Possibilities to implement pinch analysis in the steel industry – a case study at SSAB EMEA in Luleå

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Abstract: Steelmaking is an energy intensive industry. Much development work has been accomplished during the past years to make the processes more efficient. Process integration has come to play an important role for identifying efficiency measures, using mathematical programming as general tool. So far only a few minor process integration studies using pinch analysis have been made in this type of industry, and only on smaller sub-systems. This paper presents the results of a pinch targeting study that was conducted at the Swedish steel making company SSAB EMEA in Luleå. The pinch analysis methodology was originally developed to study heating, cooling and heat exchange in process systems with many streams. In the steel industry there are relatively few streams that are appropriate for heat exchange. This limits the use of pinch analysis. However, this study demonstrates that pinch analysis is a powerful tool for certain subsystems, especially the gas cleaning unit of the coke plant. The paper includes several suggestions for improved energy efficiency in this section of the steel plant.

Keywords: *Pinch analysis, Energy efficiency, Steel industry, Process integration*

1. Introduction

1.1. The steel industry

The steel industry sector is the second largest industrial user of energy in the world. In 2007 it used 24 EJ or 6700 TWh according to IEA [1]. Steel is an important construction material and the production has increased with the growth of the world economy. The development of the world production of steel is shown in Fig. 1.

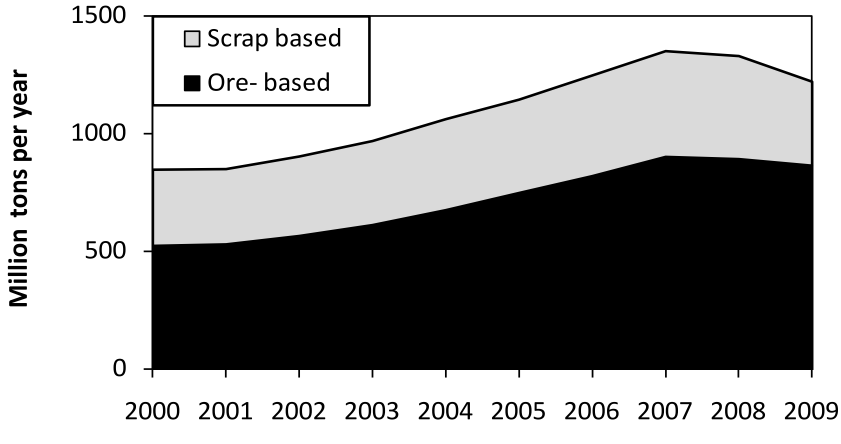


Fig. 1 Development of world steel production from ore and scrap based route[2]

The diagram shows a steady growth except from the recession years 2008-2009. A considerable part of reactants and fuels that are used in the processes are of fossil origin. The combination of production increase and use of fossil energy puts an emphasis on work to decrease energy consumption. One road to achieve this is to improve the processes to decrease their consumption. A large amount of work is and has been carried out in this area. It is, however, considered out of scope for this paper and not described here. A second road is to improve the system efficiency, with process integration as one important tool. That type of work is the subject of this paper.

Steel is produced using two alternative routes: an ore based route where primary steel is produced from iron ore and a scrap based route where recycled steel (scrap) is re-melted (Fig. 2).

