

# Heat Integration Between Plants with Combined Integration Patterns

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Total site heat integration provides more energy saving opportunities than conventional heat integration within single process. Some total site design methods including direct integration using process streams and indirect integration using intermediate-fluid circuit have been proposed during these years. In these works, it is found that direct heat integration can recover more heat, require less heat transfer area, but incur higher cost in pipeline compared with indirect heat integration. However, most research focused on total site heat integration with considering only indirect heat integration or direct heat integration, no methodology simultaneously considered both direct and indirect heat integration. Therefore, some optimal designs will be missed by using current total site integration methodologies for they do not fully utilize the features of indirect and direct heat integration. In this work, the situation that only applying direct heat integration, only applying indirect heat integration and applying both heat integration in total site heat integration are analyzed. The new idea allows the direct and indirect heat integration to be considered simultaneously. The application of the new methodology can bring a significant energy saving in total site.

## 1. Introduction

Heat integration across plants can bring large energy savings and has been studied for many years. The concept of total site heat integration, first introduced by Dhole and Linnhoff (1993), describes heat integration of multiple plants with a central utility system. The site sink-source profiles proposed by them can be used to determine the different levels of steam that can be generated in order to indirectly integrate heat through multiple processes. Hu and Ahmad (1994) 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. Klemeš et al. (1997) further developed the total site profile and the site utility grand composite curve to evaluate total site potential heat recovery.

Rodera and Bagajewicz (2001) introduced a mathematical methodology to compare the difference between indirect integration and direct integration. Moreover, they analyzed factors such as number of intermediate-fluid circuits and type of intermediate-fluid in terms of cost. Because total site contains a number of processes and each process may require different minimum temperature difference, Varbanov et al. (2012) developed a modified total site targeting procedure that can obtain more realistic heat recovery targets for total sites by specifying the minimum temperature difference. More recently, Perry et al. (2008) extended the total site concept to a broader spectrum of processes in addition to the well-studied industrial processes in terms of carbon footprint. Varbanov and Klemeš (2011) further developed the total site methodology of Perry et al. (2008) by incorporating the aspects of renewable energy sources and CO<sub>2</sub> emissions. Kapil et al. (2012) proposed a methodology for estimating the cogeneration potential for a site utility system via bottom-up and top-down procedures. In their methodology, the low-grade heat is used through heat pumping, organic Rankine cycles, energy recovery from exhaust gases, absorption refrigeration and boiler feed water heating.

Although many aspects of total site heat integration have been studied by various researchers, there are still some unexplored problems. In the work of Wang (2013), they found that because of long distance between plants, pipeline cost becomes a major part of capital cost, and the number of heat exchange

circuit directly determines the capital cost. Direct integration normally requires more heat exchange circuit indicating a higher capital cost compared with indirect integration. But direct heat integration can recover more heat, and require less heat transfer area compared with integration so that when the number of heat exchange circuit is low, direct heat integration is better from the view of economic. Therefore, the performance of direct and indirect total site heat integration is different under different situation, and only considering one heat integration pattern cannot find optimal design. In this work, the practical relevance of total site heat integration is explored by considering direct and indirect heat integration. A Chinese chemical plant is used as a case study.

## 2. Heat exchange circuit

For direct heat integration across plants, because process streams cannot be mixed with each other, each process stream requires a pipeline to transport heat. The pipeline transferred heat from one plant to another is called heat exchange circuit. For indirect heat integration across plants, because intermediate fluid can be mixed and split to transfer heat between plants, the number of heat exchange circuits is smaller than direct heat integration.

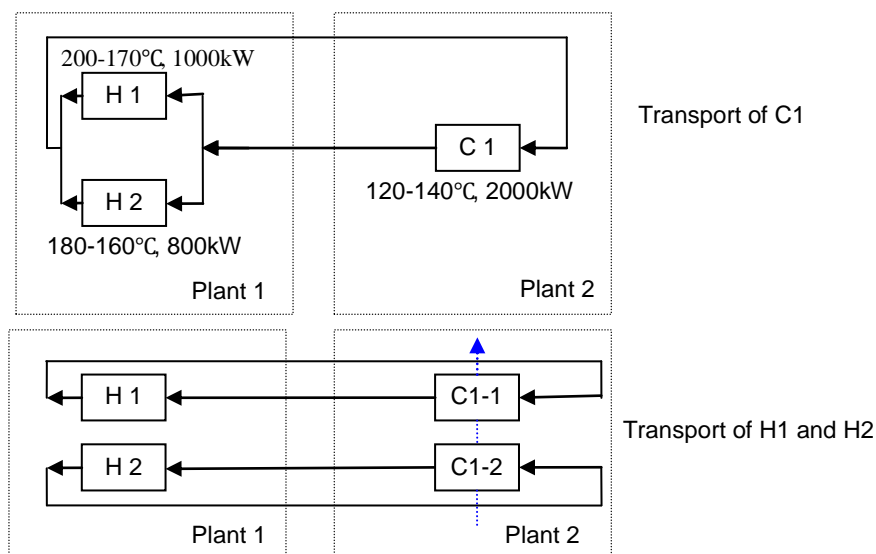


Figure 1: Comparing options for reducing the number of pipelines in direct heat integration

