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Targeting for Energy Efficiency and Improved Energy Collaboration Between Different Companies Using Total Site Analysis (TSA)

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Rising fuel prices, the threat of global warming and the start of the 2nd period of the EU Emission Trading System make efficient use of energy more and more important. Industrial clusters have the potential to significantly increase energy efficiency by energy collaboration. In this paper Sweden’s largest chemical cluster is analysed using the Total Site Analysis (TSA) method. The cluster consists of 5 chemical companies producing a variety of products. The overall heating and cooling demands of the site are around 442 MW and 953 MW, respectively. 122 MW of heat is produced from internally generated and purchased fuels and delivered to the processes.
TSA is used to stepwise design a site-wide utility system which improves energy efficiency. It is shown that utility savings of up to 122 MW can be achieved, plus a steam excess of 7 MW. The proposed retrofitted utility system involves the introduction of a site-wide hot water circuit, increased recovery of low pressure steam and changes in steam levels in several heat exchangers. Qualitative evaluation of the suggested measures shows that 60 MW of the savings potential can be expected to be achieved with moderate changes to the process utility system.

1. Introduction

Site-wide process integration studies within industrial clusters often show large potential for energy savings, on average 20-25 % compared to the current energy usage of the total site (Linnhoff March 2000). Such studies provide the opportunity to analyze integration of additional energy processes making use of the site infrastructure, thereby contributing to an increased overall efficiency. Even highly efficient single plants can further improve their energy efficiency by sharing energy with other plants within a cluster (Matsuda et al. 2009). Total Site Analysis (TSA) provides targets for the amount of utility that can be used and produced through energy recovery by the different processes. The method enables investigation of opportunities to deliver waste heat from one process to another using a common utility system and can also provide the basis for the integration of larger geographical areas, which beyond industrial sites also include building complexes, offices and residences (Perry et al. 2008).

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2. The chemical cluster

The chemical cluster investigated in this paper is located in Stenungsund on the West Coast of Sweden, and is Sweden's largest agglomeration of its kind. The companies involved and their main products are AGA Gas AB producing industrial gases, Akzo Nobel Sverige AB producing amines and surfactants, Borealis AB producing ethylene and PE, INEOS Sverige AB producing PVC and Perstorp Oxo AB producing speciality chemicals. The heart of the cluster is a steam cracker plant run by Borealis, which delivers partly feedstock and fuel to the other plants. Each plant has its own utility system. Utility system connections between the different plants at the total site are currently minimal. In total, 13 steam levels, different hot water systems, hot oil and flue gas heating together with water, air and refrigerant cooling are operated within the cluster to supply the heating and cooling demand of the processes. Waste heat from Borealis and Perstorp is delivered to the local district heating system. The companies already interact strongly with each other in terms of material exchange and are currently interested in investigating the potential for energy integration throughout the chemical cluster in Stenungsund. The objective of this study was to conduct preliminary analysis of total site level energy efficiency opportunities using the TSA methodology.

3. Methodology

3.1 Total Site Analysis (TSA)

TSA is used to integrate the individual heating and cooling demands of different processes at a total site. Excess heat from one process plant is transferred to a common utility (e.g. steam, hot water, hot oil) (Bagajewicz and Rodera 2001) and then delivered to processes with a heat deficit by the common utility system. The TSA method enables the amounts of hot utility generated and used by the combined individual processes, the amount of heat recovery in a common hot utility system, the steam demand from the boilers and the cogeneration potential to be determined (Perry et al. 2008).

3.2 Data collection approaches for the total site analysis of the chemical cluster

Data collection for TSA studies is time consuming, therefore practitioners have defined different approaches that can be used for conducting studies at different levels of detail. These approaches are briefly discussed below.

White box approach or Detailed Pinch:

A detailed pinch analysis of each plant is carried out and thereafter Composite Curves (CC) and the Grand Composite Curve (GCC) can be constructed for the total site and the minimum hot and cold utility demands are determined.

Grey box approach:

For each plant, only the process-utility interface is considered and process-process heat exchange is ignored. Only process streams which are heated/cooled by utilities are considered as based on their starting temperature T_{start}, target temperature T_{target} and heating/cooling loads. The current level of integration within the single units is not changed, but it enables to identify opportunities for transferring heat between plants.

Black box approach:

The process(-stream) is represented by its utility demand only and is in the analysis represented at the corresponding utility temperature. Other utility users such as steam tracing or tank heating are often represented as black boxes (Linnhoff March 2000).

It is important that all utility usage and potential demand is included in the study (Brown 1999). Because of a limited timeframe this study focuses on the "grey box" approach. The study is complemented by streams handled as "black box" to include utility consumers that are not included in the stream data gathered.

