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An Analysis for Identifying Energy Saving Opportunities for a Petrochemical Cluster in Times of Climate Change

Daniella Johansson* , Simon Harvey
Chalmers University of Technology, Heat & Power Technology, 412 96 Göteborg, Sweden; tel. +46.31.7723008, daniella.johansson@chalmers.se

Industrial process clusters have good opportunities to collectively reduce energy usage and CO_2 emissions. It is however essential to start an energy efficiency analysis with the process plant that is central for the cluster's energy and material conversion. This paper illustrates this strategy for a petrochemical cracker plant located at the heart of a petrochemical cluster. A number of measures are identified that could reduce the cracker plant's CO_2 emissions by 13% and decrease the use of refrigeration by 20 MW. A number of options are discussed for harnessing the energy surplus created.

1. Introduction

Industrial Ecology (IE) has emerged in response to a global call for sustainable development to counteract environmental pollution from industrial wastes. Industrial Symbiosis (IS) and Eco Industrial Parks (EIPs, hereafter referred to as "clusters") concepts have been proposed as a means to achieve these goals, as discussed by a number of authors active within for example the International Society for Industrial Ecology. Improved energy efficiency, a key issue for clusters, can be achieved by applying the Total Site Analysis method (i.e. the complex interaction between utility requirements for a cluster of neighbouring individual plants) proposed by Kemp (2007). One important characteristic of clusters is the interdependency between constituent plants, leading to energy system lock-in effects, i.e. major energy system retrofits are hard to motivate for any individual plant.

Industrial process cluster sites can be attractive for emerging biorefinery concepts with a focus on large-scale conversion of biomass to high-grade material and fuel energy products. Given the scarcity of biomass resources it is particularly attractive to locate biorefineries in such a way that energy and material flows can be efficiently integrated with other plants, as discussed in e.g. Andersson (2007). Such concepts are being considered in a number of process industry sectors, e.g. the pulping industry (Ekbom et al, 2005), and more recently the petroleum refinery industry (Berntsson et al, 2008).

2. The Petrochemical Cluster – a Description

This paper investigates energy efficiency options for a petrochemical cluster located in Stenungsund, on the West Coast of Sweden. The cluster includes a cracker plant

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producing 620 000 tonnes/year of ethylene and propylene, which are used to produce polyethylene products, primarily for pipe and wire & cable applications. The cracker plant also delivers ethylene, propylene and fuel gas (mainly consisting of methane and hydrogen) as feedstock or fuel to other plants within the cluster. The cracker plant is thus a clear starting point for a total site analysis of the cluster. A pinch analysis of the cracker plant is a first step towards identifying a common strategy for the cluster to reduce energy consumption and CO_2 emissions. Further work should include a pinch analysis of the other plants within the cluster followed by a total site analysis.

The cracker furnace unit is feedstock-flexible and can be fed with ethane, propane, butane and naphtha depending on market conditions. The cracker process temperatures range from 850°C in the cracker furnaces to -144°C for the tail gas in the cold fractionation section. The plant's utility system consists of cooling systems with water, propylene and ethylene as refrigerants, electricity and a 5 level steam system with HP steam (85 barg, 500°C), IP steam (40 barg, 275°C), MP steam (8.8 barg, 250°C), and LP steam (2.7 barg, saturated and 1.8 barg, 180°C).

The cracker process is a large energy user. The plant was built in the 1960's when oil prices were low, thus it is not particularly energy-efficient, despite a number of revamps. In 2007, the plant consumed 15 118 TJ of fuel and 422 GWh of electricity. In addition 4 676 tonnes of fuel gas were flared and 712 000 tonnes of CO_2 were emitted (Borealis, 2007) corresponding to 1.2% of the total Swedish emissions (SEA, 2007).

3. Methodology

3.1 Pinch Analysis

The energy savings potential for the cracker process plant was investigated using the standard procedure for retrofit pinch analysis (see Kemp, 2007): data extraction, retrofit targeting, retrofit design and network optimization. In this study most effort was put into the first three steps, i.e. network optimisation was beyond the scope of the study.

3.2 Stream System Definition and Data Collection

Some limitations were made in the study. The cracker furnaces were not considered since they are equipped with an integrated heat recovery system (total recovery 174.6 MW), which is hard to modify. Heating and cooling loads associated with loading or unloading of process feedstocks and products are intermittent and were therefore not included. The process also includes 4 cold box units, i.e. multiple-stream plate heat exchangers (total load 8 MW). Such units are not suitable for retrofitting and the associated heating and cooling loads were not included in the analysis.

Establishing appropriate process stream data is a tedious but crucial part of pinch analysis. Inappropriate stream data often leads to unrealistic targets. The conditions for the cracker process operations are subject to frequent change depending on various factors, for example feedstock type and availability, operating conditions, customer demand (product range and volume), etc. Such variation makes use of process data difficult for a pinch analysis study and therefore a reference engineering design study was chosen as a base for stream data definition. Historical process data was used where design data were missing. Continuous dialog with experienced plant staff was of highest importance in order to establish high quality stream data. Where calculations concerning physical properties were necessary, the simulation program Aspen Plus was used.

