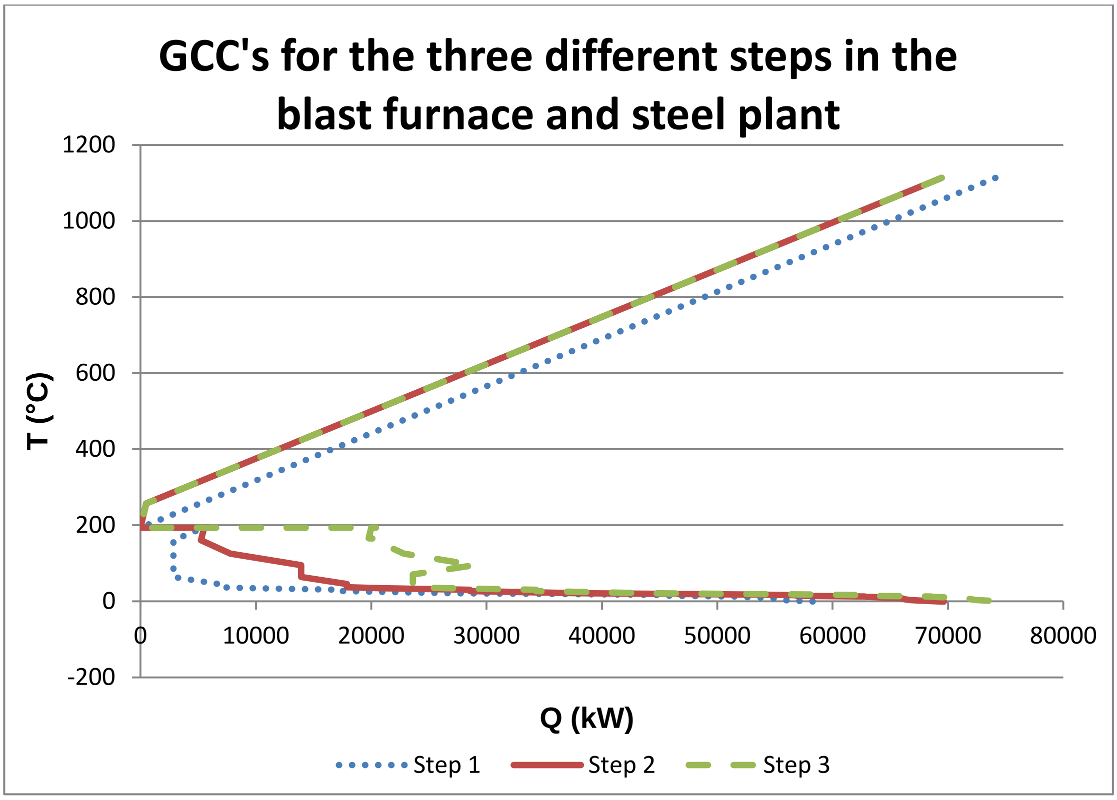

Figure 7.2 The three GCC's for the three different steps, all with the same global/(individual) temperature difference.

The difference between step 1 and step 2 is that flue gases from the hot stove and blast furnace gas are included as hot streams. Since the pinch temperature for this part of the plant is just below 200°C these two streams contribute with a lot of heat below the pinch which increases the potential for district heating.

In step 3 the heat in the off gases from the LD-converters is utilized more before filtering the gas. The gas stream can however not be inserted directly in the GCC since the production of the gas isn't continuous. The gas is used to produce steam and the heat is therefore inserted as an increased high pressure steam stream and a small medium pressure steam stream. The high pressure steam has the same temperature as the pinch and the medium pressure steam a temperature below the pinch which means that they can both be used for producing district heating and the potential is therefore increased in step 3.

In order to understand why the district heating potentials aren't increasing when the temperature of the district heating is decreased, see *Figure 7.3*. One can see that all of the district heating lines hit the GCC at the return temperature of 55°C. There are no "noses" or steep slopes touching the district heating lines before the return temperature. The figure below is for step 3 and even though the GCC doesn't look the same for step 2 the same thing occurs at the return temperature of the district heating. For step 1 there is a "nose" just above the return temperature which decreases the potential some for higher district heating supply temperatures.

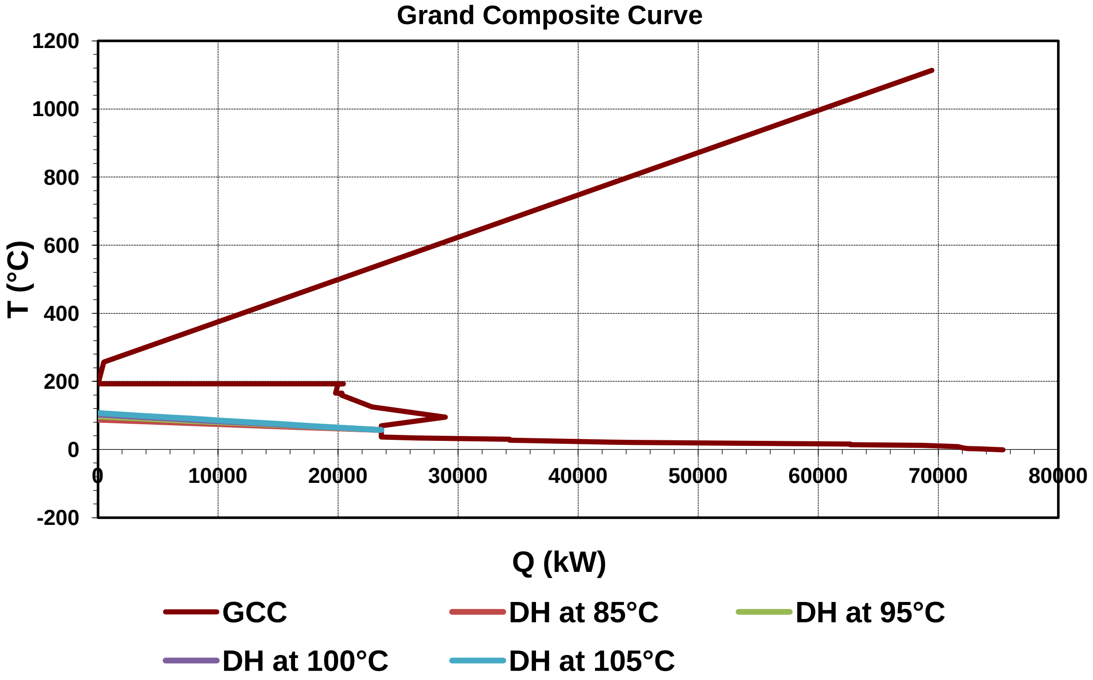

Figure 7.3 *The grand composite curve for step 3 with a global temperature difference of 10°C. All four of the district heating lines lie almost on top of each other.*

The long horizontal line at almost 200°C is the high pressure steam produced in the LD-converters, see Section 7.1.2. The steam together with the flue gases is the main source of excess heat at a high enough temperature to produce district heating for step 1 and 2 as well. The amount of steam produced in the LD-converters are changing in the different steps and is the main reason to why the potential is different in the three cases. The steam is not produced continuously but in order to include it in the GCC it has been assumed to be a continuous stream. Isaksson et al. (2010) also mentions in the report that this steam could be used to produce electricity. The steam could either produce electricity in a condensing turbine or it could produce both electricity and heat in a backpressure turbine. If it were to be produced in a backpressure turbine district heating could still be produced, though not as much.

7.3 Pinch analysis

Data from the study by Isaksson et al. (2010) described above will be used in this study's pinch analysis, see Appendix 3 for a table of the streams. Since the two parts of the whole plant are far apart they will be analyzed individually the same way Isaksson et al. (2010) did. It's not practical to have pipes back and forth from the two parts just in order to exchange heat and produce district heating.

Several different scenarios have already been accounted for in the study by Isaksson et al. (2010) and the pinch analysis done in this study is done to get some complementary data on the potential for district heating. As said above Isaksson assumed a global temperature difference of 10°C in his analyses (except for the flue gas which had a higher temperature difference to account for some process details) but in this study four different global temperature differences will be used, 0°C, 5°C, 10° and 15°C. The flue gas stream which has a different temperature difference than the global one in the study by Isaksson et al. (2010) will keep the value when the global temperature difference varies in this study. The GCCs for the different global temperature differences will be done for step 2 in the study by Isaksson et al. (2010) for the two different parts of the plant to include all the excess heat streams without making major changes to the process.

Table 7.3 The district heating potentials in MW for different supply temperatures for the different global temperature differences at the coke plant and the rest of the plant (blast furnace and the steel plant).

Global temperature difference [°C]	**District heating supply temperature [°C]**			
	85°C	95°C	100°C	105°C
coke 0°C	4.4	2.8	2.5	1.5
coke 5°C	4.4	2.9	2.5	1.6
coke 10°C	4.5	2.9	2.6	1.7
coke 15°C	4.5	3.0	2.6	1.8
rest 0°C	14.6	14.6	14.6	14.6
rest 5°C	15.0	15.0	15.0	15.0
rest 10°C	15.4	15.4	15.4	15.4
rest 15°C	16.2	16.2	16.2	16.2

The resulting potentials for district heating production can be seen in *Table 7.3* above. For the coke plant the potential doesn't change much when the global temperature difference is varied. The reason can be seen in *Figure 7.4* below which is a demand curve. The demand curve shows that neither the heat demand nor the cool demand changes much depending on the global temperature difference. The GCC's for the different global temperature differences do also almost look the same which can be seen in *Figure 7.5*. No direct change in the cooling demand or in the shape of the GCC for the different global temperature differences explains why the potential for producing district heating is almost the same as well.

The difference between the potentials for different district heating supply temperatures is because of the big "nose" at around 100°C which can be seen in *Figure 7.5*. This "nose" causes the lines representing the district heating being heated from 55°C to 85-105°C to have different slopes in order to only tangent the GCC and not crossing it.

