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Pinch analysis at Preem LYR

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ABSTRACT

This energy inventory and pinch analysis of the Preem, Lysekil refinery is a part of the Preem – Chalmers research cooperation and has been carried out by CIT Industriell Energi AB. The result in this report will be used as a basis for the research work at Chalmers.

The aim with the project is to supply the researchers at Chalmers with energy data from the refinery in a form that is suitable for different types of pinch analysis. Furthermore, the aim is to make an analysis to establish the possible energy saving potentials in the refinery at various levels of process integration constraints.

To be able to perform a pinch analysis, data for process streams has to be collected. This has been made using material received from Preem. Stream data has been extracted for all streams that have been identified on the process flow diagrams for all units of the refinery. Service areas and tank farm is not included.

The stream data extraction is documented in a file. For each stream there is a calculation area with the information gathered to explain the choice of data used as stream data for the individual stream. Calculation of stream load is made by using known data of flow and physical data. If necessary data is not available from the screen dumps, data has been estimated. For the most important data, process engineers at Preem have been involved to give background information and assistance to find the best estimation possible.

The refinery has a net heat demand of 409 MW (for the operation case studied) which is supplied by firing fuel gas. Steam is generated in the process by cooling process streams. One part of this steam (167 MW) is used in the process and the remainder (17 MW) is expanded in turbines and used for other purposes.

The energy saving potential, i.e. the theoretical savings that are achievable depend on the constraints that are put on the heat exchanging between process streams in the refinery. Three levels have been analysed.

A: There are no restrictions on the process streams that may be heat exchanged in the refinery. In this case the minimum heat demand is 199 MW giving a theoretical savings potential of 210 MW.

B: All streams within each process unit can be exchanged with each other, but heat exchange between process units is not permitted. In this case the minimum heat demand of each process unit must be calculated. Some of the identified pinch violations are impossible to eliminate, due to process constraints, and the minimum heat demand is thus corrected to reflect this. The total savings potential, 140 MW, is calculated by adding the savings potential for the separate units. However only a part of the steam generated above the pinch can be eliminated since it is used for heating purposes in other process units. Only the steam surplus can be considered a savings potential and the total potential is reduced to 117 MW.

C: Heat exchange between process units is allowed for those streams which are heat exchanged with utility today (e.g., steam, air, cooling water). The heat exchange takes place with the aid of one or more utility system. However, it is not allowed to modify existing process to process heat exchangers to improve heat exchange between process units. The scope of the analysis is limited by only looking at the 5 largest process units. This group of units are using ~90 %, 363 MW, of the added external heat. If heat from the flue gases is recovered at a higher temperature it is possible to reduce the external heat demand with 26 MW to 337 MW.

Key words: Pinch analysis, Process integration, Stream data extraction

Contents

1 Introduction

This energy inventory and pinch analysis of the Preem, Lysekil refinery is part of the Preem – Chalmers cooperation. CIT Industriell Energi is involved in this cooperation as an extra resource to support Chalmers in cluster 1 (Process integration of new processes) and 2 (CCS in refineries).

The aim with this inventory is mainly to supply the researchers at Chalmers with energy data from the whole refinery in a form that is suitable for different types of pinch analysis. Furthermore the aim is to make an analysis to establish the possible saving potentials at various levels of process integration constraints.

The inventory was performed during November - December 2011, partly with the assistance from process engineers at Preem, Lysekil. The analysis was carried out during the summer 2012.

2 Energy inventory

This chapter includes a description of the method and assumptions used to extract data and to establish stream data to be used for pinch analyses. The way we have defined present heat demand is explained.

2.1 The stream data extraction

To be able to perform a pinch analysis, data for process streams has to be collected. This has been made using the following material received from Preem:

- PFD Process flow diagrams
- Screen dumps from the process computer
- Studies made at Preem
- Contact with process engineers at Preem and access to present and historical data from the process computer

All the screen dumps are taken out on the same day (2010-04-23) and almost at the same time of day. They have been used for another detailed study and are taken at a time and operation situation that is typical for stable and normal operation.

Stream data has been extracted for all streams that have been identified on the process flow diagrams (PFDs) for all units of the refinery. Service areas and tank farm is not included.

All streams have been identified on the PFDs with a number, area-stream no[1]. The stream data extraction is documented in a file where each unit has a separate worksheet. For each stream there is a calculation area with the information gathered to explain the choice of data used as stream data for the individual stream. The calculation area is headed with the given stream number and a short description, example *150-1 Från D-1509 till R-1501*. The text in the file is with a few exceptions in English. A process stream is a stream from one piece of equipment to another, and can pass several heat exchangers in between.

Most of the data collection has been made from the screen dumps. In many cases temperature and flows are easy to identify. T_{start} and T_{target} are necessary to determine, but also temperatures between heat exchangers are valuable to

[1] The PFD with stream identification numbers have been scanned and are available at CIT Industriell Energi.

know when stream data is established and especially when the heat exchanger network is constructed.

Calculation of stream load, the increase or decrease of enthalpy in the stream, is made by using known data of flow and physical data. Flow is not always given and physical data depends on composition, which is not always known.

If necessary data is not available from the screen dumps, data has been estimated if sufficient data for equipment nearby is given. For the most important data, process engineers have been involved to give background information and assistance to find the best estimation possible. They have also been of assistance to check the data found on the screen dumps but that have seemed unrealistic. Logged data from the process history have been useful in some cases.

Heat transfer to process in furnaces has been calculated as the difference between the energy of fuel gas supply to furnace (given by Preem data) and the heat content of the flue gases leaving the furnace.

Excess heat in flue gases (i.e. heat in flue gases leaving the furnaces) is calculated and added as hot streams in the stream data sheet. We have assumed that the flue gases can be cooled to 125 °C. Even if the flue gases are used for steam generation or air preheating, we represent them as available hot streams, since they could be used for process integration. If the heat demand is reduced due to process integration, less fuel gas will be used in heaters and less excess heat will thus be available in the flue gases. This has been taken into consideration when calculating the heat reduction potential.