3.3 Analysis of Results

Standard pinch curves were used to analyse the potential utility savings above and below the pinch. A more detailed retrofit design study was thereafter performed above the pinch, focused on eliminating a number of pinch violation so as to achieve significant hot utility savings with the smallest possible number of retrofit measures, without affecting final product quality.

The CO_2 emissions reduction potential associated with the proposed retrofit measures was calculated by assuming that all hot utility consumption is achieved by offloading the auxiliary boilers (η_{blr}=0.85), thereby reducing firing of fuel gas (considered to be equivalent to methane, LHV=35.33 MJ/m^3).

4. Targeting Study

The aim of this paper was to identify energy saving opportunities for the cracker plant as a first step towards investigating opportunities for the petrochemical cluster to reduce utility consumption and CO_2 emissions. All results presented are taken from Hedström and Johansson (2008), in which two pinch analyses were presented, one for the cracking process including pre-heating of feedstock streams and one for the by-product area. The energy saving potentials for these two parts of the site were estimated to be 1.5 MW for the by-product area compared to 94 MW for the main process. The remainder of this paper focuses therefore on the main process area of the plant site only.

4.1 Existing Heat Exchanger Network and Utility Consumption

The existing heat exchanger network at the cracker plant consists of over 100 heaters and heat exchangers. 94 MW of hot utility is used, mostly LP steam with a few heaters using MP and IP steam. Since the process has very low temperatures some streams are heated with cooling medium. Cold utility usage is 260 MW. Internal heat exchanging within the process is relatively limited (20.7 MW).

4.2 ΔT_{min} Selection

In the study ΔT_{min} values of 5 K for liquid/liquid heat exchanging and 8 K for gas/gas heat exchanging were considered. When liquefaction and evaporation occurs 5 K was used and for streams colder than -50°C a ΔT_{min} of 3K was used. These ΔT_{min} values were selected based on current design practise and plant staff experience.

4.3 Results: Pinch Point and Theoretical Minimum Utility Loads

Composite curves for the process stream system selected are presented in Figure 1. The pinch is located at the hot end of the hot stream composite curve, at 184.5°C, i.e. the process stream system selected is unpinched (*threshold problem*). Thus, all use of steam heating could theoretically be removed from the studied part of the process. All existing process heaters are therefore located below the pinch, and thus constitute pinch violations (total: 94 MW). The minimum cooling demand is 166 MW and the maximum potential internal heat exchange is 115 MW. The vertical distance between the two curves in Figure 1 is so large that different ΔT_{min} values or inaccuracies concerning process stream data should not affect these results.

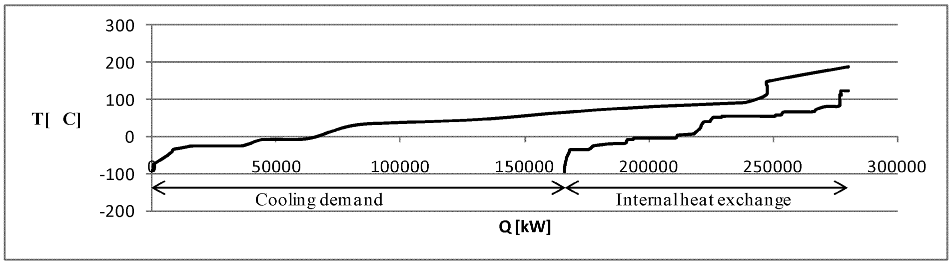

Figure 1 Composite curves of the selected stream system within the cracker plant

4.4 Results: Potential for Reduced Cold Utility Usage

The grand composite curve (GCC) can be viewed in Figure 2. Since there is no heating demand the GCC was used to evaluate utility usage below the pinch. The dashed lines in the figure indicate the theoretical optimum usage of different levels of cooling medium available for the process. These values are compared with current usage in Table 1. Sea water is available for cooling purposes, but expensive refrigeration is necessary for low temperature cooling purposes.

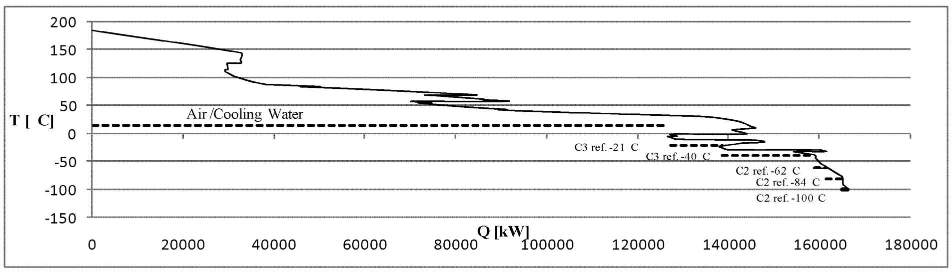

Figure 2 GCC of the selected cracker plant stream system including theoretical cold utility consumption.