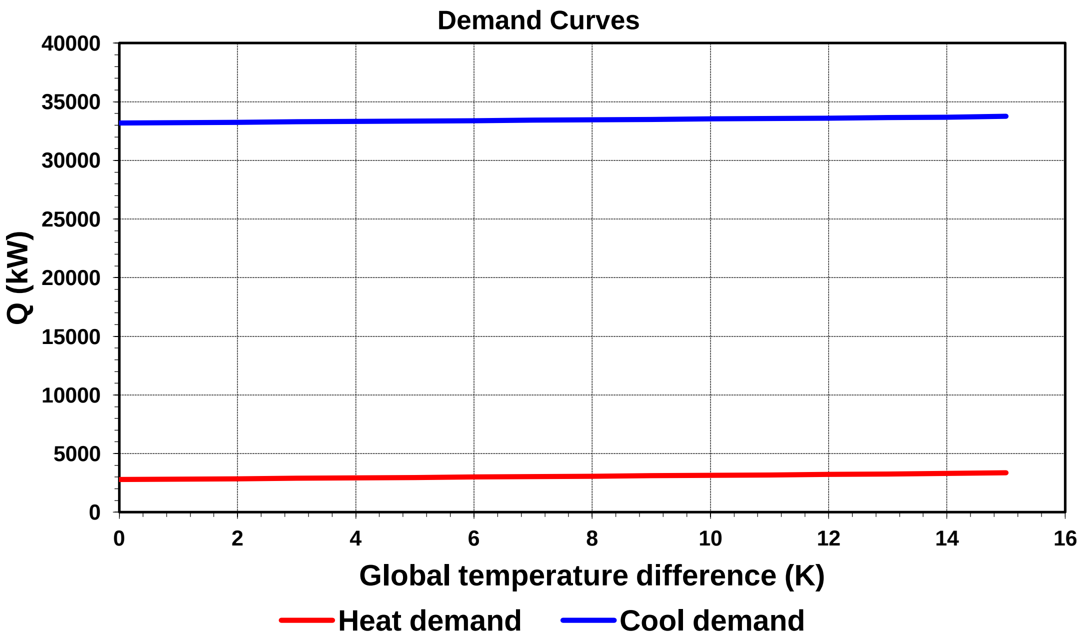

Figure 7.4 The demand curve for the coke part of the plant.

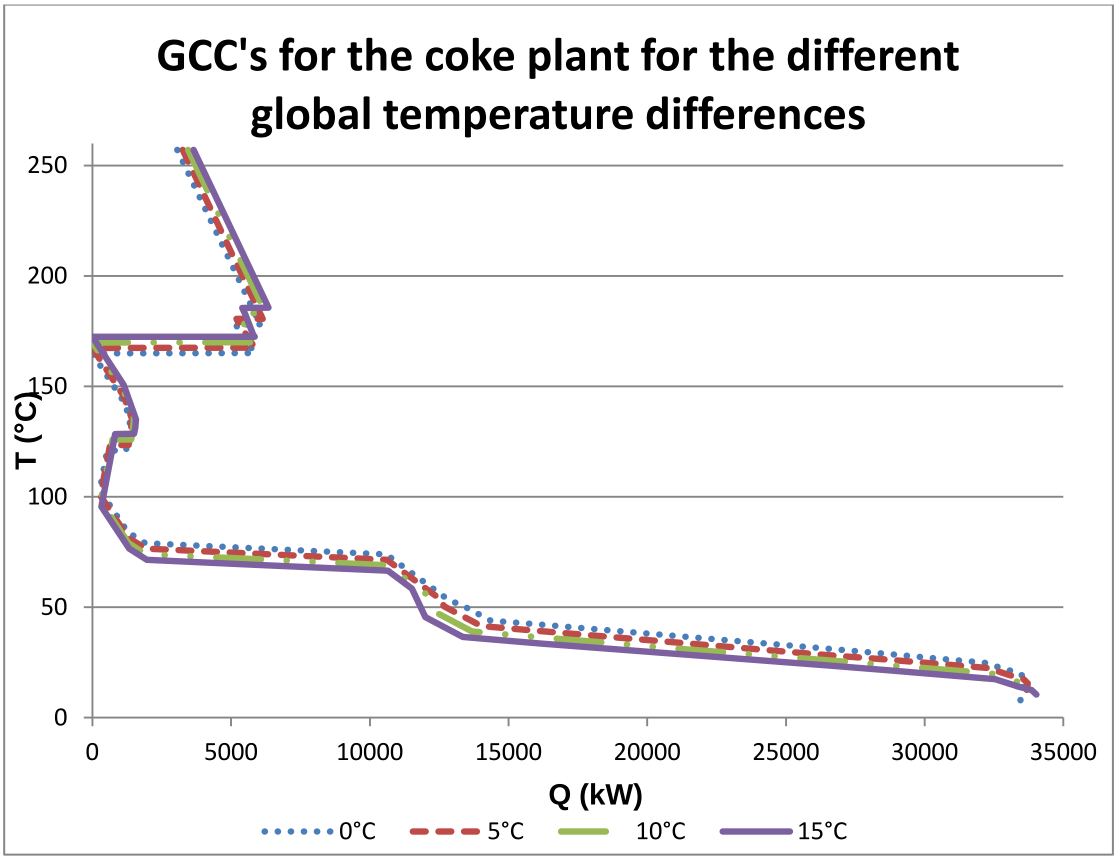

Figure 7.5 *The GCC's for the different global temperature differences 0°C, 5°C, 10°C and 15°C for the coke plant.*

For the rest of the whole plant (blast furnace and steel plant) the potential doesn't change at all when you vary the district heating temperature and the explanation is the same as in Section 7.2.2.2 and *Figure 7.3*, the point of the district heating return temperature is at a point without "noses" on the GCC which can intersect with the district heating lines. The potential does however increase with increasing global temperature difference which is in line with what you could expect looking at the demand curve in *Figure 7.6*. An increase in the global temperature difference increases the cold utility demand. And without any "noses" in the GCC and with a pinch temperature (around 200°C) much higher than the district heating supply temperature the increased cold utility demand results in an increased potential for district heating as well.

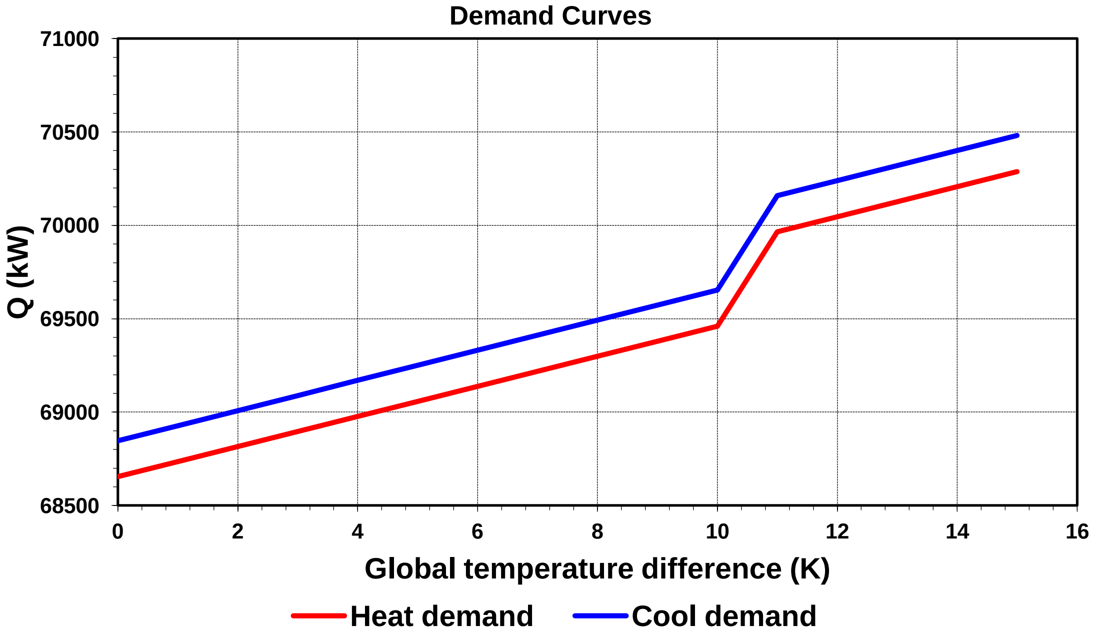

Figure 7.6 The demand curve for the blast furnace and steel plant.

The actual cooling demand of the coke plant (corresponding to step 1, the actual heat exchanger setup) is 25.7 MW. However the highest temperature of the streams that needs cooling is 84°C and can't be used to produce district heating. By including the heat in the flue gases that is not connected to any heat exchanger today (corresponding to step 2 used in this section) one can produce district heating, see *Figure 7.7* which shows the actual cooling curve including the flue gases. The potential for producing district heating from the cooling demand is between 7.2 MW and 11.0 MW for the different supply temperatures.

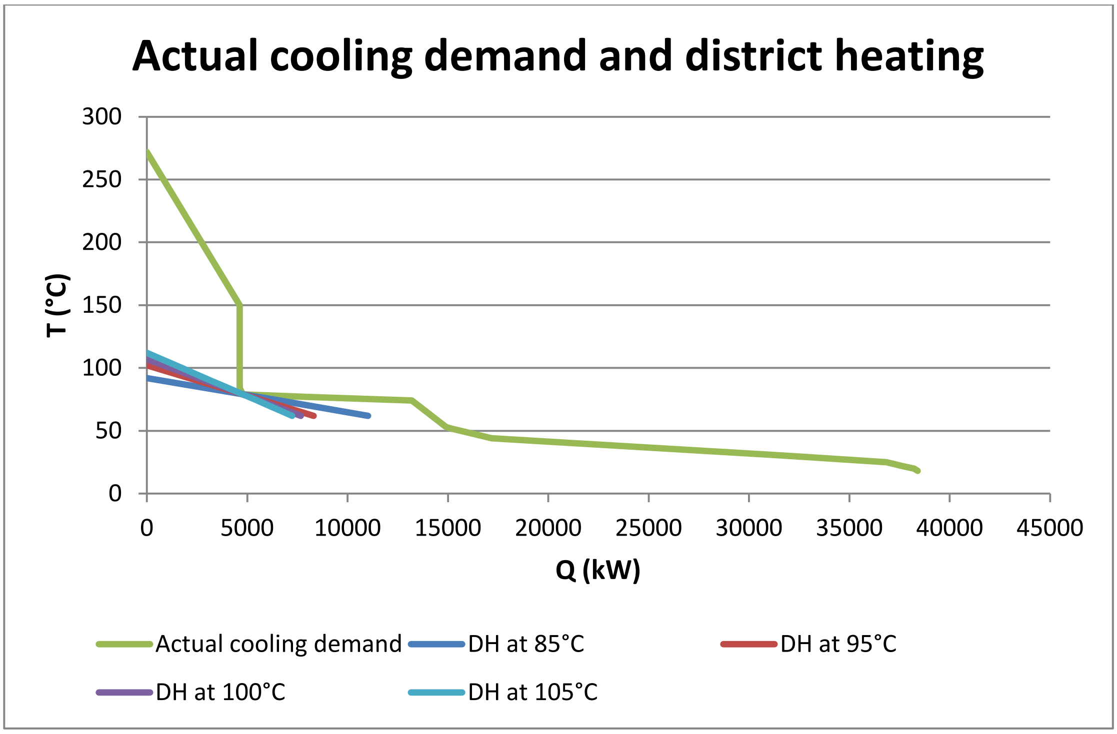

Figure 7.7 *The actual cooling demand curve for the coke plant, including the heat from the flue gases, with the district heating potentials drawn as tangents to the curve.*