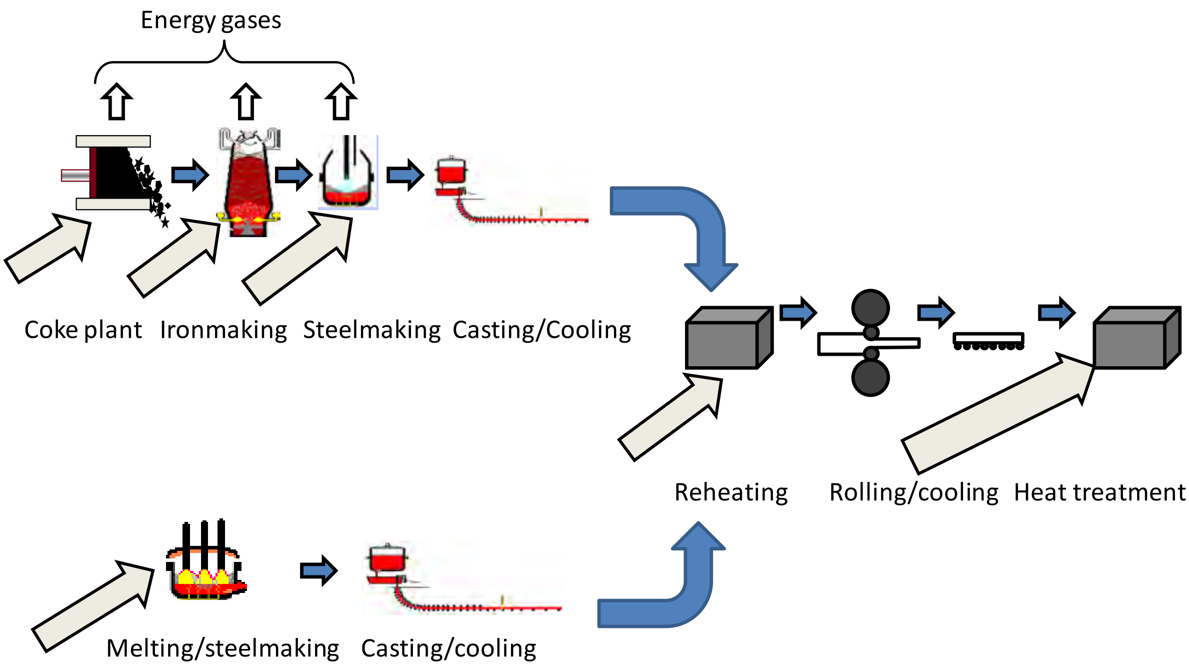


Fig. 2 Process route for ore and scrap based steel production

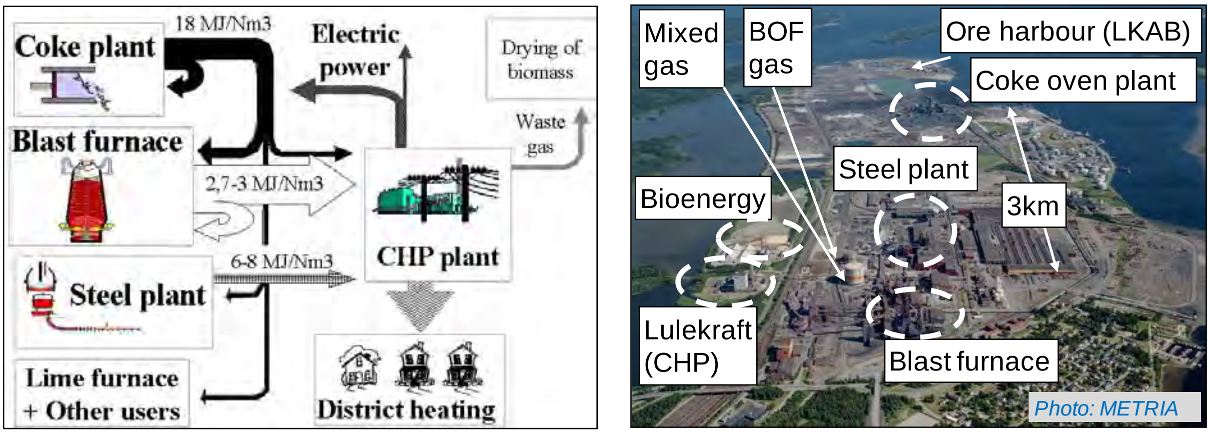
The upper branch in Fig. 2 illustrates the ore-based route. The production is based on coal and ore (mainly iron oxide). The coal is converted to coke by dry distillation in a coking plant. Approximately 25% of the weight is recovered as energy rich gas, tar and chemical products. The ore, e.g. in the form of pellets, is fed into the blast furnace along with coke and preheated blast air. The blast furnace produces a hot liquid metal with high carbon content. A combustible gas is obtained as a by-product. The hot metal is transformed into steel in an oxygen converter (BOF). An energy-rich gas is obtained as a by-product. After ladle treatment the steel is cast in a continuous casting machine. The semi-finished cast steel is cooled and transported to a rolling mill where it is heated to rolling temperature and rolled (or forged) into products and cooled on a cooling bed. Depending on the product, there may be additional treatment, such as heat treatment, cold rolling and metal coating (e.g. zinc). In most cases by-product energy gases from iron and steel-making are used in the reheating furnaces.

