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Trade-off between energy and distance related costs for different connection patterns in heat integration across plants

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HIGHLIGHTS

- Different connection patterns are first defined in total site heat integration.
- A graphical method to determine the flow rate of intermediate fluid is proposed.
- Energy targets for different connection patterns can be determined.
- Site pinch is found in series connection pattern.

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ABSTRACT

Recent research efforts on total site heat integration have mainly focused on determining the energy target without considering the following two factors. The first factor is distances between separate plants. The required pipelines between plants in total site heat integration is much longer than heat integration within one plant, so more attentions must be paid on this distance factor as it incurs more expense. The other factor is the type of heat transfer medium. In most studies, steam is used as the heat transfer medium between plants but it cannot be applied in low temperature range. In this work, three connection patterns for individual plants within one site are presented. Both the locations of the plants and the use of water as the heat transfer medium are considered. A graphical methodology for determining the energy target for the three connection patterns in total site integration is proposed. The utility of the proposed methodology is illustrated using a case study based on three plants.

1. Introduction

Energy system optimization is much more important today due to the increase in fuel cost. In 1980s, pinch technology [1,2] and mathematical programming techniques [3,4] are proposed to make good use of heat within a heat exchanger network. However, these early heat exchanger network design methodologies only consider the use of surplus heat within the process itself, the surplus heat that cannot be used within the process is not considered.

Total site heat integration is one way to save surplus heat that cannot be used within the process by providing surplus heat across different individual processes and plants. Research on total site heat integration, was firstly initiated by Dhole and Linnhoff [5]. In the pioneering work of Dhole and Linnhoff, the concept of total site was first proposed to describe a set of processes serviced by and linked through a central utility system. Pinch technology [1] was extended from single process to multiple processes in order to achieve the energy targets across several processes and plants. Energy was transferred directly from one stream to another within different processes, and such integration pattern was defined as direct integration. Hu and Ahmad [6] developed a total site heat integration methodology that considers the utility system. In their work, different levels of steam were used to transfer heat between processes, and such integration using intermediaries was defined as indirect integration. Further on, Klemeš et al. [7] developed tools such as the total site profile and the site utility grand composite curve to evaluate total site potential heat recovery. Also, the environmental aspects were accounted for. Rodera and Bagajewicz [8] proposed a systematic procedure to identify energy saving targets for heat integration across plants. In their work, the minimum number of intermediate fluid circuit can be determined, and an MILP problem was proposed to find the optimal position for the intermediate fluid circuits. Fumo et al. [9] consider the cooling, heating and power system in the optimization.

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Although total site heat integration has been studied for many year, most works are focused on heat integration by using steam as intermediate fluid. Steam is one of the most popular intermediate fluid used in industry. However, it cannot be used to deliver low range temperature. Hot water is another popular intermediate fluid used in industry but not many works have been published related to it. Matsuda [10] studied Kashima industrial area in Japan to explore the energy recovery in total site. In their work, both hot water and steam were used to transfer heat between plants, and it was found that by using hot water, the consumption of low pressure steam was further reduced. Hackl et al. [11] analyzed the Sweden's largest chemical cluster. In their work, hot water was also considered in total site heat integration, and a site pinch was found indicated that even more hot water was generated, no more energy would be recovered.

As mentioned by Chew et al. [12], very long distances between heat sources and sinks are a critical feature of total site heat integration. The distance factor has been considered in many energy system related works. For example, in heat exchanger network synthesis, Suaysompol and Wood [13] mentioned that actual capital cost is also influenced by the network topology as this will influence the cost of pipework. In their work, a network cost estimation procedure considering pipe cost is proposed. Jiang and Chang [14] considered the influence of different pipeline layout on total capital cost in a flexible multiperiod problem. In district heating, distance factor plays an even more important role in it. Dalla Rosa et al. [15] considered the length of pipeline in district heating and related the length of pipeline with heat loss. Tol and Svendsen [16] developed a district heating optimization methodology to consider pipe dimensioning, substation types and network layouts simultaneously. In district heating, exergy analysis is widely used to determine the heat loss on the way to heat sinks [17,18]. Although many works had mentioned distance factor in total site heat integration, most works did not involve it into the total site methodology. Rodera and Bagajewicz [19] calculated the distance related cost in their work, such as pump power, pipe cost et al., but pipe length is fixed in their work.