For the rest of the mill, the blast furnace and steel plant, the actual cooling demand curve is a bit harder to construct. In the blast furnace the cooling taking place is cooling of equipment such as air nozzles, hot stoves, furnace base etc. In the steel plant the cooling taking place is cooling at the LD-converters, cooling at the casting and cooling of engines. The total cooling demand from these sources is 51.8 MW. The cooling from these parts of the process are however represented as heat being removed from the cooling water which means that there is no information on the temperature of the heat source. The molten metal for example is of a much higher temperature than 30-40°C which is the temperature of the cooling water used. None of the cooling water streams have a high enough temperature to produce district heating. One could however believe that the temperatures of the cooling water could be increased to around 100°C in order to produce district heating while still keeping a high enough temperature difference to the media being cooled. However, the cooling occurring in the blast furnace should not be changed without thorough investigation on how the increased temperature of the cooling water affects the safety of the cooling since it's very important that there is no risk for explosions or other safety risks. At the steel plant there is also a risk increasing the cooling water temperature at the LD-converters according to a study by Andersson et al. (2009). The streams left where the cooling water temperature could be increased without risking any safety is cooling at the casting. There could however be technical difficulties cooling the plates with water at a higher temperature since it probably could change the quality of the steel depending on how it's cooled. Utilizing the heat from where the 800°C slabs are piled up on cooling beds is also a source of more excess heat. However, there are technical issues on how to best extract the excess heat. In this part it is important with a slow cooling since it affects the quality of the steel according to Andersson et al. (2009). In the study by Andersson et al. (2009), producing electricity from the excess heat at the cooling beds seems promising, so one might draw the conclusion that there should be technical solutions good enough to utilize the excess heat to produce district heating as well.

Since it is very unclear whether one can increase the temperatures of the cooling water streams or not they are not changed in this study. One can however bear in mind that there could be more excess heat to utilize in the process.

Including the flue gases from the hot stove and the blast furnace gas (corresponding to step 2) as cold streams in the actual cooling demand results in a potential for producing district heating of 17.2 MW, see *Figure 7.8*.

For both cases, the coke plant and the rest of the mill, it should be noted that even though the heat from the flue gases are ventilated to the atmosphere today and is included in the actual cooling in these calculations, they have temperatures above the pinch and could therefore be used to lower the hot utility demand instead.

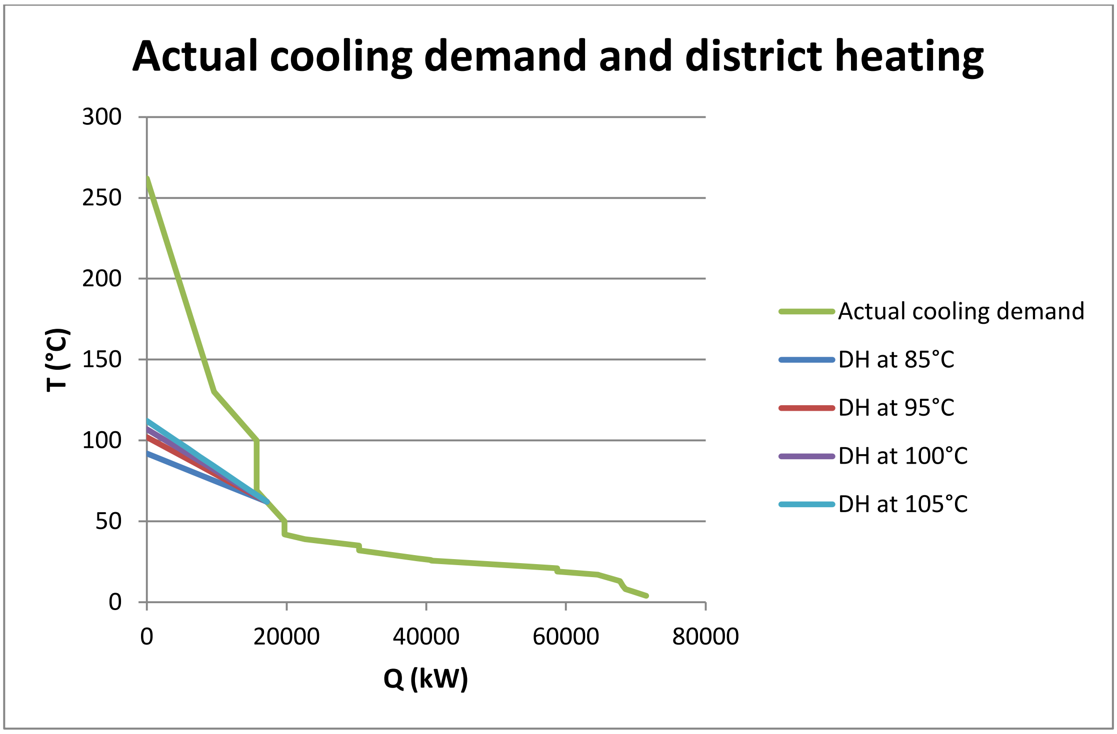

Figure 7.8 *The actual cooling demand curve for the blast furnace and steel plant, including the heat from the flue gases from the hot stove and the blast furnace gas, with the district heating potentials drawn as tangents to the curve.*

Since information is lacking about the heat exchanger network the advanced curves aren't constructed for this case study.

7.4 Calculated potential with the ratios from Cronholm's report

The ratio for the sub sectors production of iron, steel and ferro-alloys, manufacture of iron and steel pipes and other primary processing of iron and steel under the steel and metal production from the report by Cronholm et al. (2009) can be found to be 2.5 % in *Table 2.2*.

The fuel usage at this steel mill is mostly their own gases from the coke oven and the blast furnace. The total consumption of gases in 2010 was 1970 GWh divided in 779 GWh for the coke plant and 1191 GWh for the rest of the plant (1087 GWh for the blast furnace and 104 GWh for the steel plant) (SSAB, 2010).

The mill has some other smaller energy usage as well such as LPG, oil, and bought steam among others. Including these, the total fuel usage of the mill adds up to 2049 GWh.

Multiplying the energy usage with the ratio from the report by Cronholm et al. (2009) results in a district heating potential of 51.2 GWh. Assuming an annual production time of 7800 h results in a potential of 6.6 MW.

7.5 Comparison

Since the coke plant and the rest of the plant are so different and the ratio is only found for a whole sub sector the potential from the ratio calculation was done for the whole mill.

The potential for the coke plant varies from 1.8 MW to 4.5 MW and the potential for the rest of the plant varies from 14.6 MW to 16.2 MW. Adding these potentials will result in a much higher potential than the 6.6 MW from the ratio calculation. The main reason for this is the high potential in the rest of the plant (the blast furnace and steel plant). Most of this potential is from steam produced in the LD-converters which aren’t running continuously and might be hard to exploit.

Another reason is that the ratio is calculated from current district heating deliveries in similar industries. Step 2 which was the one used in the calculations in this report includes utilizing excess heat to a greater extent than what is done today. Step one, however, only contains the streams currently connected to a heat exchanger. Looking at the first row in *Table 7.1* and *Table 7.2* one can see the potential for Step 1. Adding the first row in *Table 7.1* with the first row in *Table 7.2* one almost get the same result as the 6.6 MW from the ratio calculation.

The potential from the actual cooling load looks very similar to the potential from the GCC’s. The potentials from the actual cooling load is only slightly larger and the reason is that most of the streams included in the actual cooling load is streams with a heat excess below the pinch, except for the flue gases that makes the potentials slightly larger.

As a conclusion one can say that the result from the ratio calculation is consistent with how the stream network looks like today but there is room to improve the process and utilizing more excess heat. Or as an alternative using the steam produced in the LD-converters to produce electricity depending on the demand.

8 Case study 5 – PVC plant

8.1 Description of the PVC plant

The PVC plant produces PVC (polyvinyl chloride) from sodium chloride in a three step production process.

In the first step chlorine is obtained from the sodium chloride through electrolysis. Chlorine gas is formed at the titanium anode and sodium at the mercury cathode. When the sodium is washed off from the mercury with water, hydrogen gas is produced together with sodium hydroxide. The sodium hydroxide is sold and so is some of the hydrogen gas. Most of the hydrogen gas is, however, used in the plant's boiler as fuel for steam production. (INEOS ChlorVinyls, 2009)

The chlorine gas produced is transported to the next step of the plant, the VCM unit where vinyl chlorine monomer is produced. Ethylene is bought from a nearby plant and reacts together with the chlorine, from the first step, to produce dichloroethane (EDC). The EDC is heated in a cracking oven to around 500°C where the EDC reacts to VCM and hydrochloric acid. The hydrochloric acid is reacted with ethylene in the oxi-reactors where more EDC is produced and transported to the cracking oven. The VCM is gas with a boiling point at -14°C. The gas is condensed under pressure to a liquid before being transported to the third and last step of the plant, the PVC unit. (INEOS ChlorVinyls, 2009)

In the PVC unit the VCM is mixed with water in reactors and is there polymerized to PVC. The PVC is filtered and dried and the end product is a white powder. (INEOS ChlorVinyls, 2009)

The total energy demand in 2009 for the plant was 500 GWh of electricity and 420 GWh of fuels. 70% of the electricity is used in the first step, the electrolysis, to produce chlorine gas (INEOS ChlorVinyls, 2009). The second step, the VCM unit, is the most steam consuming part of the plant according to Lindqvist (2011). 240 GWh of steam is used and 110 GWh of fuels is needed in this step (INEOS ChlorVinyls, 2008). A lot of cooling is needed in the second step too. The cooling is needed for cooling of the streams that are separated in columns and condensed as well as for cooling of the reactors.

8.2 Earlier study

A previous energy analysis has been done at the plant by Lindqvist (2011). The aim of the study was to identify pinch violations and increase the energy efficiency of the plant. Since the VCM plant is the most steam consuming part, that is the part of the plant studied by Lindqvist. The first step of the plant, the chlorine unit, uses mercury which will be prohibited in a near future and therefore INEOS is planning to rebuild the chlorine unit. The capacity of the chlorine unit will increase and will therefore also affect the other parts of the plant, including the VCM unit. Lindqvist's study has been on the future plant with an increased capacity.

Even though an energy analysis of the future plant was the objective of the study the current plant setup was also analyzed. Studies on how to make use of the excess heat from the current VCM unit was not performed. Studies on how to make use of excess heat from the VCM unit in the PVC unit for the future plant was however done. The

PVC plant has a demand of roughly 7 MW of a hot fluid around 100°C. The future VCM unit shows a potential for producing over 10 MW of 100°C water from 50°C.