After some time the steel products are returned as scrap, and converted into new steel using the scrap based route (lower branch in Fig. 2). The scrap is melted and heated, usually in an electric arc furnace. The molten steel is then refined. This post-processing can be carried out in the furnace, in the ladle treatment or in a separate unit, e.g. refining with oxygen in a so-called AOD converter. Then the finished steel is cast and treated in the same way as in the ore-based route. This recirculation is an important part of the steel economy.

The system studied in this work is the SSAB EMEA steel plant in Luleå. This is an ore-based plant. The by-product energy gases cannot be used for preheating as the rolling mill is situated 800 km from the steel plant. Instead they are used in a local CHP plant, which co-produces electricity for the steel plant and district heating for the community (see Fig. 3 a.

1.2. Process integration and Pinch analysis

A typical process industry does not consist of independent process units. Instead, it is a network of units exchanging energy and energy media with each other. Very often the local community is also involved in the network, e.g., through power generation and/or district heating. The flowsheet and photo in Fig. 3 show the network that is studied in this paper.



a) Flow sheet *b) Actual plant*

Fig. 3. Network of the Luleå energy system.

The different units exchange energy and material with each other. Changes in one unit have side effects on the other units. Energy saving in one unit does not necessarily lead to energy saving of the total system. A global approach is needed to avoid sub-optimization. A flowsheet does not tell the whole truth. At the actual plant site there is usually a great distance between some units, in this case up to 2-3 km (see Fig. 3 b). Some connections that would be optimal from an energetic point of view may be impossible from a practical and economic point of view. A good analysis tool should be able to select the solution that is technically and economically most attractive.

A first attempt to make a more systematic analysis of this type of problem using pinch analysis was made at Manchester University in the UK [3]. In this type of analysis, the heat-carrying media are categorized as either cold streams (media that require heating during the process) or hot streams (media that require cooling). Based on this information it is possible to construct *composite curves* in order to determine the minimum energy-consumption target for the process. The curves are profiles of the process' heat availability (hot composite curve) and heat demands (cold composite curve). The degree to which the curves can overlap for a specified value of minimum temperature difference for heat exchanging (ΔT_{min}) is a measure of the potential for heat recovery. The point of closest approach of the composite curves, i.e. where ΔT_{min} is reached, is known as the pinch point. The effect of different operations and/or process modifications can be studied using pinch analysis. The relative position of such operations in the composite curves with respect to the pinch point is often a determining factor. Further details are described in Section 2 (Methodology). Pinch analysis has since then become a wide-spread tool for process integration in many industrial systems. Ref [4] can be seen as an example.

Steel industry energy systems are characterized by large high temperature flows of molten, solid and gaseous materials, as well as by energy intensive chemical reactions. Mathematical programming is considered particularly suitable for optimizing energy flows in this type of system. A specific simulation and optimization tool (reMIND) was developed and implemented for steel plant applications ([6], [7]) and has reached a position as standard process integration tool for those applications.