The following temperature contributions were used to define the minimum temperature differences in heat exchanging:

Process	15 K
Condensing/boiling HC	10 K
Water	5 K
Condensing/boiling water	2,5 K

There are uncertainties in the data used. For important process data the instruments are very accurate, but there are also indicators that are less accurate. This becomes obvious when the duty for a specific heat exchanger is calculated for the hot and the cold stream respectively. The difference in duty can be quite large. Possible sources to the error are:

- lack of instrumentation
- accuracy in instrumentation (flow, temperature)
- not the correct physical data (unknown composition, phase change, temperature & pressure not correctly indicated)
- instrument on screen dump shown in a position that does not agree with the right physical position

In the report "Pinch Analysis at LYR-Data", Appendix 1 the resulting stream data sheet from the stream data extraction is listed. The stream data consists of T_{start}, T_{target}, Q and heat exchanging minimum temperature contribution.

The stream data file with all the background material is administered by CIT Industriell Energi. The file is updated if better information is found, but the file is not updated due to physical changes at the refinery.

2.2 Energy balances in the refinery

2.2.1 Present energy use - energy balance of the total refinery

The refinery has a net heat demand of 409 MW which is supplied by firing fuel gas. The heat is transferred to the process heat sinks by flue gases and hot oil. Heat supplied in H-2901 is not included in the pinch analysis since it is considered a reactor and cannot be replaced by another heat source.

Steam is generated in the process by cooling process streams. One part of this steam (167 MW) is used in the process and the remainder (16.8 MW) is expanded in turbines and used for other purposes, e.g. steam tracing, see Figure 1. Notice that the heat demand covered by the steam is not an extra demand since the steam is produced in the process. Thus the process steam demand of 167 MW is included in net demand of 409 MW.

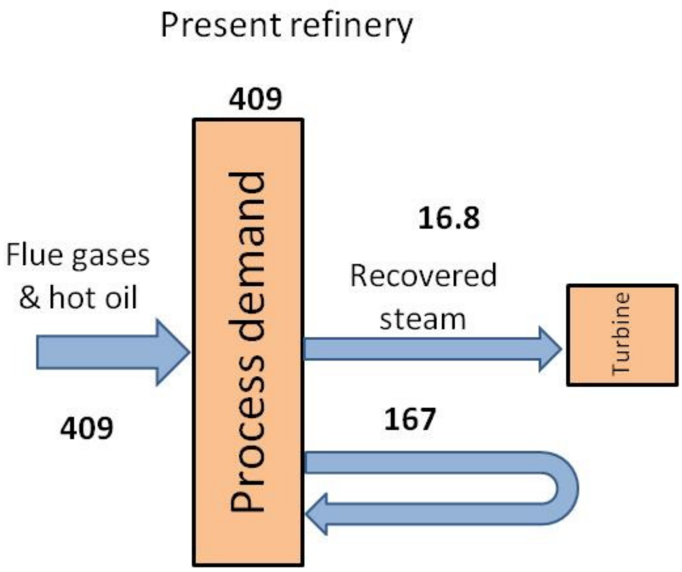

Figure 1 Heat balance of the present refinery

2.2.2 Energy balances of group of units - principles

When analyzing separate process units individually or groups of process units the energy balances become more complex. This is due to steam generation in a unit not necessarily is used in the same unit but is exported and used in another unit where there is a deficit of steam.

In this analysis the net heat demand of a process unit (or a group of process units) is calculated as the sum of the process heat demand supplied by flue gases and the net steam demand. There is no credit for steam export which implies that-the sum of all individual heat demands of the units is larger than the total refinery heat demand. See example below in Figure 4.

The calculation principle is below (Figure 2) exemplified for the CDU+VDU unit (these two process units are heat integrated and in this analysis considered to be one process unit). In this unit the net heat demand is 181 MW since the steam used for heating is generated in the unit.

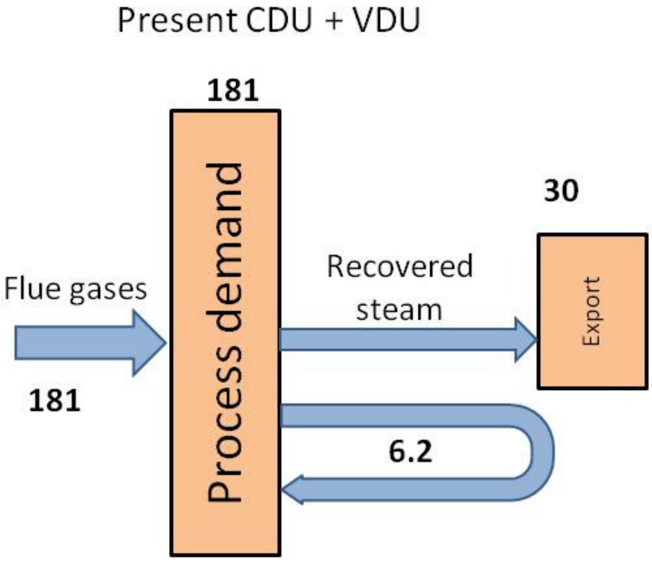

Figure 2 Heat balance of the present unit CDU + VDU

Another situation is in the SynSat unit where the heat demand is calculated as the sum of the heat supplied by the flue gases and the supplied by the steam (18.3 MW) since no steam is generated within the unit resulting in a necessary import of steam.