8.3 Pinch analysis

The pinch analysis in this report has been done on the current plant without any future changes and data from Lindqvist's report has been used, see Appendix 4. Two different cases have been studied, with and without the heat from the flue gases and the oxi-reactors which contain heat not utilized today. As in the previous case studies, the district heating return temperature is set to 55°C and the supply temperatures vary from 85°C to 105°C. The global temperature difference of the process is varied from 0°C to 15°C. The result for the case without the heat from the flue gases and the oxi-reactors can be seen in *Table 8.1* and the result for the case with the extra heat can be seen in *Table 8.2*.

Table 8.1 *The district heating potential for the mill without using the heat from the flue gases and the oxi-reactors for global temperature differences between 0°C and 15°C, and supply temperatures of 85-105°C.*

Global temperature difference [°C]	**District heating supply temperature [°C]**			
	85	95	100	105
0	17.6	5.0	4.0	-[1]
5	21.5	6.5	5.3	4.6
10	22.2	7.8	6.3	5.4
15	23.0	10.1	8.2	7.1

[1] The temperature of the district heating is higher than the pinch temperature and heat can therefore not be extracted in order to not violate the pinch rules.

Table 8.2 *The district heating potential for the mill using the extra heat from the flue gases and the oxi-reactors for global temperature differences between 0°C and 15°C, and supply temperatures of 85- 105°C.*

Global temperature difference [°C]	**District heating supply temperature [°C]**			
	85	95	100	105
0	18.5	5.2	4.2	-[1]
5	21.5	6.5	5.3	4.6
10	22.3	7.8	6.3	5.4
15	23.0	10.2	8.3	7.2

[1] The temperature of the district heating is higher than the pinch temperature and heat can therefore not be extracted in order to not violate the pinch rules.

Comparing the two cases, with and without the extra heat from the flue gases and the oxi-reactors, one can see that there is hardly any difference between them when comparing the potential for district heating. The reason is that the extra heat added is of temperatures above the pinch where there is a heat deficit and therefore no changes are done below the pinch, see *Figure 8.1*. The minimum hot utility demand is however lowered a lot for the case with the extra heat. As an example the minimum hot utility demand for a global temperature difference of 10°C is 13.1 MW for the case without the extra heat and 1.7 MW for the case with the extra heat. The minimum cold utility demand for both cases at the same global temperature difference is 30.8 MW.

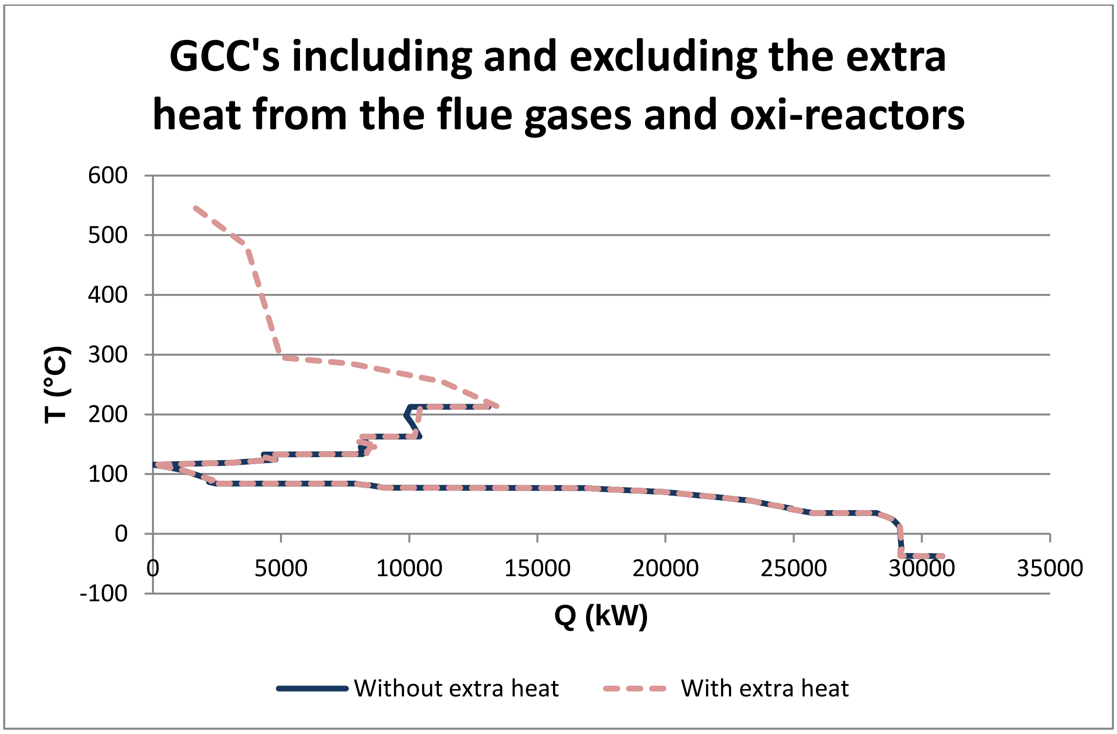

Figure 8.1 *The GCC's for the two cases with and without extra heat from the flue gases and oxi-reactors for a global temperature of 10°C. The two GCC's are on top of each other below the pinch and the first part above the pinch (to around 200°C).*

For both cases one can see that the potential for producing district heating at 85°C is much higher than for the other supply temperatures. The reason is the steeper slope between the pinch temperature and 84°C which creates a "nose" at 84°C, see *Figure 8.2*.

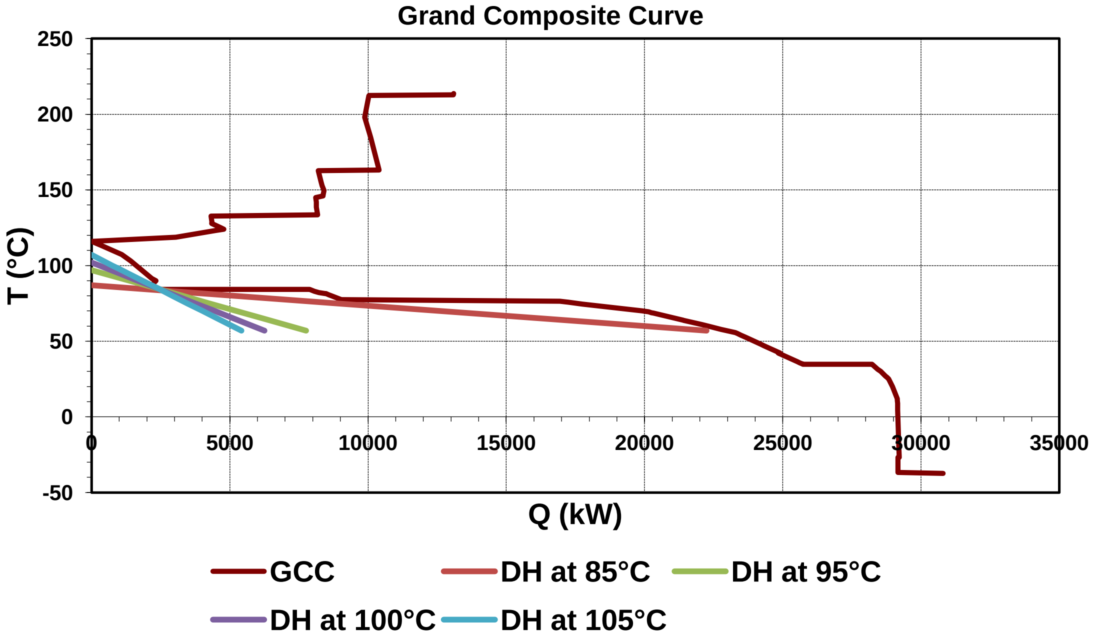

Figure 8.2 *The GCC for the case not using the extra heat from the flue gases and the oxi-reactors with a global temperature difference of 10°C.*

The actual cooling demand of the process is 38.6 MW. This cooling demand, and the actual heating demand of 20.9 MW, corresponds to a global temperature difference of 180°C. See *Figure 8.3* for the actual cooling load curve and the potential for producing district heating from the actual cooling. The potentials for the different supply temperatures 85°C, 95°C, 100°C and 105°C are 25.6 MW, 20.4 MW, 18.3 MW and 16.9 MW respectively. The temperature difference between the cooling load curve and the district heating is set to 7°C.

For the different global temperature differences between 0°C and 15°C the pinch lies below 120°C. The actual cooling of the mill includes four streams with temperatures above 130°C, the rest of the cooled streams have a temperature of 118°C or lower. The extra amount of heat from the flue gases and the oxi reactors are not included in the actual cooling load since that heat isn't used today, it's only a potential source for more excess heat. The cooling above and around the pinch temperature is the reason why the potential for producing district heating from the actual cooling is higher than the potentials found in *Table 8.1* and *Table 8.2* above. It is also the reason why there is no reasonable corresponding global temperature difference.

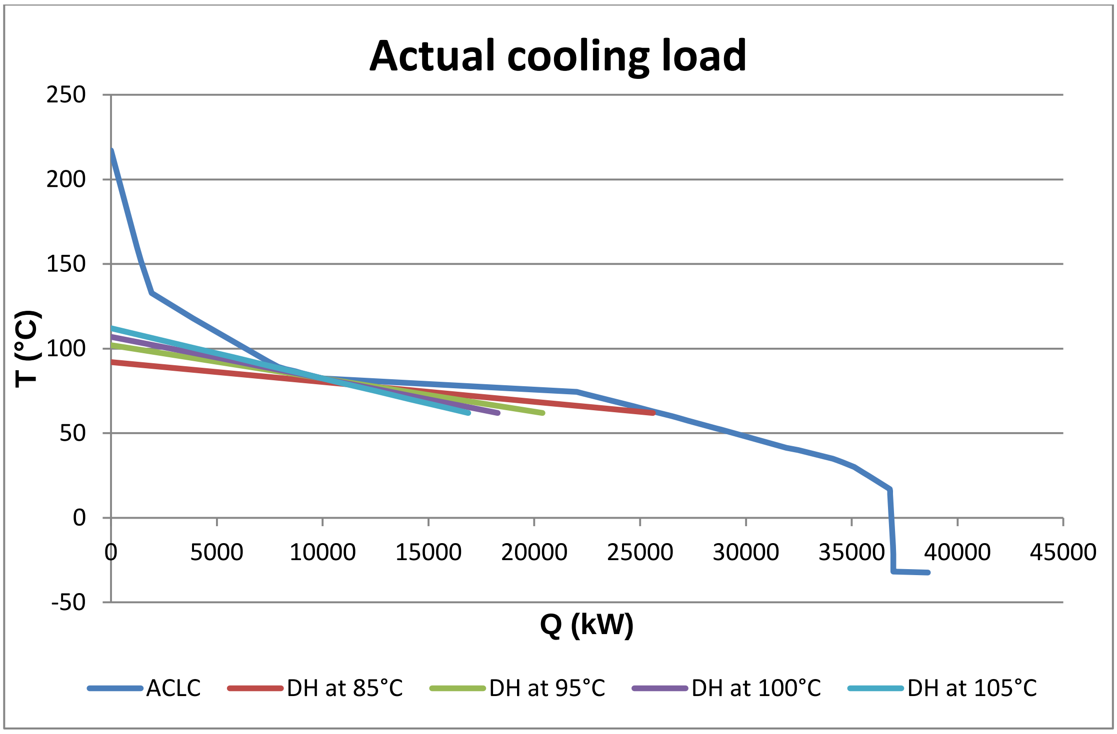

Figure 8.3 *The actual cooling load and the potentials for producing district heating from the cooling.*

The advanced curves are constructed for a global temperature difference of 180°C, see *Figure 8.4*. What is interesting to see is that the THLC and AHLC as well as the TCLC and ACLC are almost on top of each other. This means that the theoretical minimum temperature where heat can be supplied as well as the theoretical maximum temperature where heat can be removed for the specific heating/cooling demand without violating any pinch rules are almost achieved for the specific global temperature difference. However, almost 5000 kW of heat can be saved if you were to use some of the heat in the hot streams heating some of the cold streams. Looking at the HUC (hot utility curve) in the figure one can however see that almost half of the saved hot utility is at a temperature below the ACLC and TCLC. This means that if you were to heat the streams in the THLC with the streams in the TCLC and use the hot utility to produce district heating instead, the temperature of the district heating would be lower. The potential for producing district heating doesn't change much either if you were to produce it using the streams in the TCLC instead of the streams in the ACLC since they are almost the same.