Pinch analysis was originally developed for large systems with many streams that require heating and cooling and that are suitable for heat exchanging. This makes implementation in the steel industry somewhat restricted as there are relatively few streams, and the ones with the largest energy content are in the form of molten metal, hot slag or as radiation from slabs, i.e. unsuitable for conventional heat exchanging. Only limited uses of pinch analysis in the steel industry are reported ([8], [9]). However, previously conducted system studies carried out in the steel sector and PRISMA indicate that there are subsystems where pinch analysis could be a powerful tool. The Swedish Energy Agency and the national program for process integration decided to carry out a study on the possibility to use pinch analysis in the steel and mining sector. A major part of that work was a smaller pinch targeting study of the Luleå Steel plant system.

1.3. Scope of paper

The main scope of this study is to describe the above mentioned targeting study and the conclusions on possible use of pinch analysis in the steel industry.

2. Methodology

The analysis procedure for one of the subsystems (the gas cleaning system of the coke oven plant) is described in more detail to illustrate the methodology.

Data was collected together with coke plant staff. The energy streams were compiled and characterized as hot or cold streams. The cold streams, or ”heating loads”, are shown in Table 1. A similar table (not shown here) was made for the hot streams.

Table 1 Heating loads in the coke oven gas cleaning area

Process part	Unit	T_{start} (°C)	T_{end} (°C)	Flow	Load (kW)
Ammonia stripper	DB 602 A/B	MP steam			5 852
	EB 605 cold side	6.8 [1]	63	22 t/h	≈1 500
Benzene stripper	EA 2363	LP steam			42.3
	DB 2362	LP steam			633
	EA 2361	178	178.1		950
	EB 2261 A-D cold side [2]	27	143	51.8 m^3/h	2 620
2^{nd} feed water preheat	FL 1401	63	124	22 t/h	1 566
Sulfur stripper	EB 601 cold side	26	51	61.1 m^3/h	1 770

[1] Yearly average water temperature in Lule River
[2] Heat capacity of 2.13 kJ/kg K is used for the circulating oil (petroleum) Density = 881 kg/m^3. The load is the average value of the two streams: (3132 kW + 2108 kW)/2

Composite curves (CC) were constructed for the gas cleaning section of the coking plant, shown in Fig. 4, using the stream data. The minimum distance between the curves is set by ΔT_{min}, set at 10 K in this study. Internal heat recovery is theoretically possible where the curves overlap (shaded area). A larger ΔT_{min} would push the curves further apart, thus decreasing the overlap and cause an increasing demand for heating and cooling media ($Q_{H,minimum}$ and $Q_{C,minimum}$).