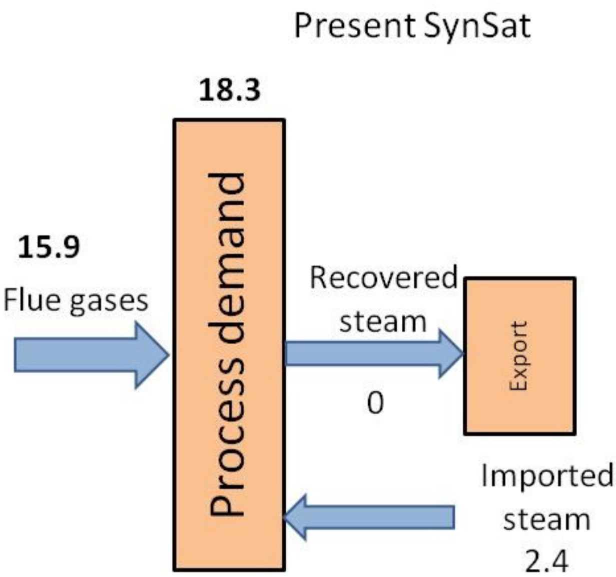

Figure 3 Heat balance of the present unit SynSat

Figure 4 shows a refinery consisting of four process units (A to D) with a total heat demand of 72 MW. The net heat demand of process units A, B and C is calculated as the sum of the heat demands supplied by flue gases, 42 MW (=12+10+20) and the net heat demand supplied by steam that is not generated in the units, 2 MW (=10-6-2). Thus the net heat demand of the three process units is 44 MW.

If the energy demand of the four process units are calculated separately and added the total energy demand would be 82 MW (flue gas = 12+10+20+30, steam = 10) compared to the net demand 72 MW.

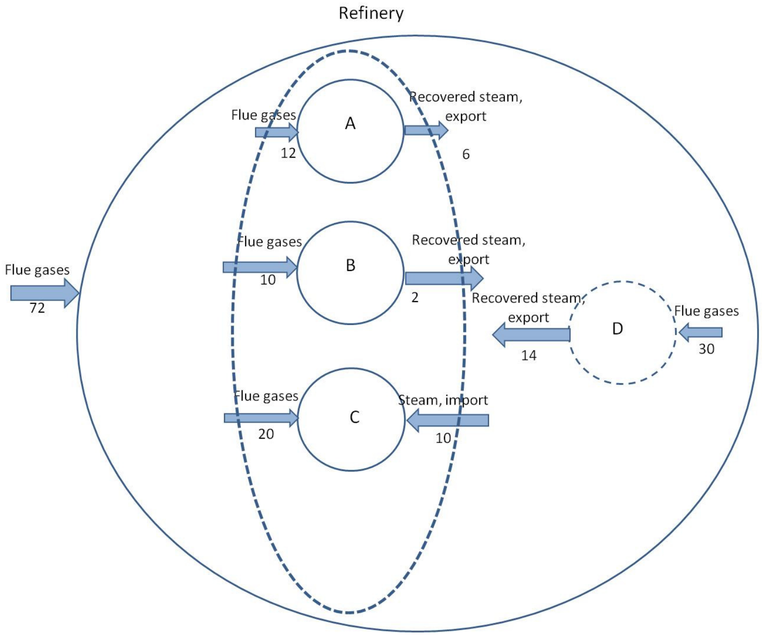

Figure 4 Net heat demands of a group of units

2.2.3Practical calculations

To establish the present utility demand for the separate units all individual heat exchangers heated or cooled with utility are identified and listed (this list is also used to analyze possible heat exchange between utility levels, see case C in Chapter 3). The present utility demand is calculated as the sum of the load of these heat exchangers according to the principles outlined above.

3 Methodology to determine energy saving opportunities

The energy saving potential, i.e. the theoretical savings that are achievable depend on the constraints that are put on the heat exchanging between process streams in the refinery.

Several levels can be identified:

A There are no restrictions on the process streams that may be heat exchanged in the refinery. This means that heat exchange between process streams in different process units is possible and that the process units thus become integrated.

B All streams within each process unit can be exchanged with each other but heat exchange between process units is not permitted.

C Heat exchange between process units is allowed for those streams which are heat exchanged with utility today (e.g., steam, air, cooling water). The heat exchange takes place with the aid of one or more utility systems. However, it is not allowed to modify existing process to process heat exchangers to improve heat exchange between process units. This level of constraint can be considered as an intermediate level where some integration of the process units is allowed.

In order to identify possible savings for the different constraints the following working procedures are proposed.

3.1 Level A: No restrictions on the process streams that might be heat exchanged

The minimum heat demand is calculated by constructing the grand composite curve using all streams in all process units and with assumed minimal individual temperature differences. The theoretical saving potential is then calculated as the difference between the present demand of the refinery and the minimum demand calculated with all streams.

$Q_{\text{saving potential}} = Q_{\text{present demand, total refinery}} - Q_{\text{minimum heat demand, all streams}}$

3.2 Level B: All streams within each process unit can be heat exchanged with each other

The minimum demand in each process unit is calculated by constructing the grand composite curve using all process streams in that unit. The saving potential in each unit is the difference between the present heat demand for the unit and the minimum heat demand. The minimum heat demand can be reached if all pinch violations are eliminated. However some pinch violations are impossible to eliminate due to the fact that they are necessary for the process. The minimum heat demand is thus corrected to reflect this constrain.

The total savings potential can be calculated by adding the savings potential for the separate units. If steam is generated above pinch in a unit, which is a pinch violation, this steam can be used in other process units. If this pinch violation is eliminated the steam demand would have to be supplied with steam produced in a boiler. Thus only the surplus of this kind of generated steam can be considered a savings potential.

$$Q_{\text{saving potential}} = \sum_{i}^{all\ process\ units} (Q_{\text{present demand, i}} - Q_{\text{corrected minimum heat demand, i}}) - Q_{\text{used process steam generated above pinch}}$$

3.3 Level C: Streams which today are heat exchanged with utility may exchange heat with other process units with the aid of utility systems.