Because the pipe cost in heat integration across plants is high, it makes sense to reduce the number of circuits in order to minimize the investment cost. In direct heat integration, both hot and cold streams can be transported to the other plant for heat transfer. In general, both streams with large duty and streams with small duty will be available. To reduce the number of circuits, streams with large duty should be transported. As illustrated in Figure 1, H1 and H2 are two hot streams with small duty, and C1 is a cold stream with large duty. If C1 is transported from Plant 2 to Plant 1, only one pipeline needed as C1 is split into two branches to exchange heat with H1 and H2 in Plant 1. If H1 and H2 are transported from Plant 1 to Plant 2, each hot stream requires a separate pipeline and C1 is split into two branches within Plant 2 to exchange heat with H1 and H2.

For indirect heat integration across plants, there are two situations: integration required only one heat exchange circuit and integration required more than one heat exchange circuit. The two situations are shown in Figure 2, the left figure illustrates the situation that the integration required two heat exchange circuits, and the right figure indicates the situation that the integration required only one heat exchange circuit. In the figure, the upper curve indicates the composite curve for hot streams in the plant with surplus heat, the medium curve(line) indicates the heat exchange circuit and the lower curve indicates the composite curve for cold streams in the plant required heat. The hot stream curve and cold stream curve are pinched with a minimum temperature difference to find a energy target. Based on the energy target, the number of intermediate fluid circuits can be determined from Figure 2.

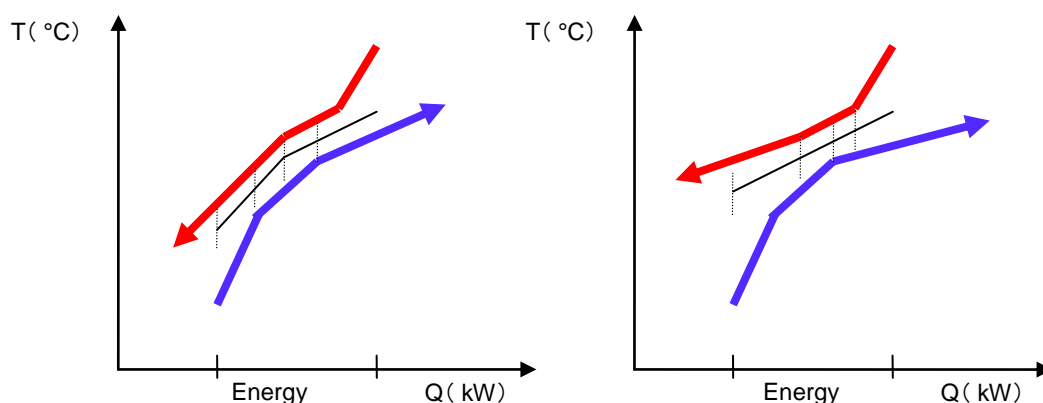


Figure 2: Situations that require different heat exchange circuits in indirect heat integration

In the situation that more than two heat exchange circuits are required, indirect heat integration may not be that beneficial, because the prominent advantage of indirect heat integration compared with direct heat integration is that it requires less heat exchange circuits.

### 3. Combination of direct and indirect heat integration

The capital cost of total site heat integration is highly depended on the number of heat exchange circuits. Therefore, when more than one heat exchange circuits are required in indirect heat integration, the combination of direct and indirect heat integration may be more beneficial because the advantage of both total site heat integration patterns can be used.

Figure 3 illustrates a way to use two total site heat integration patterns simultaneously in the design. In the figure, to achieve energy target, two heat exchange circuits are required if indirect heat integration is applied. The curves are divided into two subsystems in the place of inflection point on heat exchange circuit curve. In each subsystem, only one heat exchange circuit is required. From the left figure in Figure 3, it can be seen that if the highlight part on upper curve is consisted by only one stream, then direct heat integration can be applied instead of indirect heat integration in this subsystem, as shown in the right figure in Figure 3. Direct heat integration requires heat transfer only once (from hot streams to cold streams) and indirect heat integration requires heat transfer twice (from hot streams to intermediate fluid and from intermediate fluid to cold stream), so more heat exchangers are required in indirect heat integration. By using direct heat integration to take the place of indirect heat integration, the number of heat exchangers is reduced. Moreover, from the right figure in Figure 3, after turning indirect heat integration into direct heat integration, the number of heat transfer is reduced from two to one in highlight subsystem, which indicates a smaller heat transfer area because of the increase in temperature difference.