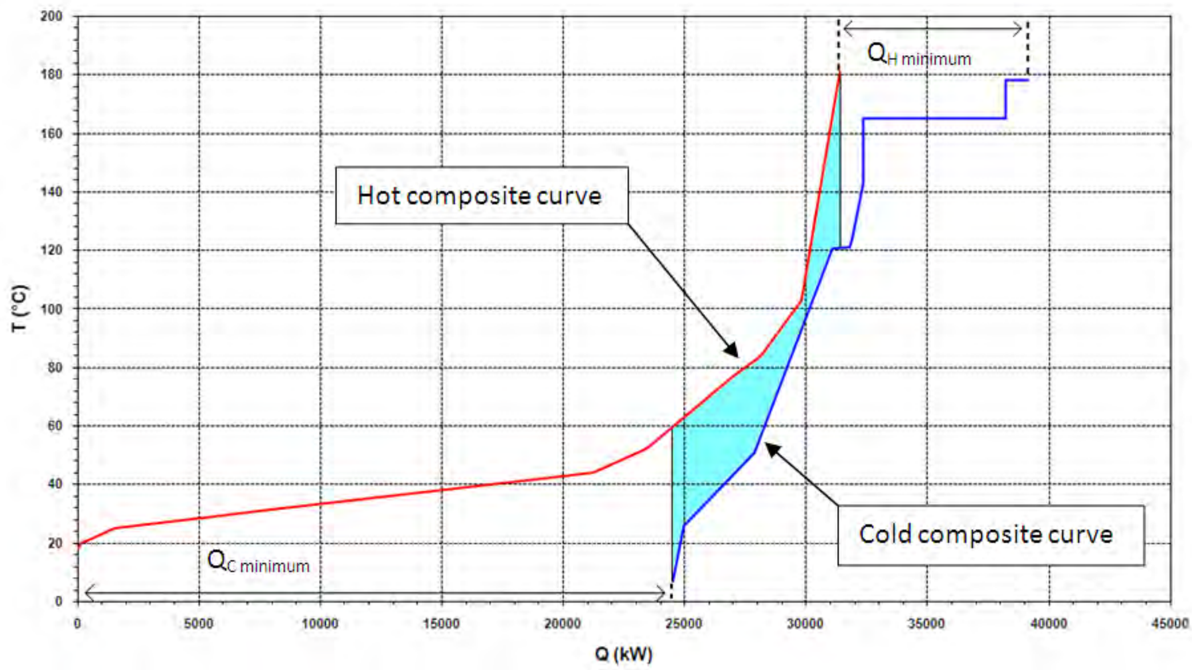


Fig. 4 Composite curves (CC) for the coking plant's gas cleaning area

The CC establish the energy targets (minimum hot and cold utility demand), but are not suitable for identifying appropriate utility steam levels and loads, or whether excess process heat can be used for hot water production instead of using cooling water. The Grand Composite Curve (GCC) is more appropriate for analyzing the interaction between the process and the utility system. Therefore a GCC was constructed for the gas cleaning area. To visualize the correspondence between CC and GCC, these are put next to each other in Fig. 5. The hot and cold composite curves are merged into one curve, i.e. the GCC, by calculating the net heat load in each temperature interval. A new interval can often be identified by a gradient change in the curve.

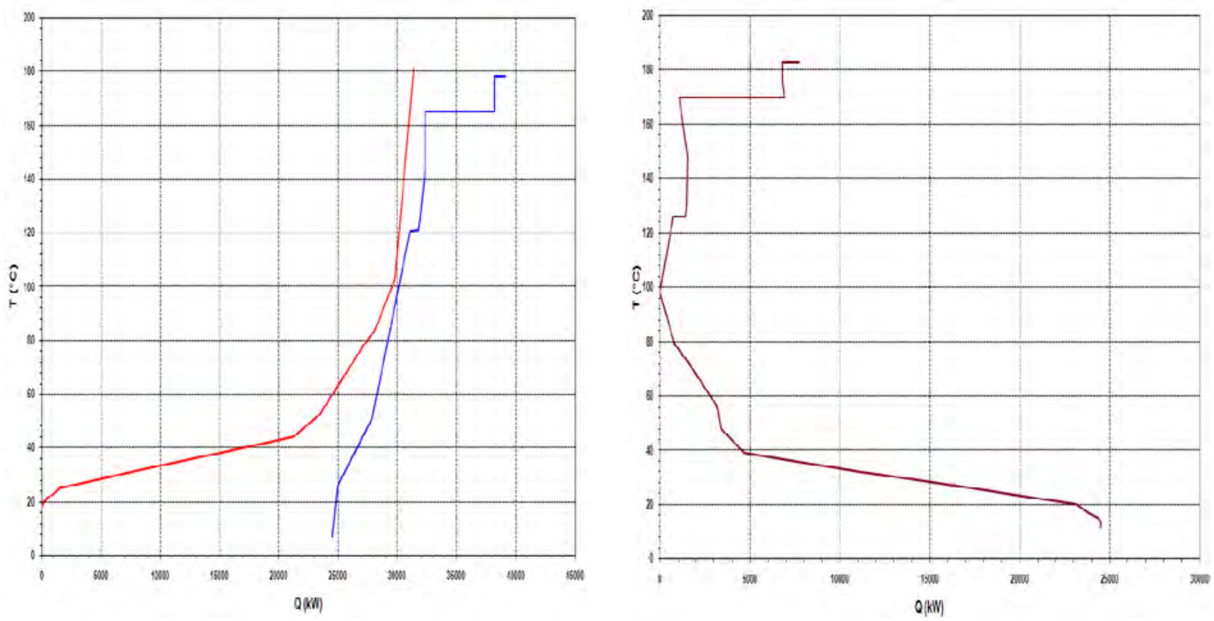


Fig. 5 Composite curves (CC) and corresponding grand composite curve (GCC) for the coking plant's gas cleaning area

A more detailed view of the GCC is shown in Fig. 6, enabling an analysis of different possible utility level setups.

