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Process modifications to maximise energy savings in total site heat integration

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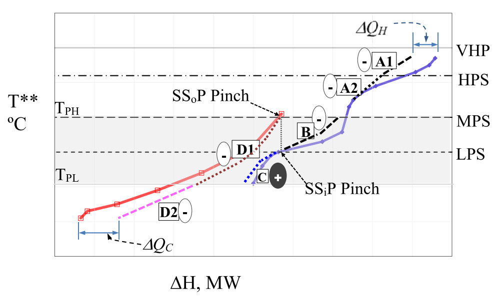
HIGHLIGHTS

- Extension of the Pinch Analysis for process modifications from single processes to TSHI.
- Adaptation of the Plus–Minus principle to select beneficial process modification options.
- Development of heuristic to set priority of streams.
- Targeting process modifications at selected process sections to improve TSHI heat recovery.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper extends the scope of the Pinch Analysis for process modifications of individual processes to total site heat integration (TSHI). The Plus–Minus principle has been adapted to enable the beneficial process modification options to be selected in order to maximise energy savings in TSHI. The Total Site Profile (TSP) is divided into three regions: (a) the region above the horizontal overlap between the Site Sink and Source Profiles, (b) the horizontal overlap region and (c) below the horizontal overlap region. The proposed methodology identifies the options to reduce utility targets in these regions using the TSP, Site Utility Composite Curves (SCC), Utility Grand Composite Curve (UGCC), modified Problem Table Algorithm (PTA), Total Site Problem Table Algorithm (TS-PTA) and some new heuristics. The identified changes on the TSP are then linked to the specific changes at the individual processes. The illustrative case study shows that the Plus–Minus principle application in the TSHI context can further improve heat recovery. The proposed spreadsheet-based methodology combines the advantages of graphical visualisation, as well as the numerical precision.

1. Introduction

Efficient integration and optimisation of the energy requirement within a site utility system can improve the Total Site energy efficiency. Energy saving as a result of improved energy efficiency subsequently translates into reduced CO_2 emissions. Such outcome from energy saving fits the European Directives 2010/75/UE which prioritises on the reduction of industrial emissions at the source [1].

Total Site Heat Integration (TSHI) is a tool used to optimise the site-wide energy demand. It extends the application of Pinch Analysis from a single process to multiple processes in an industrial site. The concept of Total Site (TS) was introduced by Dhole and

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Linnhoff [2]. Klemeš et al. [3] established the Total Site Profiles (TSPs) to represent the thermal profile of TS and the Site Utility Composite Curves (SCC), which consists of Hot and Cold utility Composite Curves. The Total Site Pinch is where the two utility CC overlap horizontally. The Utility Grand Composite Curve (UGCC) provides a visual illustration of the external utility requirements. These graphical tools are used to set targets for steam usage and generation by the site processes, the steam required to be produced by the boilers, and shaftwork produced by the steam turbines. Heat recovery depends also on the number of steam levels. Even though more steam levels may result in more heat recovery, it has to be balanced against the increased capital cost and higher complexity of the utility system [4]. The TSHI has been enhanced to Locally Integrated Energy System (LIES) which also integrates residential, business, service and even agriculture areas apart from the industrial site [5]. Liew et al. [6] extended their numerical TSHI methodology to consider the operational changes within a centralised utility system planning. A brief review of the development of TSHI over the last 40 years can be found in the recent review paper by Klemeš and Kravanja [7].

The energy targets from the TSHI analysis are dependent on the operating conditions of the existing site. A change in the process operating conditions can alter the TSP and change the energy targets. The flexibility to change the process conditions can be exploited to further improve the heat recovery. In a study to integrate new CO_2 capture and storage (CCS) plants into existing coal-fired power stations, Harkin et al. [8] showed that energy penalty associated with CCS can be reduced when TSHI is applied. Their study also identified that the pre-drying of coal could further improve the utility targets. Process modification strategies to improve the Heat Integration (HI) of single processes by exploiting the shape of Composite Curves (CCs) and the Grand Composite Curve (GCC) were developed by Linnhoff and Vredeveld [9]. The rules for process modifications using the CC and GCC include the Plus−Minus principle, keep hot stream hot (KHSH) and keep cold stream cold (KCSC) as well as the appropriate placement principle. Exploiting and optimising the process soft data, use of the appropriate minimum approach temperature (ΔT_{min}) and suitable application of insulations above and below Pinch can be effective in improving heat recovery. Lee et al. [10] has shown that knowledge of pinch can be used to optimise the location of pipe insulation to reduce utility targets. Applications of these rules have been described earlier by Smith [11], later by Kemp [12], and recently in extended ways by Klemeš et al. [13].