3.3 Total Site Profiles and Total Site Composite Curves

From the data collected the process source/sink profiles and the utility profiles can be plotted. The so called total site profiles (TSP) are obtained, see left-hand side in Figure 1. This enables to analyse how heat is supplied to and discharged from the processes by different utilities. The site utility curves are developed from process stream lists by allocating the utilities used to cool/heat each process stream.

In order to find the maximum amount of heat recovery for the total site by the utility system the total site profiles are moved towards each other until the hot and the cold utility curve intersect in one point, see Figure 1 to the right. This point is the so-called **site pinch**, which limits the amount heat that can be recovered by the utility system. The overlapping curves in this figure are the so-called total site composites (TSC). They show the minimum amount of heat that has to be supplied to the processes externally as hot utility ($Q_{heating}$). This is illustrated in Figure 1. $Q_{heating}$ therefore directly relates to the fuel requirement.

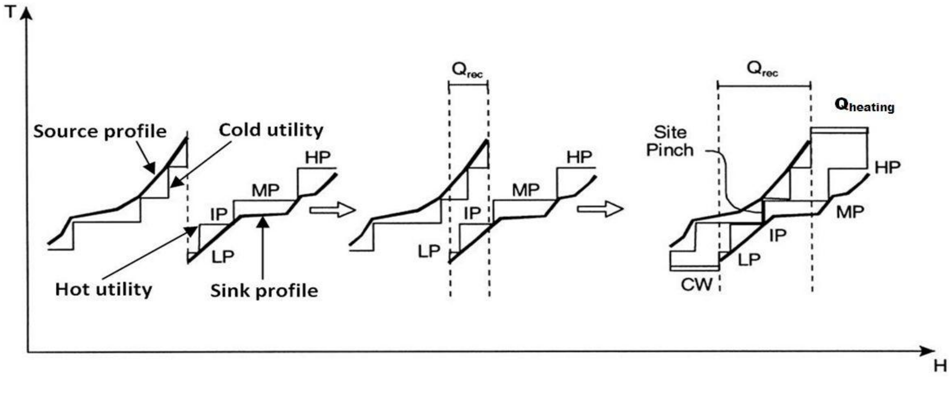

Figure 1: Total Site Profiles (TSP) and Total Site Composites (TSC)

The cooling demand, shown as cooling water (CW) in Figure 1 represents the amount of heat that has to be discharged from the processes. TSP and TSC can be used to identify changes to the utility system that improve the total site heat integration through the utility system. Utility system changes are e.g. replacing steam by introducing a hot water circuit (Bagajewicz and Rodera 2001), introduction of new steam mains, steam generation at higher levels or use at lower levels (Raissi 1994). The curves can be used to target for fuel consumption and cogeneration (Zhu and Vaideeswaran 2000).

4. Results of the TSA

4.1 Analysis of the current utility system

Figure 2 shows the TSP and the TSC of the chemical cluster. The TSP represents cold and hot process streams (full lines), and cold and hot utility curves (dashed lines).

The total cooling demand of the processes is 953 MW. Currently 324 MW heat is recovered from the processes, 281 MW in form of steam. The total amount of process heat discharged to the environment by CW and air is 560 MW. The rest of the cooling (77 MW) is achieved by refrigeration.

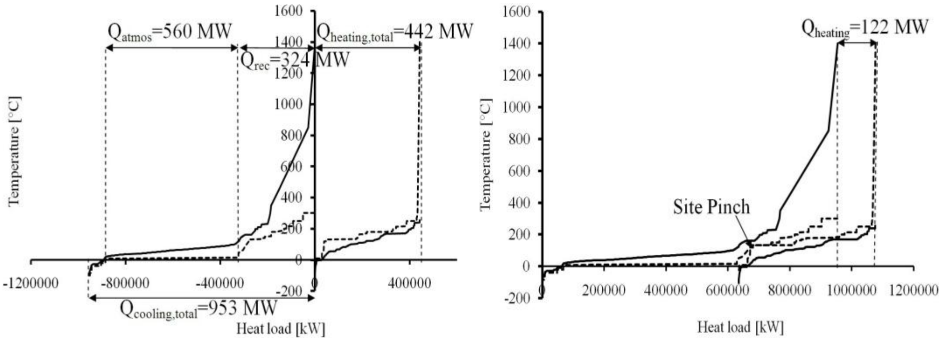

Figure 2: TSP (left) and TSC (right) of the chemical cluster in Stenungsund

The total heating demand is 442 MW of which 389 MW is covered by steam at different pressure levels, while 55 MW is covered by hot water/oil, flue gases, steam condensate and refrigerant (to recover cooling energy).As described previously the minimum heating requirement for the total site can be determined by overlapping the TSP curves to obtain the Total Site Curves and the. **Site pinch**, see Figure 2 (TSC to the right). The overlap of the source and the sink profiles represents the potential amount of heat recovery by the utility system (320 MW). The amount of heat that has to be produced by external fuel in boilers is $Q_{heating}$=122 MW.