The stream data (see the report "Pinch Analysis at LYR-Data", Appendix 1) describe streams that have to be cooled or heated. The stream heat duty is calculated by analyzing the process and by using thermodynamic data for the media. Thus this type of stream data does not show the individual duty of specific heat exchangers but rather the heating or cooling demand of a specific process stream. In the Level C analysis we instead focus on the heat exchangers.

The aim of Level C analysis is to evaluate the potential to increase the heat integration of the processes with largest heat consumption by exchanging heat from the cold utility to hot utility. To do this all process stream segments either cooled or heated with utility are identified and listed together with the utility used, see the report "Pinch Analysis at LYR-Data", Appendix 2. Flue gas from furnaces is used as utility to heat process streams. After the furnace there is still heat in the flue gas and the flue gas stream with the remaining heat is considered as a process stream.

From the stream segments cooled by utility and the excess heat in the flue gases, the source curve can be constructed. The sink curve is constructed in the same way from stream segments heated with utility. Furthermore the cold utility curve which shows the demand and temperature of cold utilities can be constructed from the cold utility used. The hot utility curve, showing the demand and temperature of hot utilities, can be constructed from the hot utility used.

The heat recovery is represented by the distance where the profiles of the heat source and heat sink overlap each other and thus also the minimal heat demand can be identified as the distance between these curves, see Figure 5. The saving potential is then calculated as the difference between the present heat demand of the refinery and the minimum identified in the diagram.

$$Q_{\text{saving potential}} = Q_{\text{present demand, total refinery}} - Q_{\text{minimum heat demand}}$$

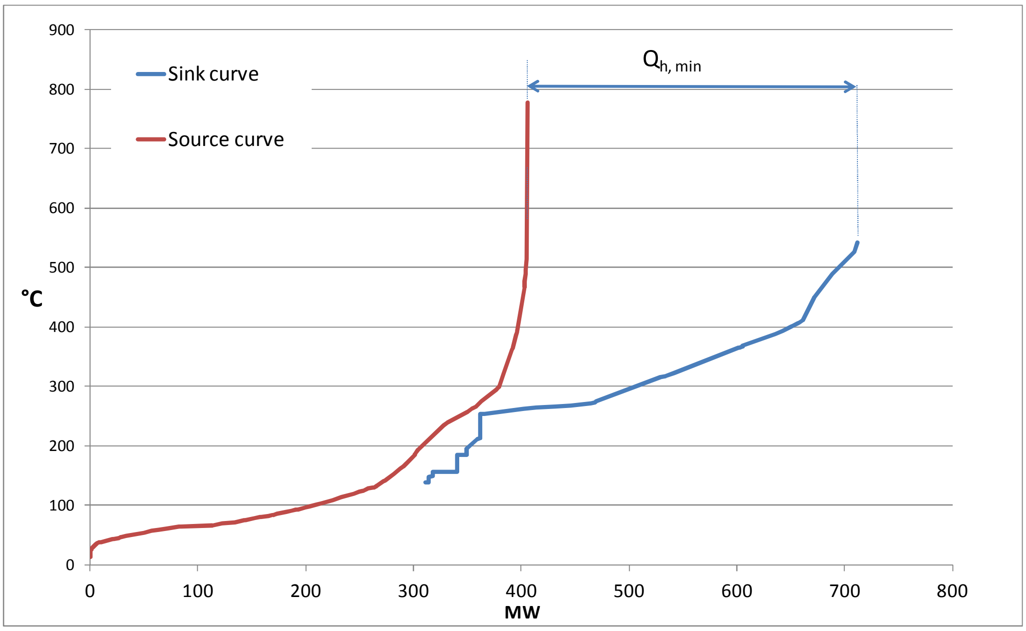

Figure 5 Minimum external heat demand for the process streams heated and cooled by utility. Δ T = 20 K.

To achieve maximum integration extensive change in utility systems is necessary. By including the utility curves in the graphical representation the possible changes are easier to identify see Figure 6.

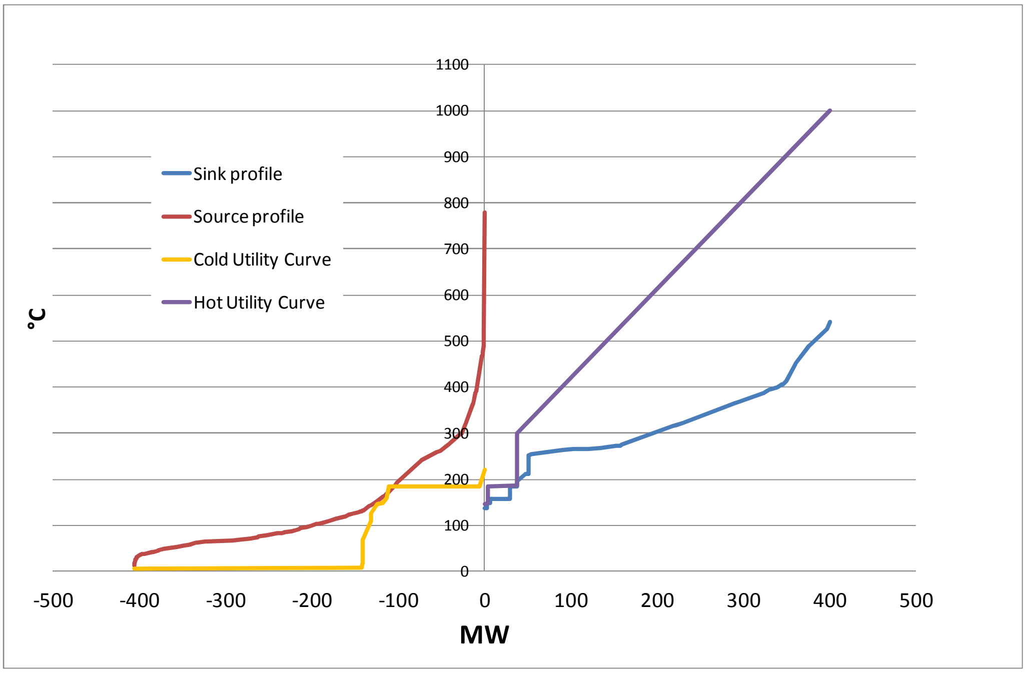

Figure 6 The Source Profile (hot process streams) that are cooled with cold utility (Cold Utility Curve) – the and the Sink Profile (cold process streams) that are heated with hot utility (Hot Utility Curve)

To determine the saving potential using the present utility system, the curves are shifted until the profiles of hot and cold utility touches each other.