Table 1 Comparison between the theoretical cooling load and the facto use of cooling medium

Cooling Medium	Q_{min} [MW]	$Q_{Currant}$ [MW]	ΔQ [MW]
Air/cooling water 15 °C	126.0	200.3	74.3
C_3-ref. 9°C/-21°C/- 40°C	0.0/ 10.7/ 19.4	3.7/17.7/ 29.3	3.7/ 7.0/ 9.9
C_2-ref. -62 °C/-84°C/ -100 °C	4.4/ 3.3/ 1.2	2.9/ 5.2/ 1.2	-1.5/ 1.4/ 0
Total (Refrigeration only)	**39.5**	**60**	**20.5**

In Table 1 above it can be seen that current cold utility usage is significantly higher than the theoretical cooling load. Figure 2 shows that the cooling medium used in some cases is of too high quality, i.e. the temperature of the cooling medium used is lower than necessary. The GCC analysis shows that it would be possible to decrease the use of C_3-refrigeration by 20 MW thereby offloading the steam driven refrigeration system. The excessive and non-optimal distribution of refrigeration load results in increased refrigeration compressor work, thereby increasing the steam and electricity consumption.

5. Overview of Potential Energy System Retrofit Measures

The study was primarily a targeting pinch study, and possible retrofit measures were not investigated in detail. This was because one of the main drivers was to rapidly identify energy saving possibilities at the cracker plant that can constitute a basis for initiating discussions about possible energy efficiency options for the petrochemical cluster site.

Since, theoretically, no external hot utility is needed in the selected part of the cracker plant, there is a significant potential to reduce steam production (94 MW) and thereby firing of fuel gas in the process auxiliary utility boilers. Since the fuel gas main components are methane and hydrogen, this provides the possibility to upgrade the fuel gas to separate methane and hydrogen streams that can be sold to the local natural gas grid or to other nearby process plants, respectively. Such opportunities provide clear economic incentives for the cracker plant to further investigate energy efficiency measures. However, steam is still produced in the cracker furnaces (which were not considered in the analysis) during cooling of the cracked gas. Some of this steam is used as a reactant in the steam reforming reactions taking place within the cracker. The excess steam could however be used for electric power production in steam turbines for export to the power grid. There is also a potential for heat delivery to the local district heating network. This opportunity is however limited due to the relatively small heat load of the local community. As discussed previously, reduced low temperature refrigeration can lead to significantly reduced steam or electricity consumption, depending on the type of mechanical shaft driver used for the process compressors.

Achieving the theoretical energy saving potential is not economically realistic, because of very short timeframes for process retrofitting (scheduled shutdowns for the cracker unit occur with 6-7 year intervals), location of the streams etc. Five new heat exchangers with the largest potentials for energy savings were identified that could reduce the plant's CO_2 emissions by 13 % compared to 2007 levels, see Table 2. The new matches were selected on the basis of stream location, low risk for reduced product quality, and ability to cover the entire heating demand for the cold stream selected. More detail about the proposed matches is provided in Hedström and Johansson (2008). These measures could potentially reduce costs for CO_2 emissions, and generate income from sales of 33 000 tonnes/year of fuel to the natural gas grid.

Table 2 Summary of key suggestions

Retrofit suggestions	Heat exchanger load [kW]	Utility savings	Potential for fuel savings [tonne/year]	Decrease of CO_2 emissions [tonne/year]
Match no.1	21 230	LP steam	15 753	43 217
Match no.2	4 055	LP steam	3 009	8 255
Match no.3	1 338	MP steam	993	2 724
Match no.4	11 160	LP steam	8 281	22 718
Match no.5	6 252	LP steam	4 693	12 727
Total	**44 035**		**32 675**	**89 641 (-13%)**

In addition to potential CO_2 emissions reduction, the results of the study also suggest that it could be attractive for the cracker plant to switch to biomass based feedstock, since the potential energy surplus (in the form of methane, hydrogen or electricity) could be classified as renewable and thus eligible for further economic incentives. Hydrogen could be conveyed by dedicated pipeline to one of several oil refineries located in West Sweden. Alternatively, excess process fuel gas could be upgraded to synthetic diesel or methanol. It is also important to underline that all parties within the cluster should be interested in considering this type of measure, since all parties are currently consumers of excess process gas from the cracker plant. Thus the plants located within the cluster have the opportunity to be a leading example of cluster collaboration in times of climate change.

6. Conclusions

Industrial process clusters have good opportunities to collectively reduce energy usage and CO_2 emissions. This paper presented the results of a pinch analysis of a cracker plant in a petrochemical cluster. The analysis shows that the process is unpinched and that the current hot utility consumption of 94 MW constitutes a pinch violation. 44 MW of hot utility can be saved by implementing a limited number of energy system retrofit measures. Further energy savings can be accomplished by process cooling efficiency measures. By offloading the refrigeration system, 20 MW can be saved i.e. both fuel and electricity use can be reduced. The resulting energy surplus can be harnessed in a number of ways, including increased cogeneration of electric power, export of methane or hydrogen, etc. Further work will involve a total site analysis of the complete cluster together with an analysis of incentives for individual plants to collaborate to achieve the potential combined savings for the cluster.

7. Acknowledgements

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