4.2 Improvements to the total site utility system

One option to increase energy efficiency is to shift the site pinch by introducing a hot water circuit between 50 and 100°C (see TSC in Figure 3). The dashed lines represent the new hot and cold utility profiles. Heat from hot process streams can be recovered in a circulating hot water system and delivered to cold process streams. Thereby 2 bar(g) steam use is replaced by hot water, which shifts the site pinch and increases the overlap of the TSC. This can be seen when comparing $Q_{heating}$ in Figure 2 (right graph) and Figure 3 (right graph). Introducing a hot water circuit results in:

- Increased recovery of hot water between 50 and 100°C
- Savings of 51 MW steam at 2 bar(g) and below

In practice this new site pinch implies that if more 2 bar(g) steam is replaced with hot water there will be an excess of steam. To further increase energy savings it is necessary to shift the site pinch even further. This can be done by changes to the operating conditions of heat exchangers. In heat exchangers where it is not a process requirement to use steam at a higher level than 2 bar(g) the steam level can be decreased and thereby the demand for 2 bar(g) is increased. TSP in which all necessary changes are applied to reach maximum energy recovery is shown in Figure 4 (left). The measures are summarised in Table 1. The overall savings by the suggested measures are 129 MW.

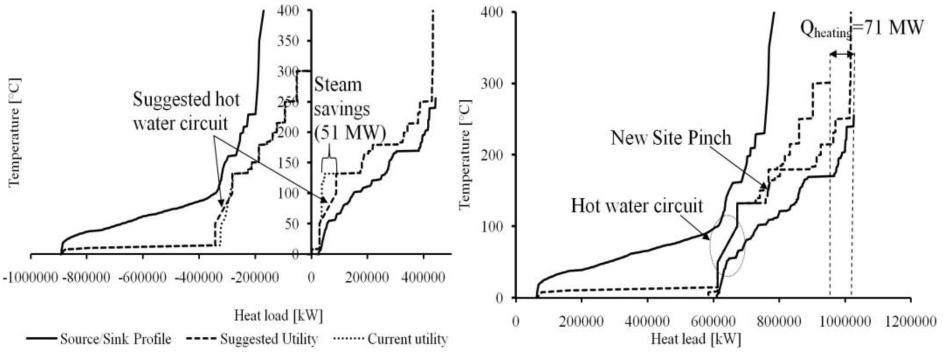

Figure 3: TSP (left) and TSC (right) after introduction of a new hot water heat recovery circuit

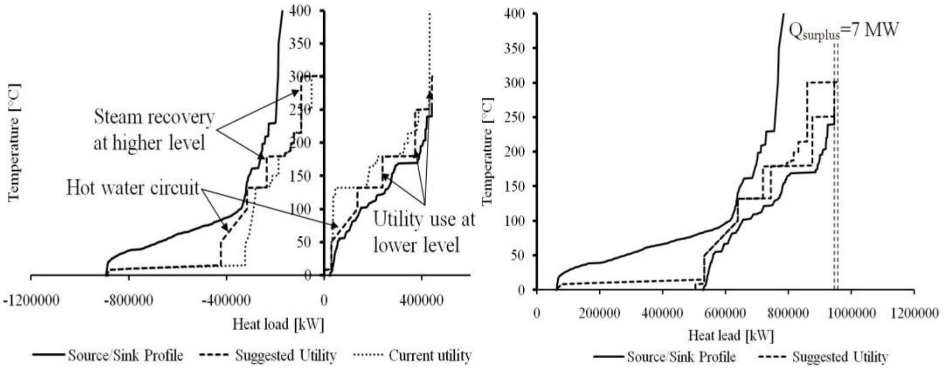

Figure 4: TSP (left) and TSC (right) of an utility system for maximum heat recovery

Table 1 Summary of measures to improve heat integration identified by TSA

Measure	Max. Savings [MW]	Comments
Hot water circuit	96	Utilizing more than 51 MW demands changes in process heat exchangers
LP steam recovery	33	Utilizing more than 51 MW together with hot water circuit demands changes in process heat exchangers
Total	129	

This means that the site's external utility demand of 122 MW can be covered by recovered process heat distributed by the utility system. Additionally 7 MW of excess steam would be available (see TSC in Figure 4). Qualitative evaluation of the suggested measures indicates that 60 MW of the savings potential can likely be achieved with moderate changes.

5. Conclusions

It has been shown that by site-wide collaboration it is possible to increase heat recovery and utilisation of excess heat. The results from this study provide a basis to identify concrete projects which can contribute to cost and CO_2 emissions savings. The study also shows the advantages of TSA in order to find solutions for process integration by the utility system on a site-wide level. Several measures to improve the energy efficiency of the chemical cluster were identified, which can save up to 122 MW of the external current utility demand. Qualitative assessment of the suggested measures showed that 50 % of the savings can be achieved by moderate changes to the existing heat exchanger system.

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