Possible savings by minor changes to the utility systems can also be identified. If the Source curve and the Sink curve can be further overlapped, the heat recovery will increase. To be able to increase the overlap, the utility system must be modified so that the cold utility and hot utility curves does not overlap.

4 Results of pinch analysis

The result is presented for the three levels of heat exchange constraints according to Chapter 3:

Level A – no restriction in heat exchange between process units

Level B – only heat exchange within process units

Level C – heat exchange between process units only permitted for heat exchangers using utility

4.1 Level A: Calculation of minimum heat demand for the refinery

The minimum heat demand for the refinery is calculated with pinch analysis where all the process streams for the entire refinery are included. Data for the process streams are listed in the report "Pinch Analysis at LYR-Data", Appendix 1.

The minimum heat demand is 199 MW and the Grand Composite Curve is shown in Figure 7. This minimum heat demand should be compared to the present energy demand, 409 MW (calculated in 2.2.1). The theoretical savings potential is thus 210 MW. This savings potential assumes that all process streams in all process units can exchange heat and would require extensive modifications of the existing heat exchangers. The potential should be regarded as a very theoretical number that is calculated to indicate that there is energy savings potential.

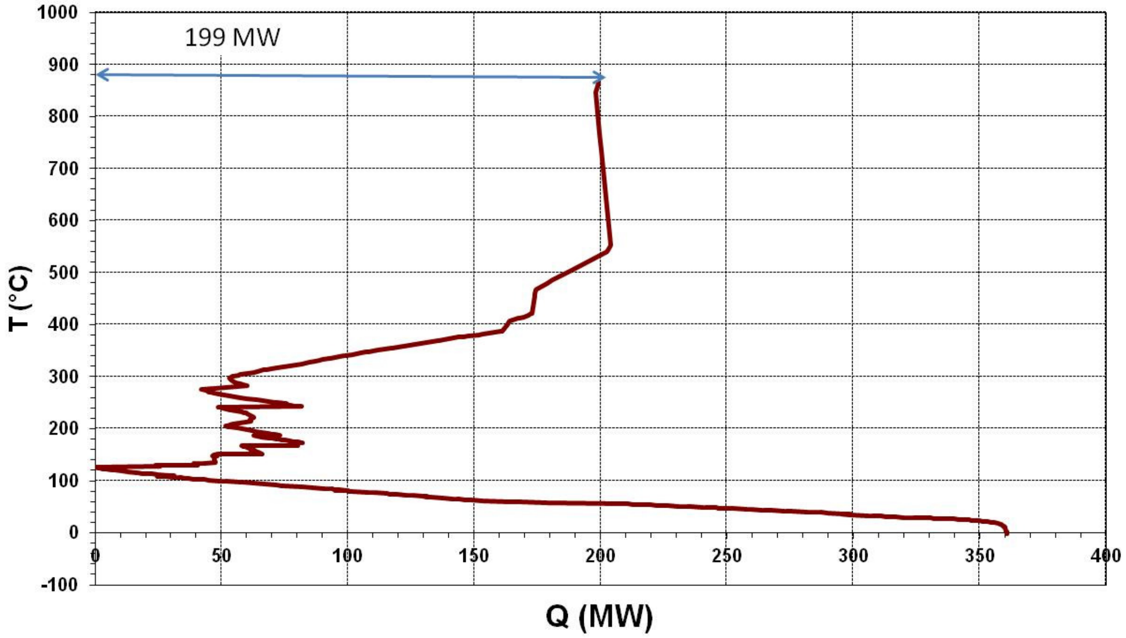

Figure 7 Grand Composite Curve including all streams at the refinery. The figure show that the minimum heat demand, $Q_{h,\ min}$, is 199 MW.

4.2 Level B: Calculation of minimum heat demand for separate process units

4.2.1 Identification of pinch violations

To reach the energy savings potential at Level B all the pinch violations in the separate process units must be eliminated. It is often hard to eliminate pinch violations. How difficult the elimination is depends on the type of pinch violation (cooling above pinch, heating below pinch or heat exchange through pinch) at what temperature level the pinch violation occurs and practical possibility to rearrange the heat exchange. To find out what kind of pinch violations there are, the heat exchanger networks of the process units with the five largest heat demands were evaluated. The Grand Composite Curves of the five largest process units are shown below in Figure 8.

