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A Methodical Approach for Energy Efficiency Analysis Based on Existing Process Models

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Comprehensive energy efficiency analysis is a major scope of recent process optimisation developments. By now many chemical processes are already highly integrated. Process heat is recovered directly by applying a heat exchanger network and indirectly by using a super ordinated utility system. Responding to market demands or utilizing particular new process alternatives may lead to small scale process changes. Within this document a set of novel handling procedures for evaluating the effects of these process changes on a given heat integration solution are formulated. This methodical approach will be the first step for the development of an efficient energy integration management framework.

1. Introduction

The general concept of heat integration is about forty years old. The strategic improvement of heat integration for a single process was developed by Linnhoff and Vredeveld (1984). The graphical analysis based on the Composite Curves (CC) and Grand Composite Curve (GCC) is an essential part of almost all recent optimisation approaches. Briefly described: The CC are a temperature-enthalpy plot to visualize the thermal distribution of heat sources and heat sinks within a process. The GCC can be derived from that plot to visualize the heat flow through the process in heat duty versus temperature. Key thermodynamic limits, like the maximum possible amount of heat recovery, can be identified in this way.

Site-wide energy analysis considering indirect heat integration between different processes, known as total site analysis, was introduced by Dhole and Linnhoff (1993). This concept was extended by the graphical analysis of the Utility Grand Composite Curve (UGCC) first described by Raissi (1994) and the evaluation of Total Site Profiles (TSP) as well as the resulting Site Pinch (SP) by Klemeš et al. (1997). The targeting procedure for total site analysis is closely related to the targeting procedure of a single process. An overview of the distribution of all heat sources and heat sinks is generated in order to choose suitable intermediate fluids for heat transfer. The most common intermediate fluid is steam, which can be supplied at different pressure levels.

The state-of-the-art scientific development is taking the concept of heat integration to a more sustainability focused level of interest. Wan Alwi et al. (2013) proposed a comprehensive principle to identify process modification potentials for Total Site Heat Integration. Feng and Liang (2013) demonstrated the possibilities for energy system retrofit of a chemical plant with the help of an interesting case study. A modern target of those approaches is the improved generation of cogenerated electrical energy. Smith et al. (2013) suggested a visualization of this improved cogeneration by an advanced steam cascade (StC) analysis following the idea of enabling low-grade heat recovery (Kim et al., 2011) and the implementation of renewable energy sources (Varbanov and Klemeš, 2011). Feedback from global industry enterprises like the report about STRUCTese® from Drumm (2013) point out the necessity of these sustainability focused strategies. However, the previous works have only considered certain detailed aspects of new heat recovery strategies or process modifications. A simplified workflow to enable a fast quantitative overview, independent from the exact kind of process modification, is missing.

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2. Initial Situation

As mentioned above, there are various reasons that could lead to small scale process changes. Because of the high complexity of modern heat integration strategies a full re-evaluation would be time consuming and may lead to several costly modifications since the existing process equipment is mostly not taken into account. In most cases this would be economically infeasible. Regarding a chemical site consisting of a number of independent processes, each having its own heat exchanger network, and all sharing a super ordinated utility system, the following questions will be important:

- Do I need to update the pinch analysis (PA) for the changed process?
- Do I need to re-evaluate the related heat exchanger network (HEN)?
- Do I need to re-evaluate the overall total site utility system (TSUS)?

The initial situation for the following handling procedures is as follows. A known process P0 is changed. The resulting new process is called P1. P0 was fully analyzed regarding the rules of pinch analysis and the utility system was design regarding the total site analysis. On the contrary to that P1 is not analyzed in terms of heat integration or total site implementation.

3. Developed handling procedures

In order to trace back the effect of certain process changes a novel hierarchical methodology is proposed. Therefore two levels of consideration have to be examined. On the one hand there is the direct heat integration of the effected process represented by the results of pinch analysis and the designed heat exchanger network. On the other hand there is the indirect heat integration represented by the utility system. Corresponding to the formulated questions of Chapter 2 all three aspects (PA, HEN, TSUS) have to be analyzed.

3.1 Aim of handling procedures

Within this document the overall objective is an energetic evaluation based on the rate of heat recovery. For the PA and the HEN the amount of directly recovered - process intern - heat duty is of major importance. For the TSUS the objective is to minimize the required fuel, which would be needed to even out the inter-process steam cascade. Economic targets like the investment cost will not be taken into account since it is expected that some kind of Heat Integration is applied and most of the equipment is already available.

3.2 Update of pinch analysis

Technically the update of the pinch analysis is not too complex and can be done by a problem table algorithm. An updated PA is needed to perform a new total site study in any case. Nevertheless, there are two scenarios that enable handling rules for a quick evaluation without recalculation. Crucial is the knowledge of the Pinch Point of P0.