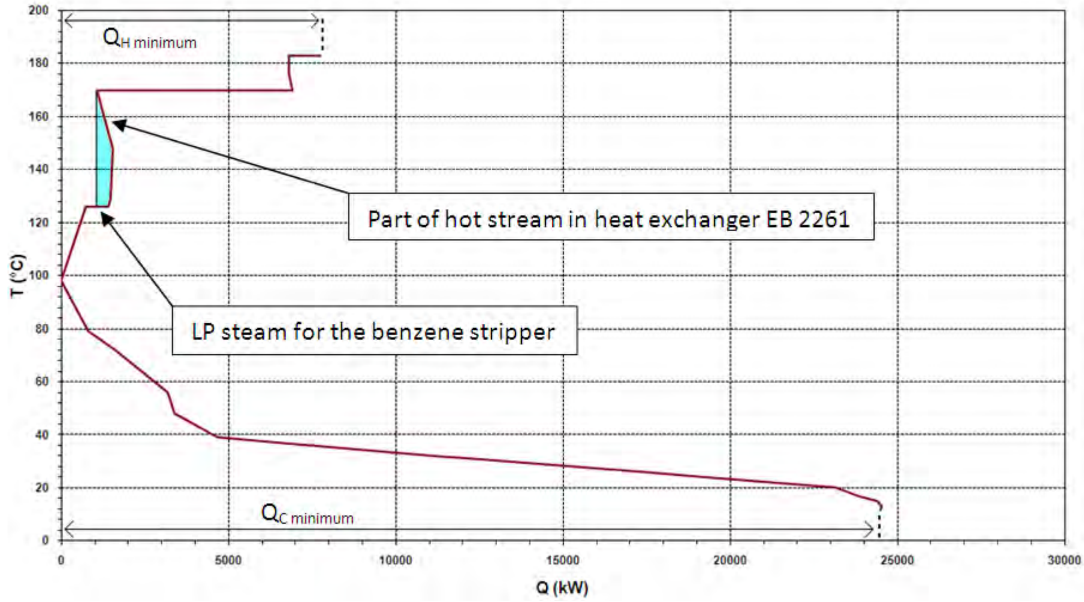


Fig. 6 Grand composite curve for the coking plant's gas cleaning area

One can for example examine whether there is any heat surplus (below the pinch) at useful levels, which could be used for steam generation, district heating, electricity production in a Rankine cycle, etc. The shaded part shows where internal heat exchange between temperature intervals is possible, i.e. a so-called pocket. The curve shows that part of the hot stream in EB 2261 is used to generate LP steam for the benzene stripper. The same methodology was used to analyze the other subsystems and the total plant.

3. Results

3.1. Coke plant

The analysis of the gas cleaning section of the coking plant (Fig. 4) shows that the demand for feed water preheating will decrease since less steam is needed in the process. The current preheating load is approximately 1500 kW in heat exchanger EB 605 and 1566 kW in FL 1401 (Current preheating load ≈3066 kW). The minimum preheating requirement turned out to be 2779 kW in total in this first step of the analysis of the coking plant. The horizontal parts of the lower line represent the demand for condensing steam in the strippers. The slope is determined by the flow multiplied by the heat capacity [kJ/°C] in each temperature interval. In all, the gas cleaning area currently uses 25.7 MW of cooling water whereas the minimum cooling demand, determined by pinch analysis, is 24.5 MW ($Q_{C,minimum}$ in Fig. 4). The process uses 9 MW of external heat, compared to 7.7 MW ($Q_{H,minimum}$.). This means that there is a 14% steam savings potential if a maximum energy recovery heat exchanger network were to be built, assuming ΔT_{min} = 10 K. The pinch temperature is 103°C for hot streams and 93°C for cold streams. That tells us, for example, that external heating media has to be at least 103°C and that the cooling media can be 93°C at the most, in order not to violate the ΔT_{min} of 10 K for heat exchange between utility and process streams.