The process modification strategies such as the Plus−Minus principle can be used together with the TSP to identify the scope for process modifications to improve TSHI. Hackl et al. [14] showed that the gap between the TSP and SCC can be used to identify the potential utility systems changes that can reduce the overall site heating and cooling requirements in a Side-Wide Process Integration study of a chemical cluster in Sweden. Replacing the low pressure steam (LPS) heating with hot water (generated from the Site Source) reduced the gap between TSP and SCC, changed the shape of the SCC and shifted the TS Pinch. This increases the overlap of the Site Source and Sink Profiles and increases the heat recovery. Nemet et al. [15] developed the strategies to plan the extension of an existing site by using the Plus−Minus principle on the TS. The Plus−Minus principle, together with the Process Utility Matrix (which lists the utilities consumptions of the various processes), were used to evaluate the merits of integrating a new process to an existing TS. Only options which are beneficial, i.e. those resulting in improved overall heat recovery will be selected for integration. In this study, the Plus−Minus principle of process modifications is used to identify process changes that can further reduce the TS utility targets. This is essentially done by manipulating the shape of the Site Source and Sink Profiles.

2. Application of pinch strategies for process modifications of a single process to TS

Knowledge of Pinch location is crucial when exploring the process modification opportunities for single processes. The Total Site (TS) Pinch location can provide similarly a guide during process modifications to reduce the overall energy consumption of the site. The TS Pinch limits the amount of heat that can be recovered from the Site Source and Sink. According to Klemeš et al. [3], the TS Pinch is the point where the cold utility CC first intersects with the Site Sink Profile (SS_iP) or when the hot utility CC first intersects the Site Source Profile (SS_oP). TS Pinch occurs where the horizontal overlap between the Utility Composite Curves is maximised. The TS Pinch occurs at the utility temperatures, and spans between the temperatures of two successive utility levels as shown in Fig. 1. An assessment of the impact of process modifications of a single process on the TS as given in Table 1 shows that Heat Integration strategies applied for the single process can be directly extended to TS. These include the exploitation of soft data, the appropriate use of minimum temperature of approach (considering the fluids in service and the type of heat exchanger used) and the suitable use of insulation (e.g. apply insulation only on hot streams above pinch, etc.). Adaptations of the Plus−Minus Principles to TS are described in the subsequent sections.

3. The Plus−Minus principles for TS

A TS comprising several units (e.g. chemical processing plants, business and commercial units) typically uses steam as the working fluid. For an existing steam system of a TS, little can be done to optimise the steam utility levels to improve heat recovery. The utility targets can be reduced by exploring the potential for process modifications in the TS context. The TSP can be a powerful tool to evaluate the potential for further heat recovery improvement even for a TS. The Site Source Profile (SS_oP) is analogous to the Hot Composite Curve and the Site Sink Profile (SS_iP) is analogous to the Cold Composite Curve.

The TSP can be divided into three regions: (a) above the SS_oP and SS_iP horizontal overlap, (b) at the SS_oP and SS_iP horizontal overlap and, (c) below the SS_oP and SS_iP horizontal overlap. Note that the overlap between the SS_oP and SS_iP spans between the highest (T_{PH}) and lowest (T_{PL}) process pinch temperatures on the site, as shown in Fig. 1. Above and below the SS_oP and SS_iP horizontal overlap region, the location of TS Pinch has no implication on TS heat recovery. Above the horizontal overlap region, the heating requirement can be reduced by decreasing the duty of the cold streams. Below the horizontal overlap region, the cooling requirement can be reduced by decreasing the duty of the hot streams.

Within the SS_oP and SS_iP horizontal overlap region, TS Pinch affects heat recovery in the same way the Pinch does for a single process. For the SS_oP, the TS Pinch can also be taken as the temperature equal to the higher steam level of the TS Pinch. Above this temperature, increasing the duty of the SS_oP (+) reduces the hot utility. Below this temperature, decreasing the duty of SS_oP (−) reduces the cold utility. For the SS_iP, the SP can be taken at the temperature equal to the lower steam level of the TS Pinch (SP). Above this temperature, decreasing the SS_iP (−) reduces the hot utility. Below this temperature, increasing the duty of SS_iP reduces the cold utility.

The UGCC provides a quick visual impression of the external utility requirements, and can be used to prioritise the changes on the TSP segments in order to reduce utilities. Fig. 1 illustrates the