What one can say is however that it is possible to improve the energy efficiency of the process and thus save 5000 kW of hot utility. Instead of using the hot utility to produce district heating one can buy/produce less hot utility which would result in less fuel usage. The potential for producing district heating will then also be lowered by the same amount compared to the potential using the actual cooling, in this case this also applies if one were to use the theoretical cooling.

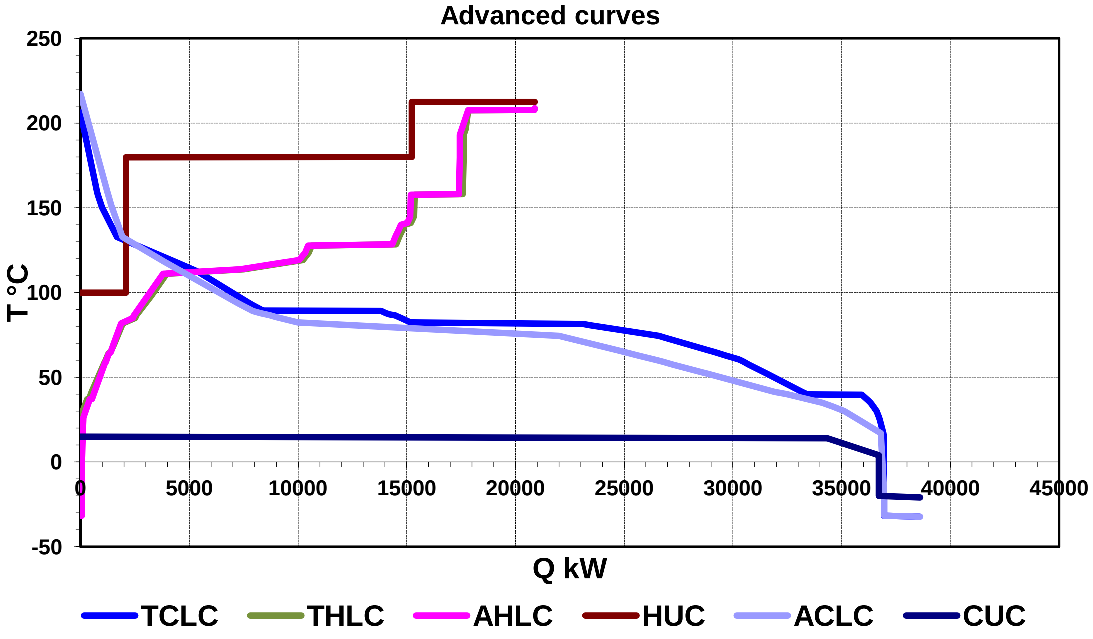

Figure 8.4 *The advanced curves for a global temperature difference of 180°C. The THLC and AHLC are on top of each other which is why it's hard to distinguish the THLC in the figure.*

8.4 Calculated potential with the ratios from Cronholm's report

The percentage of delivered excess heat delivered per unit of fuel usage for the industrial sector *chemicals and chemical products* is 24.3 %, see *Table 2.2*. The total fuel usage of the whole plant was in 2009 420 GWh. In the VCM plant however the energy demand was 90 GWh of steam and another 110 GWh of fuels for the cracking oven. Assuming an efficiency of 85 % for the steam boiler results in a fuel usage for the VCM plant of 215.9 GWh. Multiplying this with the ratio from the report by Cronholm et al. (2009) results in a potential for delivering excess heat in the form of district heating of 52.5 GWh. Assuming an annual production time of 7800 h gives the result 6.7 MW.

Since the VCM plant is only a part of the whole industrial plant it's also interesting to know the potential for delivering district heating from the whole industrial plant. The fuel usage for the whole plant is, as said above, 420 GWh which results in a district heating potential of 102.1 GWh. Assuming an annual production time of 7800h gives the result 13.1 MW.

8.5 Comparison

The two values from the ratio calculation are consistent with the values from the GCC calculations, depending on the temperature of the district heating supply temperature. With a supply temperature of 85°C the potential from the GCC's are much higher than the one from the ratio. Looking at *Figure 8.2* again one can however see that the district heating line corresponding to a supply temperature of 85°C is very close at intersecting the GCC line on more than one spot (unlike the other supply temperature lines which are only close to the GCC at one point, where they tangent the GCC curve). This means that the potential for producing district heating of 85°C needs the process to be optimized energy wise or the DH line will cross the GCC curve and the production of the DH will then be a pinch violation and a higher heating/cooling demand than necessary for the process will be obtained.

Looking at a supply temperature of 95°C and above the potential from the GCC calculations are in the range of 4.2 MW to 10.2 MW. The 6.7 MW only for the VCM unit from the ratio calculations is in between those potentials and is therefore consistent with the actual potential at the unit. However, when looking at the whole PVC plant, the 13.1 MW from the ratio calculations is a bit higher than the 4.2 to 10.2 MW from the GCC calculations. But since the 13.1 MW includes the whole plant and the GCC is only for the VCM unit there might be excess heat available at the other two parts (chlorine and PVC unit) as well even though most of the steam use and excess heat is found at the VCM unit.

The potential for producing district heating from the actual cooling is bigger than both the potential from the GCC calculations and the ratio calculations. The actual cooling demand is around 38 MW and the minimum cooling demand corresponding to the GCC's where the potentials have been calculated are in the range of 29 MW to 32 MW (depending on the global temperature difference). This is an increase by around 20-30 % which makes the potential for producing district heating increase as well. For supply temperatures of 95°C and above the potential from the actual cooling is however more than doubled for many of the different global temperature differences compared with the potential from the GCC calculations. Even though the cooling demand is increased by "only" 20-30 % one cannot say that the district heating potential will increase by the same amount since it depends on which temperatures the cooling is occurring. Looking at *Figure 8.2* again one can see that what's limiting the potential is the "nose" at around 84°C and around 2500 kW. Looking at *Figure 8.3* one can see that the limiting "nose" is still at around 84°C but is moved much more to the right to around 8500 kW. So even though the cooling demand is "only" increased by 20-30 % the position of the limiting "nose" is changed so much that the slope of the district heating lines can be decreased and the potential is increasing by more than the 20-30 % for the actual cooling compared with the GCC calculations.

Comparing the district heating potential from the ratio calculation with the potential from the actual cooling they are not nearly the same. The larger potential from the ratio calculation is for the whole plant and not only for the VCM unit. If there were no excess heat available at all for the other two parts of the plant the potential from the ratio calculation would almost be as large as the potential from the actual cooling. It should however be kept in mind that the ratio is for the whole chemical and chemical products industry and not only PVC production. Chemical production can vary a lot depending on the chemical/chemical product produced. Having that in mind it would have been expected that the potentials would differ more than they actually are.

9 Summary of results and further discussion

For a summary of the results for the five case studies, see *Table 9.1*. The table first presents the potentials estimated using pinch analysis conducted using different values of ΔT_{min} in heat exchangers. The table also presents the potential estimated from the actual cooling load curve (ACLC) as well as the potential calculated based on the plant fuel usage using the ratio proposed by Cronholm et al. (2009). These potentials are presented for the lowest and highest supply temperature of the district heating water, 85°C and 105°C. An increase of ΔT_{min} increases the cooling demand and in most cases the potential for producing district heating increases as well. This is, however, not the case for Case studies 1 and 3 (the chemical pulp and paperboard mill and the mechanical pulp and paper mill). In these cases there is a "nose" in the GCC limiting the district heating potential and when ΔT_{min} is increased the "nose" moves to the left becoming the new pinch at a lower temperature. Thus, the district heating potential is lower even though the cooling demand increases.

Table 9.1 A summary of the potentials for district heating export [MW] from Sections 0-0. The results are presented for the minimum and maximum supply temperature values of the district heating (DH) water.

	Case study 1		**Case study 2**		**Case study 3**		**Case study 4**				**Case study 5[4]**	
							Coke		**Rest**			
DH [°C]	**85**	**105**	**85**	**105**	**85**	**105**	**85**	**105**	**85**	**105**	**85**	**105**
Theoretical potential for DH export based on analysis of GCC curves for varying values of ΔT_{min}												
ΔT_{min}=0	28.0	-	38.2	-	-	-	4.4	1.5	14.6	14.6	17.6	-
ΔT_{min}=5	24.2	-	42.2	-	2.3	-	4.4	1.6	15.0	15.0	21.5	4.6
ΔT_{min}= 10	12.6	11.9	45.5	-	-	-	4.5	1.7	15.4	15.4	22.2	5.4
ΔT_{min}= 15	-	-	48.9	-	-	-	4.5	1.8	16.2	16.2	23.0	7.1
Potential for DH export based on the ACLC of the process												
ACLC	14.3[1]	11.5[1]	-[2]	-[2]	-[3]	-[3]	11.0[1]	7.2[1]	17.2[1]	17.2[1]	25.6	16.9
Potential for DH export based on the fuel usage of the plant and the ratio DH export per unit of fuel usage proposed by Cronholm et al.												
Cron-holm et al.	10.0-11.4		9.8		1.6-1.8		6.6				6.7 (13.1)	

[1]The actual cooling includes the heat in the flue gases which aren't connected to any heat exchanger today but they are included in the results for the different global temperature differences as well.
[2] The three streams being cooled with utility are not at a high enough temperature to produce district heating. However, there are uncertainties if there is overproduction of warm and hot water in the secondary heating system and this heat could potentially be used to produce district heating.
[3] Around 1 MW could be produced if flue gas condensing is included.
[4] The flue gases and the heat from the oxi-reactors not utilized today are not included.