Normally, the connections between heat sources and sinks are mainly dependent on the energy demand and supply in terms of both energy quality and quantity. However, in practice, the mutual locations of heat sources and sinks will directly determine the connections among them. A long distance between heat sources and sinks will result in both high investment and operation costs associated with pumps and pipes and high heat loss. A trade-off between distance-related costs and energy savings is needed to ensure the cost-effectiveness of a heat integration project. Therefore, the distance factor plays an importance role in total site heat integration, and it must be considered with the energy aspects simultaneously.

The mutual locations of heat sources and sinks are accounted for in our new methodology for total site integration. This approach allows us to consider energy savings in a more realistic way. Direct heat integration is normally not appropriate in practice due to economic and operational concerns, especially when distances between plants are long. Therefore, in this work, only indirect heat integration is considered. In addition, the use of water or hot oil as the intermediate fluid is included in the proposed methodology. Steam is normally considered as the intermediate fluid in indirect total site heat integration. However, using water instead of steam is economic in a low temperature range while hot oil may be used as the intermediate fluid in a very high temperature range. Also, using hot water or hot oil enable a tighter integration between processes through the possibility to adapt the slope of the intermediate fluid line to fit the slopes of the source sink profiles. As such, this represents a novel aspect of the proposed methodology. A black box approach is used in this work. A case study based on a set of chemical plants located in China is used to illustrate the utility of the proposed methodology.

2. Different connection patterns between several plants

When the distance between plants is accounted for in the total site heat integration, it is necessary to consider the connection pattern between each heat sink and source. In this work, only the situation of heat integration between three plants is considered, and a total site normally consist of more than 10 plants. However, when hot water is used in total site heat integration, only the heat around 100–150 °C is recovered. With this temperature range, the number of plants participated in heat integration is largely reduced. Fig. 1 illustrates three possible connection patterns when there are three plants. In Fig. 1(a), a heat source exchanges heat with two heat sinks separately, and this connection pattern allows the heat source to provide intermediate fluids with different temperatures and flow rates to the two heat sinks. However, this connection pattern requires the longest pipe length. The connection shown in Fig. 1(b) indicates a connection pattern with a medium pipe length. In this connection pattern, one intermediate fluid stream flowing out of a heat source is split into two to serve two heat sinks. With this connection pattern, the inlet temperatures of the intermediate fluid to the two heat sinks are the same, and the flow rate can be varied. The connection in Fig. 1(c) gives a connection pattern that requires the shortest pipeline. In this connection pattern, a full intermediate fluid flows from a heat source to two heat sinks consecutively. With this connection pattern, the flow rates of the intermediate fluid going to the two sinks are the same, and the intermediate fluid inlet temperature of the second heat sink almost equals the intermediate fluid outlet temperature of the first heat sink. The three connection patterns has been discussed with industrial engineers, and they agreed that the three connection patterns are valid in practice.

We define the three connection patterns shown in Fig. 1(a), (b) and (c) as parallel, split and series connection pattern, respectively. The potential heat sinks and sources are taken from Grand Composite curves to consist a new Composite curves [1] which are used to illustrate the heat feature in the three connection patterns, as shown in Fig. 2.

In Fig. 2, the gray thick lines indicate the intermediate fluid. In Fig. 2(b), the black thick lines denote the two split intermediate fluids. From Fig. 2(a), it can be deduced that in the parallel pattern, because of the two independent intermediate fluid circuits, the two intermediate fluid lines can be combined into one intermediate fluid curve. It is clear that a curve is more likely to fit the profile of the heat source composite curve so that heat with a higher quality may be taken from the heat source. Therefore, this connection pattern is most likely to satisfy the high quality heat demand for the heat sink with higher temperature. Because the intermediate fluid curve is more likely to fit the profile of the heat source composite curve, it is relatively difficult to get pinched with the heat source curve, so this connection pattern should recover more heat than the other two patterns.

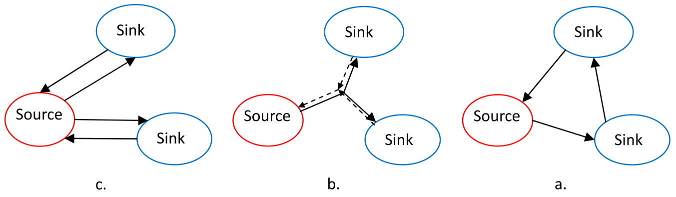

Fig. 1. a) Parallel b) split and c) series connection patterns between one heat source and two heat sinks.