The first scenario describes the addition of heat duty (ΔH_1) exclusively above or the addition of heat demand (ΔH_2) exclusively below the previous pinch point of P0. The resulting Pinch Point and the maximum of achievable heat recovery of P1 will be the same as P0. The minimal demand of hot cold utility (minH, minC) will be changed accordingly to the new heat duty/demand. This can be described by the following equations:

$$minH(P1) = minH(P0) + \Delta H_1 \quad (1)$$

$$minC(P1) = minC(P0) + \Delta H_2 \quad (2)$$

A graphical presentation can be found in Figure 1.

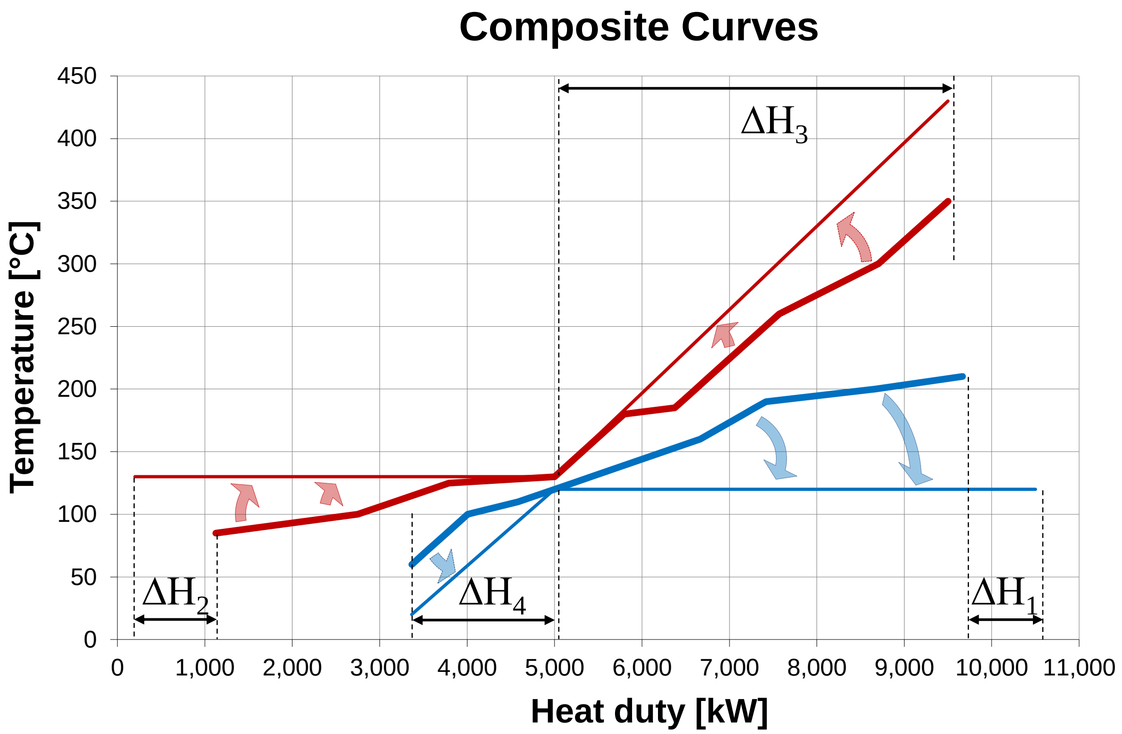

Figure 1: Effect of process changes regarding the CC

The second scenario describes a shift of temperature intervals. If temperature intervals above the pinch point (ΔT_{app}) are increased without major changes to the process heat duty (ΔH_3) the resulting pinch point, the maximum of achievable heat recovery and the minimal utility demand of P1 will be the same as P0. Due to changes in temperature differences the area of affected heat exchangers have to be adjusted. For increased temperature intervals below the pinch point (ΔT_{bpp}) and constant process heat demand (ΔH_4) the same conclusion is valid. This can be described by the following equations:

$$\Delta T_{app}(P1) > \Delta T_{app}(P0) \big| \Delta H_3 = \text{const} \Rightarrow minH(P1) = minH(P0) \quad (3)$$

$$\Delta T_{bpp}(P1) > \Delta T_{bpp}(P0) \big| \Delta H_4 = \text{const} \Rightarrow minC(P1) = minC(P0) \quad (4)$$

Apart from these two scenarios the Pinch Analysis has to be redone in order to retrieve all necessary key parameters for further planning steps.