9.1 Case studies 1 to 3

For Case studies 1 to 3, one can see in the table above that the potential for producing district heating at a high supply temperature (105°C) is non-existent except for Case study 1 with ΔT_{min}=10 K. All of these case studies have in common that they are for the pulp and paper industry, even though they differ from each other in the ways the pulp is produced. Case studies 1 and 2 that are for chemical pulp (and paper for Case study 1) do however have a potential for producing district heating at a lower temperature unlike Case study 3, the mechanical pulp and paper mill. The difference between Case studies 1 and 2 is that Case study 1 is an integrated mill where paperboard is produced as well. The paperboard production unit has a heating demand but the process does not generate any heat, and therefore the potential for producing district heating is a lot lower for Case study 1 compared to Case study 2. The paperboard production has a cooling "demand" (not always a demand, more of a possible source of heat) as well but a lot of the heat that can be utilized in the paperboard production is warm/hot moist air from the drying of the paper which is hard to extract.

For a ΔT_{min} of 10°C in Case study 1 and for all values of ΔT_{min} in Case study 3 the potential for export of district heat based on the GCC calculations is in relatively good agreement with the value estimated from fuel usage using the method proposed by Cronholm. Even though the pinch temperature is too low to allow export of district heating in Case study 3 for most cases (different ΔT_{min} values and different DH supply temperatures) it is reasonable to assume that the mill's energy system includes some pinch violations such as cooling above the pinch, which would allow for some DH production. The potential estimated based on fuel usage is in good agreement with the potential estimated using the ACLC curve for both cases. For Case study 1 the agreement is better for the higher supply temperature.

For Case study 2, the potential estimated based on fuel usage does not match the values estimated from the GCC curves at all for the supply temperatures shown in the table above. The potentials estimated from the GCC curves are either too high or non-existent. The pinch temperature of the process is close to the temperature required in order to produce district heating which is why the pinch temperature is too low to produce any district heating for some cases. As long as the pinch temperature is high enough the potential is high (higher than the potential estimated based on the ACLC curve or the plant's fuel usage). Part of the explanation could be that information about the secondary heat system is uncertain and part of the excess heat identified as available to produce district heating should in fact be used to produce warm and hot water used in the process. Both Case study 1 and Case study 2 use around the same amount of fuel in their processes. The difference between them is that in Case study 1 paperboard is produced as well which uses a lot of steam produced in boilers.

Looking at *Table 2.1* one can see that the adjusted potentials for the industrial sector pulp and paper production and publishing is higher than the calculated national potential using the ratios for the different sub sectors. The ratio should therefore be higher in order to correspond to the adjusted potential. It is however hard to say if the ratios from the different sub-sectors, pulp and paper, should increase equally or if one of the two should increase more than the other. If detailed statistics were available for more sub-sectors than used by Cronholm et al. (only the two; pulp and paper), the calculated value of the ratio between fuel usage and district heating export potential could be more reliable since there is a big difference between different kinds of pulp and paper mills. There are pulp mills, paper mills and integrated mills and the pulp can either be produced chemically or mechanically. Data for only two different sub-sectors for these different combinations is insufficient. More sub sectors would also remove the problem with not knowing if an integrated mill should count as a pulp mill or a paper mill.

9.2 Case study 4

Case study 4 (both the coke part and the blast furnace- and steel part) has the potential for delivering district heating at a higher temperature, unlike Case studies 1, 2 and 3. However, the potential differs a lot between the coke plant and the rest of the plant. Looking at the results in *Table 9.1* above, which includes excess heat not connected to any heat exchanger today, the potential estimated using GCC curves is a lot higher than the ratio estimated from plant fuel usage. The reason is simply because excess heat that is not utilized today is included, whereas the value based on fuel usage is based on current excess heat deliveries from similar industrial plants. In Section 7.2.2, the results from the current streams connected to the heat exchanger network are presented and these results match the results based on fuel usage. The industrial plant in Case study 4 is one of the plants (total of 13 in the same industrial sub sector) which is currently delivering excess heat in the form of district heating to the local grid and is therefore included in the plant data that was used by Cronholm et al to estimate the ratio between fuel usage and excess heat export.

The total potential based on the ACLC curve (with the flue gases included) is around 26 MW (17 MW from the blast furnace and steel plant, and 9 MW (7-11) from the coke plant). If this value and the fuel usage are used to calculate a new ratio, this results in a ratio of 10 %. In *Table 2.1* one can see that the adjusted potential for the industrial sector Steel and metal production is 33-91 % higher than the calculated national potential using the ratio proposed by Cronholm et al. If the ratio were increased by the same percentage it would result in a ratio of 3.3-4.8 % which is still lower than the ratio calculated from the ACLC curve. A ratio calculated based on the potentials estimated based on the GCC curves (from 16.1 MW for ΔT_{min}=0 K and a supply temperature of 105°C to 20.7 MW for ΔT_{min}=15 K and a supply temperature of 85°C) would result in a ratio of 6.1-7.9 % which is a lot higher than the ratio proposed by Cronholm et al. The big difference is once again that the heat not utilized today is included in the potential estimated using the ACLC and the plant in Case study 4 is included in the statistical data used to estimate the excess heat export potential per unit of fuel ratio proposed by Cronholm et al.

9.3 Case study 5

For Case study 5, the potential estimated based on plant fuel usage matches the potentials estimated from the GCC curves. This conclusion is however not valid for the district heating supply temperature of 85°C. The district heating water line used to estimate the theoretical potential at 85°C in the GCC curve is however close to intersecting the GCC at several places which means that this potential is very dependent on the exact topology of the heat exchanger network.

The potential estimated based on plant fuel usage is however lower than the potential estimated from the ACLC curve which has the highest potential. One reason to why the actual cooling has a higher potential is because the actual cooling demand corresponds to a global temperature difference of 180°C which is a lot higher than the 0-15°C used when estimating the potentials from the GCCs. A higher ΔT_{min} value increases the minimum cooling demand which leads to a higher potential for producing district heating as well, since the pinch is high enough to not interfere with the district heating production and there are no “noses” in the GCC.

One could however say that the potential estimated based on plant fuel usage in fact matches the calculated potentials based on the ACLC curves if one looks at the potential for the whole plant and the PVC part looked at in this case study is the only part with a potential for delivering district heating.

For this case study some advanced composite curves were constructed as well. These show that with today's heating and cooling demand there is a way to increase the energy efficiency and freeing hot utility. If this were to be done the actual cooling would decrease and with that the potential for producing district heating.

9.4 "True" excess heat

One thing that concerns all five case studies is that the potential estimated from the ACLC doesn't always match the potential from the GCC calculation or the potential based on fuel usage. The important question to ask is if the actual cooling load is "true" excess heat or not. When the district heating potential is calculated from the GCC's it is done without violating any pinch rules, i.e. the cooling and heating demands are kept to a minimum for a certain global temperature difference. If for example district heating were to be produced using a stream with a temperature above the pinch, the total heating demand of the process would increase by the same amount of energy that is used to produce the district heating. This increased heating demand results in an increased fuel use. Indirectly, the district heating produced using a stream with a temperature above the pinch causes the plant's fuel usage to increase. This extra amount of fuel causes emissions and contributes to the world's use of resources.

The different global temperature difference values considered in this report correspond to different heat exchanger networks with different cooling and heating demands. If the plant would have a heat exchanger network that maximizes heat recovery, that would correspond to a global temperature difference of 0°C. This is however not practical because it implies infinite areas of the heat exchangers. The same discussion as in the previous paragraph can be repeated for different values of the global temperature difference. If the plant invests in new heat exchangers and changes the heat exchanger network and decreasing the temperature differences in the heat exchangers, the excess heat from the plant would decrease together with the heating demand (fuel use) and so will the potential for producing district heating in most cases.

Bendig et al. (2013) defines excess heat as either "avoidable" or "unavoidable". The "unavoidable" excess heat is heat excess that occurs even though process heat recovery is maximized. This would correspond to what in this report is referred to as "true" excess heat. The avoidable heat is the heat that is the result of a bigger heat input to the process than what is required for a plant with maximum heat recovery for a given value of ΔT_{min}. Bendig et al. suggests that the avoidable heat shouldn't be used for any secondary application since it could block investments to become more energy efficient.

Defining "true" excess heat using global temperature difference is hard since a global temperature difference of 0°C is not feasible. The question then is at what global temperature difference one should draw the line for defining "true" excess heat. Different types of process streams (steam, gas, liquids etc.) have different economical optimums for the temperature differences in the heat exchangers and different industries have different kinds of streams which would make it hard to come up with a global temperature difference on equal terms for all industries. Excess heat from industrial plants has the same behavior when the global temperature difference is decreased or increased. However, if the excess heat is used to produce district heating the potential for using the excess heat in order to produce district heating behaves different for different industrial plants. It can both decrease and increase when the global temperature difference is increased. This makes it even harder to come up with a global temperature difference that would decide what is “true” excess heat and not.

Without a definition of excess heat it’s hard to have economic incentives for using excess heat for district heating (for example). In some cases it might be justified to use “avoidable” excess heat in order to reach the target temperature for the district heating if there is a high amount of “unavoidable” excess heat at the plant but at a temperature not high enough for district heating. It depends on the local demand for district heating and the alternatives for producing it.

9.5 Uncertainties about the results

There are some uncertainties about the results in this report besides the use of the ratios for a whole industrial sub sector on a single industrial plant that might be very different from the “normal” industrial plants in the sub sector. Mainly because data from existing studies has been used and not all the data needed for a complete analysis has been found. For some cases, the ones where the fuel use was presented as energy and not power, the potential calculated with the ratio has been converted from energy to power in order to have comparable results. An annual production time has been assumed in order to calculate the power. There is however uncertainties in the comparison since the power calculated from the annual fuel usage gives the mean value over the whole year but the power calculated from the GCC’s are for a certain production rate. There can be seasonal variations concerning the production and the results might not be completely comparable. For most of the case studies though, the data used has been collected to represent a year around production.

Other variables that affect the results are the temperature of the district heating. The supply temperature has been varied but not higher than 105°C even though some older systems have a supply temperature around 120°C. The reason why a higher district heating supply temperature was not evaluated is because most of the new systems built in Sweden are designed for a maximum temperature of 100°C. The return temperature of the district heating affects the potential as well. The temperature of the return was not varied in this study. A lower return temperature should however result in a higher potential for producing district heating, and a higher return temperature should result in a lower potential. The return temperature should probably vary together with the supply temperature but the return temperature was as said not varied in this study.