An extended study (diagram not shown) was carried out to study the effect on heating and cooling loads in the total coking plant area assuming that steam is used at as low pressure as possible. This is particularly important if the steam is extracted from a turbine, in order to maximize electricity production. This showed a 1290 kW steam saving potential. The main reason was elimination of the use of LP steam for feed water heating and avoiding heat exchange through the pinch.

A lot of heat at high temperature is wasted when washing water at around 70°C is used to cool the hot coke oven gas directly after it leaves the ovens. It should be possible to heat exchange the gas down to the tar dew point. A study was made to study what could be gained from such an arrangement. The dew point is between 350 and 150°C. An inlet temperature at a temperature of 450°C (i.e. significantly above the dew point) was assumed to give a safety margin. A gain of 9 MW was indicated if the heat is used to replace steam from the boiler.

3.2. Blast furnace and steel plant

A first attempt was made with separate studies of the blast furnace, the steelmaking converter plant, the ladle metallurgy and the continuous casting. However, limited availability of cold streams limited meaningful implementation of process integration based on pinch analysis. Since the distance between the units was not very large, a merged study of the Blast Furnace-Steel Plant system was tried. The analysis showed a potential hot utility savings of 2.7 MW that could be accomplished by using BOF steam for preheating the inlet gas to the cowper. This is further commented in the discussion chapter.

3.3. Total system

The study indicated that there actually is a match between the two sites, where the steel plant fits in the coking plant's "pocket". Flue gases and hot coke oven gas are in that case used to heat the blast air and steam from the BOF converters is used to run the strippers in the coking plant. There is a difference in load magnitude between the two sites, where the blast furnace and steel plant demand lots of external utility.

4. Discussion

4.1. General results

The expected result was that many sources of excess heat at hot water temperature level would be found. However, that is not the case assuming that this study shows the whole picture. Excess heat is available either at low temperatures, where utilization is more or less impossible, or at levels where steam could be generated. The dominating energy carrier suggested in this study is steam at fairly moderate pressure and temperature (below 200°C). Before heat recovery of that kind is realized, there must be heat sinks where the steam can be utilized. Several options are available but the simplest solution appears to be a steam turbine for electricity production.

4.2. System blast furnace + steel plant

The study in section 3.2 suggested that BOF steam should be used to preheat input cowper gas. For different reasons this is not technically feasible. However, it indicates another option that was not visible with the available stream data. A solution that has been used in some plants is preheating of the combustion air using a heat exchanger with the off-gas from those burners. The results confirm that this is interesting, although a different technical solution was suggested due to lack of detailed data regarding internal cowper streams.

4.3. Analysis of the total system

The analysis shows a large energetic gain by transportation of flue gases and steam between the sites. However, under present conditions this can be judged as less realistic due to the transport distances. Combining the two sites does not seem to be a feasible option just by investigating integration possibilities. It would, however, add a degree of flexibility to have a common steam net.

4.4. Effect of process integration on sustainability

The effect is usually indirect, energy that would otherwise have gone to waste is used elsewhere, e.g. to replace consumption of fuel. Pinch analysis is useful where matches can be found at proper temperature between heat sinks and excess heat.

4.5. Future work

It would be interesting to carry out further studies at other plants. It is suggested that this is done as integrated projects where Pinch analysis is used together with other methods. Commonly available software and educational tools could increase industrial general awareness about pinch analysis.

5. Acknowledgments

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