3.3 Update of heat exchanger network

The design of a heat exchanger network is affected by economic and process-technological necessities. Therefore, the applied rate of heat recovery (R) is mostly lower than the maximum of achievable heat recovery (maxR). Due to this fact the design of the regarded HEN has to be checked for two different cases. The first case would be if the maximum of achievable heat recovery is higher in P1 than it was in P0. The second case would be if the applied rate of heat recovery is so low that it has to be checked if a higher value could be achieved in P1, even if the maximum of achievable heat recovery is unchanged compared to P0. Depending on the kind of process and the significance of Heat Integration, comprehensive limits could be developed and implemented into the proposed workflow, for example: If the maximum of achievable heat recovery increases by 10 %, the optimisation of the HEN structure should be considered. The proposed workflow is presented with the help of Figure 2.

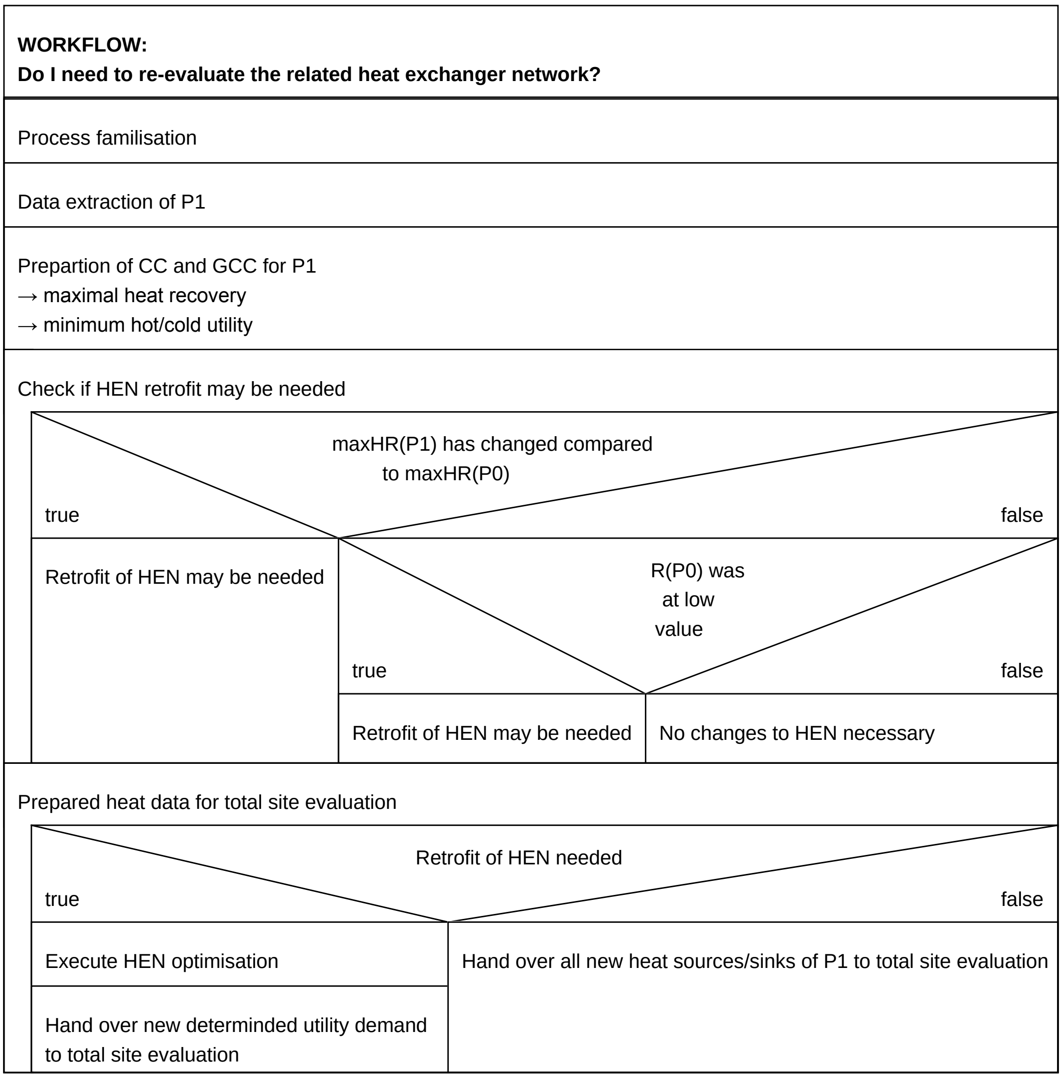

Figure 2: Workflow for HEN evaluation

3.4 Update of total site utility system

As mentioned in Chapter 3.1 the aim for a site-wide utility system update is the evaluation of the demand of fuel for the generation of very high pressure (VHP) steam. In some situations a trade-off between cogenerated electrical power and the required fuel is possible. If P1 has a higher demand on certain steam levels than P0, a reduction of cogenerated power may enable an unchanged fuel demand. In the graphical presentation of Figure 3 it is shown that a constant fuel demand is only possible for heat duty variations of utilities below the Site Pinch. In the shown example, the Site Pinch is specified by utility number 2. Heat duty variations above the site pinch, as shown in Figure 4, will always result in a change of the site pinch and therefore a change to the steam savings as well.