The temperature difference between the district heating and the process has a set value of 7°C in this study. This value would primarily affect the potentials where the district heating supply temperature is close to the pinch temperature of the process. A lower temperature difference might mean that district heating could potentially be produced, whereas a higher temperature difference might mean that the pinch temperature is too low to produce any district heating at the set supply temperature. In the first case study the temperature between the process and the district heating was varied to some extent. Comparing the values in *Table 4.2* and *Table 4.3* one can see that the temperature difference between the process and the district heating has a great impact on the resulting potential. Increasing the temperature difference would decrease the potential for producing district heating, and decreasing the temperature difference would increase the potential for producing district heating. However, the main goal was to calculate the potential for producing district heating for different configurations of the process the value was chosen to be constant.

The focus in most of the reports used in this study has been on collecting data to construct GCCs to find targets for reduction of the hot utility demand. Not all of the reports include a complete description of the current heat exchanger network, which would have been needed in order to construct the advanced composite curves. For most cases this has therefore not been done and conclusions have not been drawn concerning the advanced curves.

One last thing to say about the results is that the potential taken from the GCCs and the potential from using the actual cooling are values for producing district heating at the specified supply temperature. There could be a lot more excess heat from the process but at a lower temperature that could be used to produce district heating provided that final heating up to the required temperature level is provided with steam.

10 Conclusions

In this study the potential for producing district heating has been calculated using different methods for five different industrial plants. One of the methods was to use a ratio from a previous study describing the potential for producing district heating per fuel usage. The other method was to calculate the amount of excess heat that could be used for district heating, based on results from previous energy analyses of the industrial plants using pinch analysis.

Even though the results from the ratio calculations differ somewhat compared to the potentials calculated from the pinch analysis using GCCs (with different global temperature differences) and the actual cooling they are in the same order of magnitude. The use of the ratios to calculate the total potential at a national level should therefore give an approximate result. The result is however only a theoretical potential for producing district heating and does not take in consideration whether or not there is a demand for district heating locally around the industrial plants. The supply temperature does affect the results as well. A lower supply temperature increases the potential for producing district heating.

When the global temperature difference increases the minimum cooling demand increases as well. However, the possibility for producing district heating isn’t always increasing for an increased global temperature difference. It depends on the shape of the GCC.

The term “excess heat” should be used with consideration since excess heat might just be heat that contributes to an increased fuel usage at the plant and could be lowered or eliminated if the heat exchanger network were constructed more efficiently. Since industrial plants strive to become more energy efficient and thereby reducing their fuel usage (their costs) as well as being more environmentally friendly, the “excess heat” found at industrial plants today might decrease in the future and with that the potential for producing district heating might decrease as well. It is very difficult to define what “true excess heat” is. Should one define it as excess heat when the minimum allowable temperature difference for heat exchanging is 0°C (which naturally is unobtainable)? Or should another more reasonable minimum temperature difference be used? What further complicates the picture is that, as mentioned, all processes don’t increase their potential for district heating production with an increased value of ΔT_{min}.

For most of the case studies the potential estimated form the ACLC curve is higher than the potential from the GCC curves, at least for higher values of ΔT_{min} and higher district heating supply temperatures. This implies that the industrial plants aren’t optimized energy wise and investments to increase the energy efficiency at the plant might decrease the cooling demand and also the district heating potential.

Even if the “excess heat” at the plant doesn’t reach up to the needed temperature to produce district heating it might be a good solution to use the heat available and provide final boost heating with steam in order to achieve the temperature needed. Even if this doesn’t count as only excess heat it’s better than producing heat directly from burning of other fuels. It does however depend on the alternative for producing the heat.

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Appendix 1

Stream data for Case study 1

Type	T_{start} [°C]	T_{target} [°C]	Q [kW]	Process part	Comments
Hot	99	98	2 200	Digester 3	Turpentine condenser
Cold	61	85	2 200	Digester 3	Warm water production
Cold	138	144	2 016	Digester 3	Cooking circulation
Cold	148	151	1 535	Digester 3	Cooking circulation
Cold	109.2	144.5	4 822	Digester 3	Cooking circulation
Hot	108	96	3 900	Digester 3	Weak liquor
Cold	61	92,5	3 900	Digester 3	Warm water production
Cold	122.5	160	4 194	Digester 4	Cooking circulation
Cold	143	148	3 622	Digester 4	Pre impregnation
Hot	141	140,9	1 398	Digester 4	Vapor from cyclone
Hot	98.1	98	1 200	Digester 4	Turpentine condenser
Cold	61	75	1 200	Digester 4	Warm water production
Hot	111	94	3 500	Digester 4	black liquor
Cold	61	92	3 500	Digester 4	Warm water production
Cold	45	76	1 698	Digester 4	Black liquor
Hot	84	77	1 698	Digester 4	Warm water production
Cold	10	31	455	Bleaching 4	Chlorine dioxide, pre heating
Hot	70	38	455	Bleaching 4	Pulp water
Cold	75	86.5	2 683	Bleaching 4	Pulp water
Hot	66	65.9	18 126	Evaporation 3	Evaporation vapor
Hot	65.9	46.6	674	Evaporation 3	Sub cooling of evaporation vapor
Cold	14,7	44	18 800	Evaporation 3	Warm water production
Hot	26	24	854	Evaporation 3	Cooling of secondary condensate
Cold	18	25.5	854	Evaporation 3	warm water production
Hot	80	78	788	Evaporation 3	Evaporation vapor
Cold	40.1	90	5 267	Gas&cond	Cooling after stripper
Hot	93.4	93	5 267	Gas&cond	Cooling after stripper
Hot	53.1	53	18 000	Evaporation 4	Condensation
Cold	14.7	44	18 800	Evaporation 4	Warm water production
Hot	53	33.9	800	Evaporation 4	Sub cooling of evaporation vapor
Hot	85	84.9	600	Kaust	Green liquor cooling
Cold	4	76.4	600	Kaust	Warm water production
Hot	60	37	4 830	Bleaching 3	Effluent
Hot	60	37	4 562	Bleaching 3	Effluent
Hot	65	37	6 533	Bleaching 4	Effluent
Hot	60	37	4 562	Bleaching 4	Effluent
Hot	72	37	25 521	Bleaching 3	Effluent
Hot	63	20	86275.2	Water	From scrubber

Cold	42.8	63	36 369	Water	Warm water production
Hot	80	37	9 486	Water	
Hot	70.1	70	5 978	Gas&cond	Methanol condenser
Hot	70	17	722	Gas&cond	Methanol sub cooling
Cold	14.7	45	6 700	Gas&cond	Warm water production
Hot	100.1	100	5 700	Gas&cond	Imcondenser
Cold	37	80	5 700	Gas&cond	Cooling of imcondensor
Hot	140	105	6 000	Kraft	Flue gas cooling, recovery boiler
Hot	135	100	3 000	Kaust	Flue gas cooling, lime kiln
Cold	1	56	3600	KM1	Chemical cleaned water
Hot	88.1	88	3600	KM1	Flash
Hot	90.1	90	5500	KM2	Flash
Cold	1	60	5500	KM2	Chemical cleaned water
Cold	207.1	207.2	7239	MT17	Soot blowing, recovery boiler
Cold	191.6	191.7	822	MT12	Soot blowing, economizer
Cold	191.6	191.7	561	MT12	Bleaching 3
Cold	191.6	191.7	6862	MT12	Digester 4
Cold	191.6	191.7	1542	MT12	Bleaching 4
Cold	191.6	191.7	2212	MT12	KM1
Cold	191.6	191.7	804	MT12	KM2 coating
Cold	191.6	191.7	6166	MT12	TM4
Cold	191.6	191.7	2614	MT12	Unaccounted and losses
Cold	170.4	170.5	1690	MT7	Lime kiln
Cold	170.4	170.5	34874	MT7	KM1
Cold	170.4	170.5	51389	MT7	KM2
Cold	170.4	170.5	1630	MT7	TM4
Cold	170.4	170.5	5291	MT7	Misc. and losses
Cold	143.6	143.7	1095	LT3	Digester 3
Cold	143.6	143.7	1582	LT3	Bleaching 3
Cold	143.6	143.7	1978	LT3	Digester 4
Cold	143.6	143.7	44942	LT3	Evaporation
Cold	143.6	143.7	1030	LT3	Chemical preparation
Cold	143.6	143.7	11840	LT3	The saw mill
Cold	143.6	143.7	4056	LT3	Unaccounted and losses
Cold	15	125	11601	Kraft	Dilution water
Cold	105.37	125	3545	Kraft	Condensate
Cold	144	144	6385	Kraft	Steam feed water tank

Appendix 2

Stream data for Case study 2

Type	T_{start} [°C]	T_{target} [°C]	Q [kW]	Process part	Comments
Hot	103.3	103.2	16585	Digestion	Blowing steam condenser
Hot	90.1	50.5	1120	Digestion	Turpentine condenser
Cold	90.8	108.1	1788	Digestion	Heating of white liquor
Hot	165.4	146.5	1788	Digestion	Cooling of hot liquor
Hot	80.0	74.3	6041	Digestion	Cooling of Acc. 0
Cold	70.6	80.0	2235	Digestion	HW production
Cold	148.4	148.5	3470	Digestion	Steam demand
Cold	184.8	184.9	20200	Digestion	Steam demand
Hot	87.0	82.0	1068	Wash	Filtrate Tank Diffuser to COP1
Hot	87.0	78.0	4506	Wash	Back water (Liquor Tank 2 to AWP1)
Hot	67.9	38.3	4090	Wash	Thin liquor cooling to Blow Tank
Cold	184.8	184.9	0	Oxygen bleaching	Steam demand Oxygen bleaching
Cold	1.9	46.5	14337	Bleaching	Heating of water to Filter 4
Hot	99.7	90.1	293	Bleaching	Gas cooling after step 4
Cold	81.2	83.3	293	Bleaching	Heating of KLR to Filter 2 & 3
Hot	82.7	77.8	4613	Bleaching	Cooling of BB2 to AWP white wash
Hot	83.2	71.5	9216	Bleaching	Cooling of BB4
Cold	1.9	65.0	17730	Bleaching	HW to Diluter Screw Feeder
Cold	184.8	184.9	1498	Bleaching	Steam demand Step 2
Cold	184.8	184.9	3052	Bleaching	Steam demand Step 4
Cold	148.4	148.5	9748	Bleaching	Steam demand
Hot	66.3	66.2	39395	Evaporation	Surface condenser
Cold	148.4	148.5	51793	Evaporation	Steam demand for evaporation
Hot	117.8	84.4	11774	Stripper	Cooling of KLR