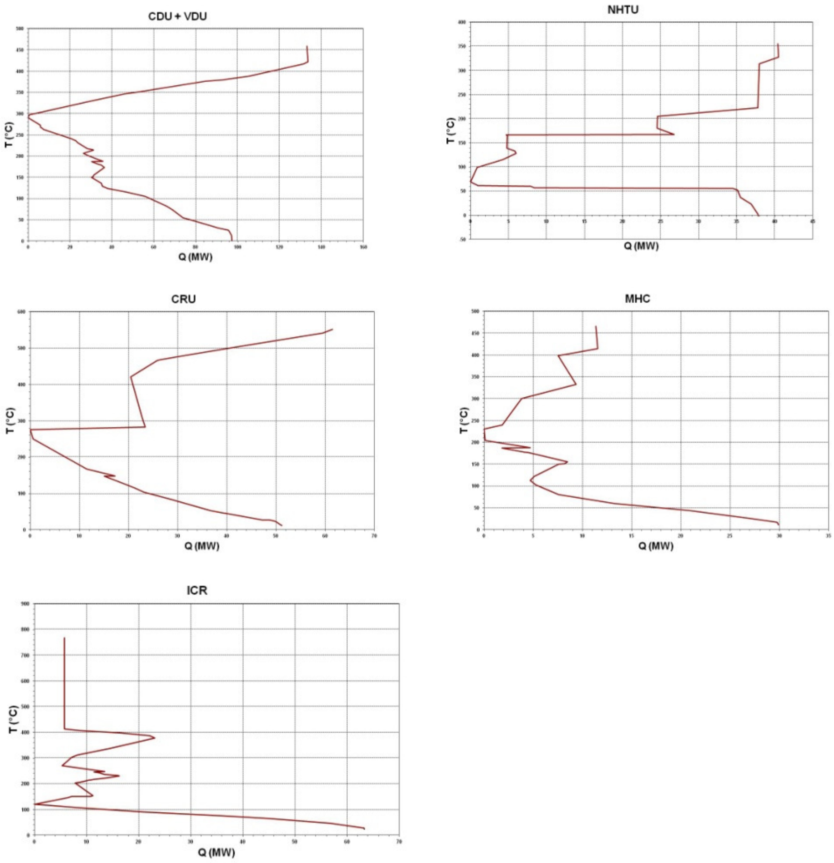

Figure 8 The Grand composite curves of the process units with the largest heat demand.

Table 1 summarizes the pinch violations that were identified when the networks were evaluated.

If steam is generated when cooling above pinch it is specified in the table. Heating below pinch is in some cases supply of steam used as stripping steam in towers and cannot be replaced by heat integration. This is also indicated in the table.

A detailed description of the pinch violations is found in the report "Pinch Analysis at LYR-Data", Appendix 3.

The pinch temperatures of the separate process units are very different (from 298 to 69 °C). This means that excess heat from the process units with high pinch temperature could be available to the units with lower pinch temperature. This explains why the sum of all the minimum heat demands of the individual process units is more than the minimum heat demand of the total plant. Some heat integration between process-units exists but more site-wide process integration could reduce the energy demand.

Table 1 Pinch violations in the five process units evaluated

Process unit	Pinch temperature [°C]	Cooling above pinch/Steam generation [MW]	Heat down through pinch [MW]	Heating below pinch/Stripping steam [MW]	Total pinch violations (net evaluation) [MW]	Savings potential from PA [MW]
CDU + VDU	298	10.6/~10.6	15.6	22.7/6.5	48.9	48
NHTU	69	8.6/0	0	2.3/0	10.9	8.7
CRU	275	10.0/0	11.1	2.2/0	23.3	16.9
MHC	230	4.2/0	14.2	6.2/3.6	24.6	25.3
ICR	120	32/28,9	8.6	0	40,6	39.8

Total pinch violations (identified by network construction) should be equal to identified savings potential (calculated with pinch technology). There is some difference that is due to poor data quality, which leads to different Q on the two sides of the heat exchangers so that streams are not ticked off properly when the network is constructed.

4.2.2Energy savings potential

The minimum heat demand for each process unit is calculated with pinch analysis. To reach the minimum heat demand all pinch violations must be eliminated. Some of the identified pinch violations are impossible to eliminate due to the fact that they are necessary for the process, such as stripping steam added below pinch (described in 4.2.1). The minimum heat demand is thus corrected to reflect this constrain. The corrected minimum heat demand and the theoretical energy savings potential is presented in Table 2.

The units CDU and VDU have been analysed together since these two units are already heat integrated.

Table 2 Heat demand and potential savings for the separate units at the refinery

Process Unit	Corrected minimum heat demand $Q_{h,min}$ [MW]	Present heat demand* Q [MW]	Energy savings potential ($Q–Q_{h,min}$) [MW]
FCC	4.0	0.0	0.0
CPU	4.3	0.9	0.0
CDU +VDU	139.2	181	41.5
NHTU	40.4	49.0	8.7
CRU	61.5	78.4	16.9
ISO	26.4	23.4	0.0
MHC	11.4	36.7	25.3
LPG	5.1	3.1	0.0
SRU	3.7	4.1	0.4
ARU 270	28.6	33.2	4.6
SynSat	16.0	18.3	2.3
VBU	6.9	0.0	0.0
ICR	5.8	45.6	39.8
HPU	58.5	29.4	0.0
ARU 830	5.1	5.1	0.0
			140

***For process units with a deficit of steam, external steam used is added to calculate the present heat demand. Process units with a steam excess is not credited for the steam export.**
**** For process units with negative savings potential the potential is set to 0.**

The savings potentials presented in Table 2 show a great spread. Some units even show a lower actual heat demand than the minimum heat demand. One explanation, besides the uncertainty of the input data, can be that the actual temperature difference in the heat exchangers is smaller than assumed when the minimum heat demand is calculated.

The total savings potential can be calculated by adding the savings potential for the separate units. This gives a savings potential of 140 MW. One pinch violation identified in the separate units is cooling above pinch, 40 MW. This cooling is however done with boiler feed water and steam is produced. This steam can be used in other process units. If the pinch violation is eliminated the steam demand would have to be supplied with steam produced in a boiler. There is however more steam produced above pinch than the total demand of the process units. Only this surplus can be considered a savings potential. The surplus is 17 MW. This gives us a new savings potential of 117 MW, (140- (40-17)). The total present energy use is 409 MW, and this could thus be reduced to 292 MW (409-117). All calculations on savings potential are given in Appendix 1.