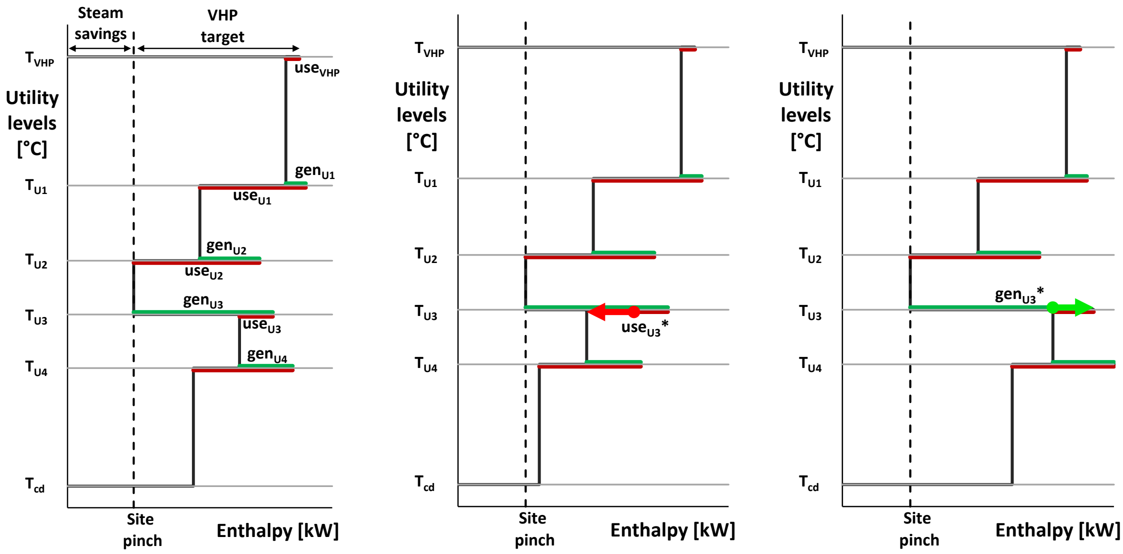

Figure 3: Effect of process changes to steam cascade below the Utility Pinch

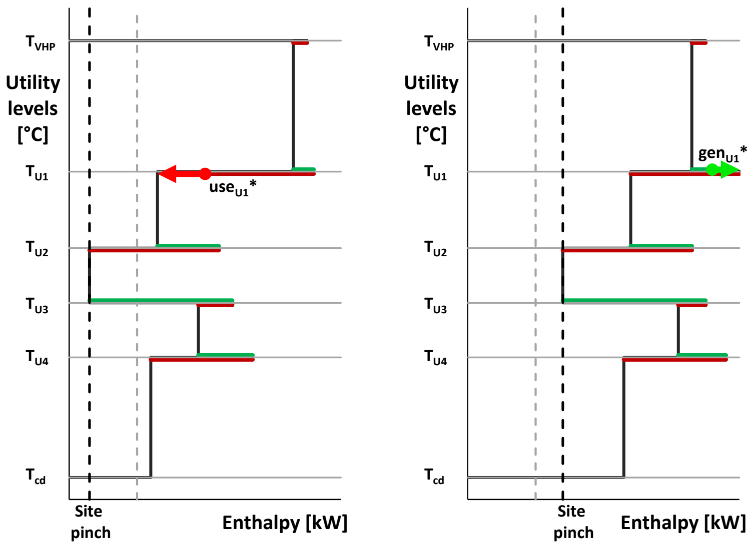

Figure 4: Effect of process changes to steam cascade above the Utility Pinch

4. Discussion and Conclusion

To evaluate the effect of small scale process changes a set of handling procedures was formulated and presented graphically. The appliance of these evaluation methods enables a better classification and selection of continuative strategies, depending on the consideration level of interest. Specific scenarios, especially for the heat exchanger network structure, have been pointed out to minimise the engineering work by proposing a suitable workflow. A suitable workflow is of major significance for a completely automated working approach. Related to the industrial practice, there is mostly no personnel capacity for a detailed process familisation and re-evaluation. A reliable quantitative validation method, like the presented one, helps to reduce working time and costs. For future research the presented ideas can be used to develop an energy integration manager system, which is linked to specific software tools for pinch analysis, heat exchanger network synthesis and total site utility system optimisation. Further information on this matter has recently been published by Bohnenstaedt and Fieg (2014).

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