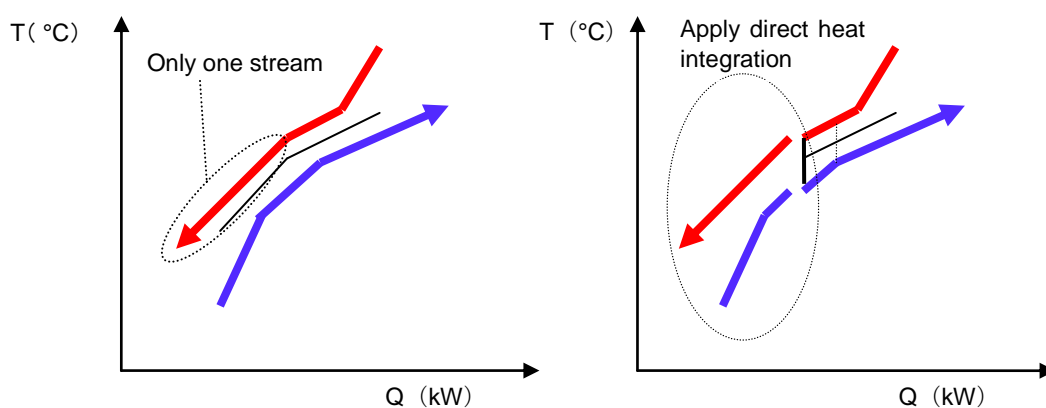


Figure 3: Applying two integration patterns to reduce heat exchanger cost

As mentioned, the feature of direct heat integration is that it requires less heat exchanger area and can recover more energy. The analysis in Figure 3 only utilize the feature of reducing heat exchanger area, but cannot recover more heat. The reason is that after dividing the system into two subsystems, both subsystems become threshold problems and the maximum heat recovery had been achieved. It is known that pinch point is the heat recovery bottleneck of the system, to reduce energy consumption, the minimum approach temperature ( $\Delta T_{min}$ ) must be reduced. For indirect heat integration, twice heat transfer is experienced during the heat exchange between hot streams and intermediate fluid and the heat exchange between intermediate fluid and cold streams. This means that indirect heat integration requires larger  $\Delta T_{min}$  to allow twice heat transfer. Therefore, if the heat integration pattern at pinch point can be changed from indirect heat transfer to direct heat transfer, the  $\Delta T_{min}$  can be reduced so that the total energy consumption can be further reduced.

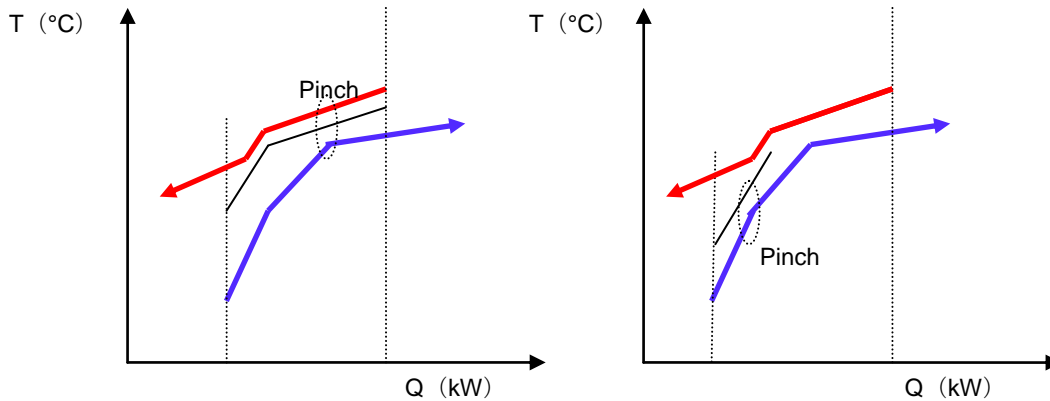


Figure 4: Applying two integration patterns to recover more heat

Figure 4 illustrates the situation that switching heat integration pattern from indirect heat integration pattern to direct heat integration pattern. The medium curve(or line) in the figure indicates intermediate fluid circuits. In the left figure, two intermediate fluid circuits are used to achieve energy target and in the right one, one intermediate fluid is kept and the other is substituted by direct heat integration. Because the  $\Delta T_{min}$  for direct heat integration is smaller, the cold stream composite curve can be further moved leftwards until new pinch point emerges. Then the energy consumption can be reduced. Moreover, the number of heat exchangers is also reduced after changing heat integration patterns.