4.3 Level C: Heat exchange between utility streams – no change in process to process heat exchangers

Minimum heat demand, when only heat exchangers using utility can be modified, is identified using the graphic method described in Chapter **Fel! Hittar inte referenskälla.** as Level C. The scope of the analysis is limited by only looking at the 5 largest process units, see Table 3. This group of units are using ~90 %, 363 MW, of the added external heat.

Table 3 The five largest process units analyzed for increased exchange between utility levels.

Unit	Minimum heat demand $Q_{h,min}$ [MW]	Present energy use, only fuel gas [MW]
CDU + VDU	133	
NHTU	40.4	
CRU	61.5	
MHC	11.4	
ICR	5,8	
		363

4.3.1 Present external energy demand for the selected units

Figure 9 shows the temperature-load profiles for heat exchangers heated or cooled with utility with the present utility demand. The energy demand is covered with heat from furnaces, 363 MW.

The yellow cold utility curve overlap the purple hot utility curve, which means that steam used as hot utility is generated from hot process streams within the selected units. There is an excess of MP steam generated and the present total steam surplus is 34 MW today from the selected units. This steam is used in other process units, turbines and in other services.

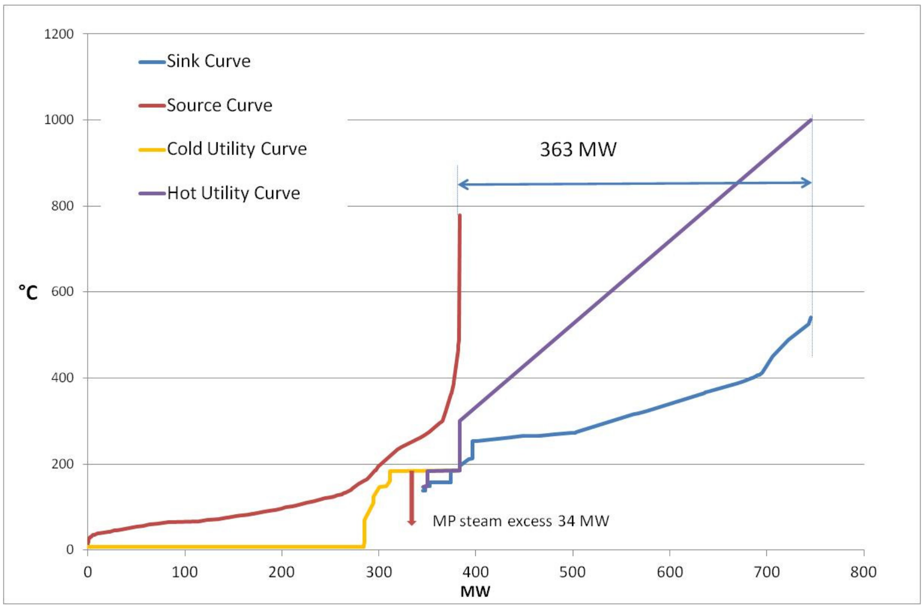

Figure 9 The Sink and Source profile of the process and the hot and cold utility curves with present utility data. The external energy demand is 363 MW.

Figure 9 shows that if heat from the flue gases is recovered at a higher temperature the two curves could be pushed together and reduce the external heat demand. This is illustrated in Figure 10.

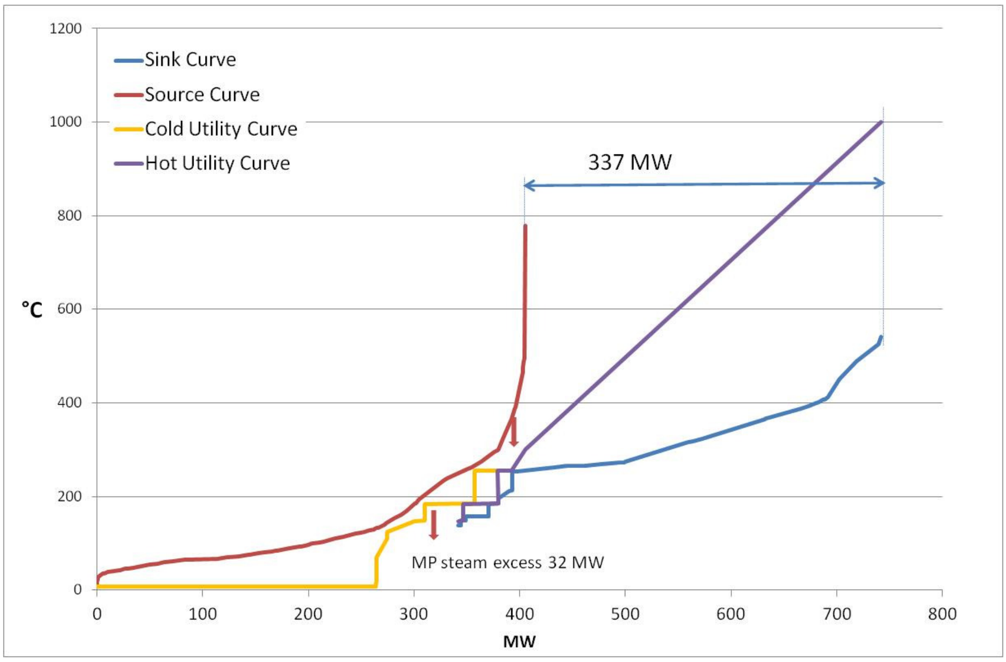

Figure 10 Process curves and utility curves after modification of the utility system. The MP steam production will decrease with 2 MW, and the external heat demand will be reduced to 337 MW.

If the flue gas heat is used for heating process streams by using new utilities at higher temperature, less external heat is needed for the process.

The gap between the source and the sink curve would be 337 MW, which means that heat from fired heaters can be reduced with 26 MW (363-337=26). The excess MP-steam production will be almost the same, 32 MW.