Cold	66.8	107.7	6288	Stripper	Heating of KLB
Cold	68.3	102.9	5486	Stripper	Heating of KLS
Cold	148.4	148.5	3007	Stripper	Steam demand Stripper
Cold	148.4	148.5	805	Stripper	Steam demand MeOH column
Cold	3.0	34.9	499	Paper room	Heating of Paper Room Facilities
Cold	3.0	36.8	2074	Paper room	Heating of Paper Room Facilities
Cold	148.4	148.5	2876	Paper room	Steam demand, Wire Steam box
Hot	129.1	129.0	1395	Paper room	Flash steam condenser
Hot	104.0	59.0	3599	Paper room	Air Cooling from air drier, step 1
Hot	59.0	50.0	8967	Paper room	Air Cooling from air drier, step 2
Cold	36.8	122.7	9882	Paper room	Heating of air to air Drier
Cold	148.4	148.5	21690	Paper room	Steam demand, air drier
Hot	120.2	120.1	2808	Paper room	Flash steam condenser
Cold	52.0	70.0	2808	Paper room	HW to BSB-tank
Cold	2.7	52.1	7730	Paper room	WW demand in tank
Cold	1.9	45.0	3419	Paper room	WW to Back Water Tank
Cold	4.3	148.3	10946	Paper room	Heating of air to Cyclone drier
Hot	97.1	87.6	2322	Causticizing	Cooling of Green liquor
Cold	148.4	148.5	865	Causticizing	HW heating
Cold	1.9	70.0	940	Causticizing	HW to lime washer
Hot	84.1	68.4	6353	Causticizing	Mist condenser
Hot	76.8	53.6	19146	DH	Cooling of V1
Cold	105.4	111.9	4128	DH	District heating demand Saw mill
Cold	148.4	148.5	3676	DH	Steam demand Saw mill
Cold	37.7	50.0	703	DH	District heating to Tomato farm
Cold	49.2	54.7	42	DH	R&D facilities heating
Cold	65.0	75.0	200	DH	Office facilities heating
Cold	148.4	148.5	13127	Rec. Boil.	Steam demand Feed water tank
Cold	16.1	17.0	134	Rec. Boil.	Heating of VKT to Feed water
Hot	204.5	133.2	9884	Rec. Boil.	Flue gas cooling

Cold	83.0	106.2	9884	Rec. Boil.	Feed pre-heating
Cold	184.8	184.9	4335	Rec. Boil.	Steam demand, Feed pre-heating
Cold	148.4	148.5	6352	Rec. Boil.	Steam demand Recovery Boiler
Cold	184.8	184.9	11767	Rec. Boil.	Steam demand Recovery Boiler
Hot	65.0	36.0	3795	Misc.	Cooling of BSB to bio cleaning
Hot	53.6	36.0	14427	Misc.	Cooling of V1 to bio cleaning
Cold	1.9	20.0	3368	Misc.	VKT production
Hot	40.2	18.8	581	Misc.	Turbine cooling
Hot	99.6	99.5	718	Misc.	Leakage steam cooling
Cold	8.3	88.3	7319	Misc.	Heating demand, hot air to Bark drier
Cold	148.4	148.5	1106	Misc.	Steam demand, Chemical plant

Appendix 3

Stream data for Case study 4

Type	T_{start} [°C]	T_{target} [°C]	Q [kW]	Comments
Coking plant				
Hot	272	150	4617	Coke oven flue gas
Hot	79	74	8112	Washing water
Cold	178	178.1	950	Benzene
Cold	6.8	124	723	Feed water preheating
Hot	44	25	11228	EB101A-E
Hot	44	20	5006	EB102A-E
Hot	22	18	148	EB501
Hot	52	29	480	EB603
Hot	52	29	480	EB604
Hot	84	52	1335	EB605 hot side
Cold	6.8	175	1153	Feed water to flue gas boiler
Hot	84	42	1336	EB606
Hot	42	31	350	EB1001
Hot	103	77	1770	EB601 hot side
Cold	26	51	1770	EB601 cold side
Hot	77	18	2940	EB602A/B
Hot	53	25	3708	EB2271
Hot	181	53	2620	EB2261 hot side
Cold	27	143	2620	EB2261 cold side
Cold	164.9	165	5852	MP in separation unit
Cold	120.9	121	633	LP in separation unit
Cold	120.9	121	42.3	LP in separation unit

Blast furnace + steel plant				
Cold	155	1108	76778	Blast air
Hot	10	4	280.4	Cooling water air intake
Hot	8	4	2603	Cooling water hot stoves
Hot	130	100	3940	Blast furnace gas
Hot	25.7	21	17005	Cooling water furnace
Hot	17	13	2606	Cooling water furnace
Hot	19	17	5851	Cooling water furnace
Hot	262	100	11793	Flue gas hot stoves
Hot	198.1	198	5927	Generated steam in LD
Hot	16.8	6.8	1390	Oxygen lance cooling
Hot	69	50	3963	LD washing water
Hot	27	22	1352	LD cooling
Cold	187.9	188	426	Steam to create vaccum in RH
Hot	42	35	6823	Cooling water continuous casting
Hot	32	26	10017	Cooling water continuous casting
Hot	39	35	3847	Cooling water continuous casting

Appendix 4

Stream data for Case study 5

Type	T_{start} [°C]	T_{target} [°C]	Q [kW]	Process part	Comments
Cold	63.8	65	66	EDC	Reboiler EtCl-column 1
Hot	62.9	59.1	60	EDC	Condenser EtCl column1
Cold	58.8	59	19	EDC	Reboiler EtCl-column 2
Hot	52.9	32.8	19	EDC	Condenser EtCl-column 2
Cold	133.6	145.6	74	EDC	Reboiler Tri-column EDC
Cold	127.7	128.5	3858	EDC	Reboiler Azeo column
Hot	85.6	80.7	26	EDC	Condenser Azeo column, cooling
Hot	80.7	60.6	1994	EDC	Condenser Azeo column, condensation
Hot	60.6	30	276	EDC	Condenser Azeo column, cooling
Hot	87.9	86.5	80	EDC	Tar condenser (Condenser Tri-column EDC)
Cold	111	113.8	3397	EDC	Reboiler EDC column , cond1
Cold	113.8	119.1	2406	EDC	Reboiler EDC column , cond2
Hot	89.3	35	6634	EDC	Condenser EDC-column
Hot	89.3	89.2	5413.8	EDC	Condenser EDC-column, condensation
Hot	89.2	35	1220	EDC	Condenser EDC-column, cooling
Cold	140	141	78	EDC	EDC tar boiler
Hot	82.4	74.4	9482	HTC	HTC-condenser
Hot	82.4	81.5	8404	HTC	HTC-condenser, condensation part 1
Hot	81.5	74.4	1078	HTC	HTC-condenser, condensation part 2
Hot	73.5	15.8	150	HTC	EDC-condenser
Hot	73.5	57.5	98,5	HTC	EDC-condenser, condensation part 1
Hot	57.5	15.8	51.5	HTC	EDC-condenser, condensation part 2
Hot	15.8	-16.5	5	HTC	Remaining gas condenser
Cold	118	123.5	170	HTC	Reboiler Tri-column HTC
Hot	87.1	13.9	157	HTC	Condenser Tri-column HTC
Hot	87.1	86.4	121	HTC	Condenser Tri-column HTC, condensation
Hot	86.4	13.9	36	HTC	Condenser Tri-column HTC, cooling
Hot	89.2	26.7	364	HTC	Pure EDC-cooler
Hot	57.5	34	33	HTC	Cooler

Cold	22	179.6	342	OXI	HCl heater
Hot	217.2	93.9	2618	OXI	Precooler
Hot	217.2	150	1082	OXI	Precooler, condensation part 1
Hot	150	93.9	1536	OXI	Precooler, condensation part 2
Hot	93.9	30	1641	OXI	Condenser after precooler H302 after R303
Hot	93.9	65	1005.7	OXI	Condenser after precooler, condensation part 1
Hot	65	30	635.2	OXI	Condenser after precooler, condensation part 2
Cold	30.7	137	245	OXI	Heater before R304
Hot	151.5	40	389	OXI	Condenser after R304
Hot	151.5	57.5	236.3	OXI	Condenser after R304, cooling
Hot	57.5	40	152.8	OXI	Condenser after R304, condensation
Hot	40	-21.5	240	OXI	Remainder gas condenser
Cold	3.4	69.6	109	OXI	Chlorine evaporator
Cold	3.4	37.1	14,6	OXI	Chlorine evaporator, heating 1
Cold	37.1	37.2	88.6	OXI	Chlorine evaporator, evaporation
Cold	37.2	69.6	5.8	OXI	Chlorine evaporator, heating 2
Cold	-0.4	119.9	237	OXI	Ethylene preheater
Hot	160	25	307	OXI	Intermediate air cooler
Cold	-31.9	41	57.2	OXI	HCl- evaporator
Cold	-31.9	-31.7	49,6	OXI	HCl- evaporator, evaporation
Cold	-31.7	41	7.6	OXI	HCl- evaporator, heating
Cold	41	98	300	VCM	From VCM-column/To EDC column
Hot	157.7	118	300	VCM	From VCM-column/To EDC column
Hot	118	60	389	VCM	Cooler before R102
Cold	193.1	208.6	3442	VCM	EDC-evaporator
Cold	193.1	207.5	385	VCM	EDC-evaporator, heating
Cold	207.5	207.8	3042.7	VCM	EDC-evaporator, evaporation
Cold	207.8	208.6	14.6	VCM	EDC-evaporator, heating
Hot	132.8	66	7007.5	VCM	Condenser cooling column
Hot	132.8	112.4	2905.5	VCM	Condenser cooling column, cond. Part1
Hot	112.4	66	4102	VCM	Condenser cooling column, cond. Part2
Hot	66	40	2098	VCM	Condenser 2 cooling column
Hot	-31.7	-32.3	1640	VCM	HCl condenser

Cold	86.5	144.7	1559	VCM	Reboiler HCl-column
Cold	157.7	158.1	2210	VCM	Reboiler VCM column
Hot	41.4	17	2880	VCM	Condenser VCM column
Hot	41.4	39.8	12.33	VCM	Condenser VCM column, cooling
Hot	39.8	39.7	2501.3	VCM	Condenser VCM column, condensation
Hot	39.7	17	365.8	VCM	Condenser VCM column, cooling
Hot	92.4	52.1	113	VCM	VCM tar condenser
Hot	92.4	85	59.3	VCM	VCM tar condenser, cond part 1
Hot	85	52.1	53.9	VCM	VCM tar condenser, cond part 2
Cold	-32.3	21	110	VCM	HCl preheater/cooler in HCl column
Hot	40	13	110	VCM	HCl preheater/cooler in HCl column
Cold	81.8	85	457	VCM	Preheater ingoing stream to VCM-column
Cold	26.3	118.2	1980	VCM	EDC-preheater
Cold	140	141	178	VCM	VCM tar boiler

CHALMERS UNIVERSITY OF TECHNOLOGY
SE 412 96 Göteborg, Sweden
Phone: + 46 - (0)31 772 10 00
Web: www.chalmers.se