#### 4. Case study

The case analyzed here is a heat integration project for two existing plants. The distance between the two plants is 2 km. The hot streams with surplus heat in heat source plant and the cold streams required additional heat in heat sink plant are shown in Table 1.

Table 1: The stream data for case study

Streams	Supply temperature (°C)	Target temperature (°C)	Duty (kW)
H1	115	90	2,500
H2	160	110	11,500
H3	210	150	4,800
H4	230	210	1,000
H5	210	190	2,000
C1	90	120	2,200
C2	120	121	8,600
C3	120	200	7,000

The minimum temperature difference in this case study is 20 °C for indirect heat integration and 10 °C for direct heat integration. Because indirect heat integration require twice heat transfer, the minimum temperature difference is doubled compared with direct heat integration. Based on the analysis used in this work, the figures are used here to illustrate the designs that applying only direct heat integration, applying only indirect heat integration and applying both integration patterns, as shown in Figure 5.

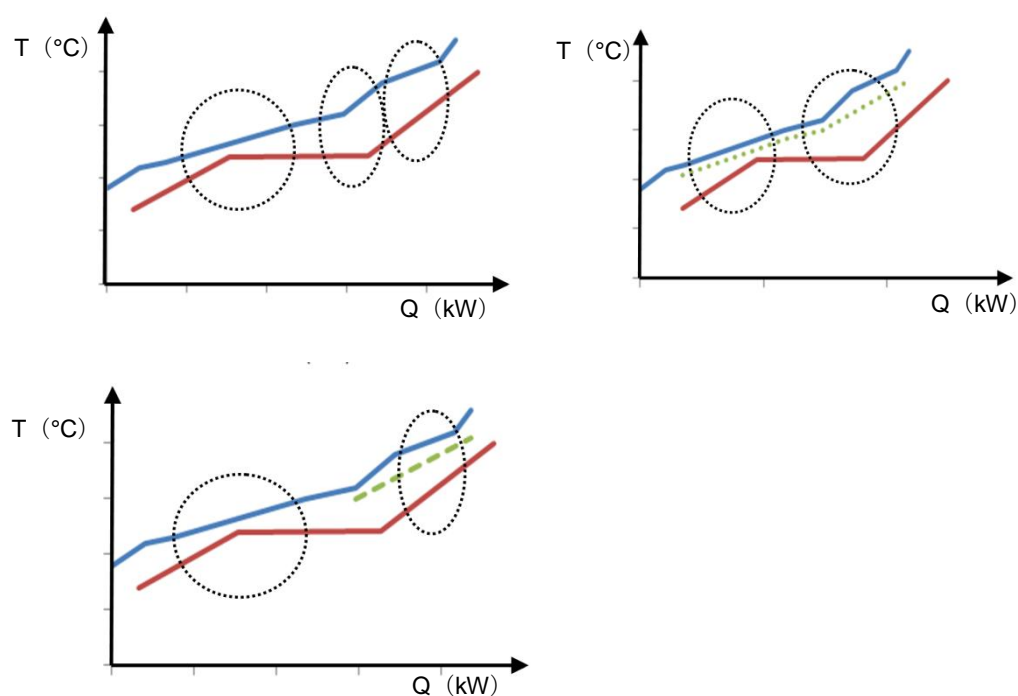


Figure 5: Composite curves for different situations in case study

The upper left figure in Figure 5 shows the situation of direct heat integration, the upper right figure shows the situation of indirect heat integration and the lower figure in Figure 5 shows the situation of combined heat integration patterns. In Figure 5, the dashed circles indicate the required heat exchange circuits. It is mentioned that the feature of direct heat integration is that it can recover more heat but normally require more heat exchange circuit and the feature of indirect heat integration is opposite. And the combined integration pattern can have the advantage of both direct heat integration and indirect heat integration simultaneously in this case study. The detail results are shown in Table 2.

Table 2: The detail results for case study

Heat integration pattern	Energy recovery target(kW)	number of circuits
Direct	20,200	3
Indirect	18,400	2
Combined	20,200	2

## 5. Conclusions

Heat Integration across plants can bring large energy saving. Because the distance between plants is normally long, the pipeline cost between plants become the major expense. Therefore, it is desirable to reduce the energy consumption and the number of heat exchange circuits simultaneously. Direct heat integration pattern is good for reducing energy consumption but require more heat exchange circuits. Meanwhile, indirect heat integration pattern require less heat exchange circuit but cannot recover as much heat as direct heat integration. The opportunities of combining both heat integration patterns are explored in this work. It is found that combined pattern can be used to reduce the heat exchange area, heat exchange circuit and energy consumption. In case study, by using combined integration pattern, the energy recovery target is equal to direct connection pattern (20,200 kW), but the number of circuits is 2, which is less than the 3 circuits in direct integration pattern. The future work is to establish a methodology to apply this idea systematic.

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