It is also possible from Figure 10 (from the source and sink curves) to identify at which temperatures excess heat can be available and at which temperatures heat must be supplied. These loads are shown in Figure 11.

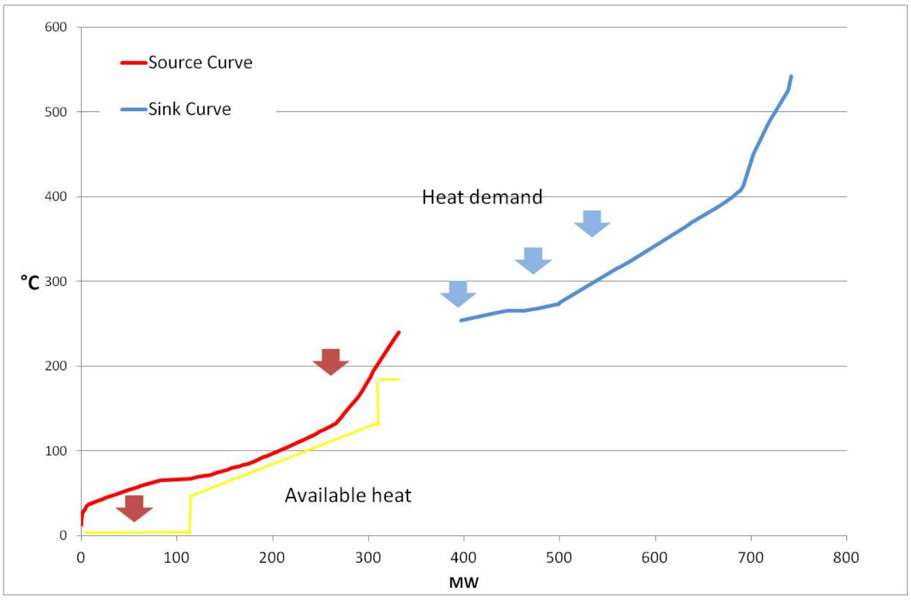

Figure 11 Process source and sink curve showing available heat and heat demand. The cold utility line show today's utility with possible surplus steam generation and heat cooled with air or cooling water. The heat demand is covered with flue gases from furnaces.

4.3.2Further improved utility system

By introducing infinite utility levels all heat can be transferred from the Source Curve to the Sink Curve where they overlap. This would reduce the heat demand to 306 MW, see Figure 12.

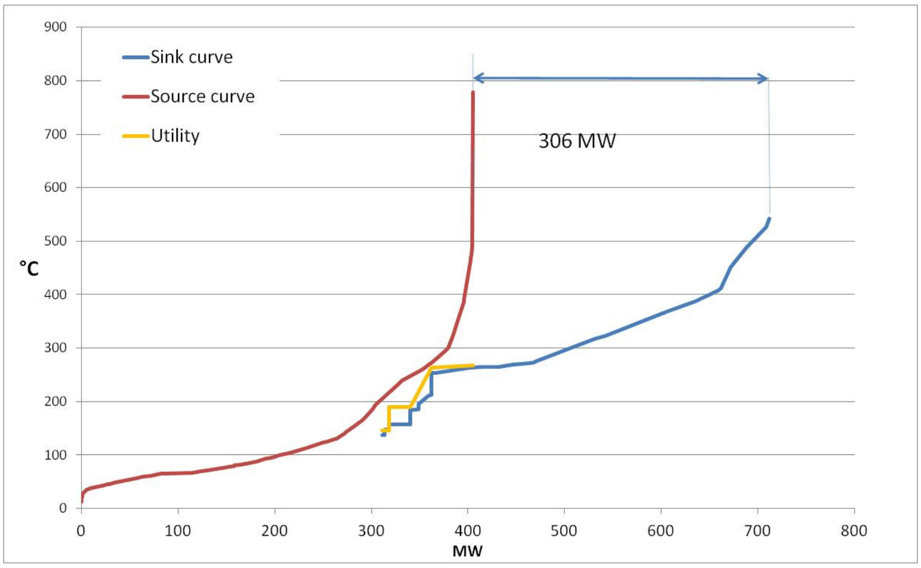

Figure 12 Maximum heat recovery with new design of utility levels.

Appendix 1

[MW]	Present heat supply*	Flue gas heat	Steam net input	Minimum heat demand	"Necessary" pinch violations**	Corrected minimum heat deman	New potential heat reduction		Steam generation above pinch	Steam generation below pinch
FCC	0,0			0,0	4,0	4,0	0,0			20,9
CPU	0,9		0,9	4,3		4,3	0,0			
CDU+VDU	180,7	180,7		133,0	6,2	139,2	41,5		10,8	25,4
NHTU	49,0	23,3	25,7	40,4		40,4	8,7			
CRU	78,4	76,2	2,2	61,5		61,5	16,9			
ISO	23,4		23,4	26,4		26,4	0,0			
MHC	36,7	36,7		11,4		11,4	25,3			6,4
LPG	3,1		3,1	5,1		5,1	0,0			
SRU	4,1		4,1	3,7		3,7	0,4			
ARU 270	33,2		33,2	28,6		28,6	4,6			
Synsat	18,3	15,9		13,6	2,4	16,0	2,3			
VBU	0,0			2,5	4,4	6,9	0,0			34,2
ICR	45,6	45,6		5,8		5,8	39,8		28,9	
HPU	29,4	29,4		17,2	12,2	29,4	0,0			57,3
ARU 830	5,1		5,1	5,1		5,1	0,0			
	508	408	98	358	29	388	140		40	144
							117			
							corrected for steam surplus			

* Calculated as **flue gas heat + (steam input-steam output)** if steam input>steam output

** Steam necessary for process - supplied below pinch