Korean J. of Chem. Eng., **12**(5), 589-592 (1995)

SHORT COMMUNICATION

THE SYSTEM SEPARATION METHOD FOR THE OPTIMAL TARGET OF HEAT EXCHANGER NETWORK SYNTHESIS WITH MULTIPLE PINCHES

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(Received 6 May 1995 • accepted 21 August 1995)

Abstract—This article proposes a new method to the optimal target of a heat exchanger network synthesis problem of which data feature multiple pinch points. The system separation method we suggest here is to subdivide the original system into independent subsystems with one pinch point. The optimal cost target was evaluated and the original pinch rules at each subsystem were employed. The method is illustrated with two examples of which data features two pinch points.

Key words: *HEN, Heat Exchanger Network, Multiple Pinches, System Separation Method, Constraints*

INTRODUCTION

How to conserve and utilize energy with great efficiency has been one of the most important subjects in chemical engineering. Many researchers have been achieved in energy conservation technology through the optimization of heat exchanger network synthesis. The pinch theory, proposed by Linnhoff and Flower [1978] and also known to be an epoch-making method, has contributed to the establishment of optimal energy recovery, and researches are now directed towards designing new energy recovery systems as well as reexamining and revising/repairing of the established designs.

The pinch design method (PDM) proves the pinch point, the most constrained part, and systematically directs stream splitting and match placement in a heat exchanger network which does not always have a single pinch point [Trivedi et al., 1989]. However, a given network can not always be synthesized with a single pinch point but can be with multiple pinches, thus difficulties over the synthesis/determination of cost target are raising in using the PDM. As a solution to a network with multiple pinches, Trivedi et al. [1989] suggested a method using the 'inverse pinch' concept, and recently 'simultaneous synthesis method' based on original PDM was proposed by Jezowski [1992]. However, the applications of these methods appear to be limited to a certain extent in actual synthesis depending on a given network, and we may have to look for better methods.

Here we propose a new method called 'system separation method', which divides a given network with multiple pinches into two subnetworks so that the pinch number in each subnetwork can be either one or zero. With this method, we can easily apply the original PDM in computing the cost target, and also the method will be very useful in copying with given constraints for matching between streams in terms of safeguard and layout. In general, people determine the annual cost of a given network first and then synthesize the heat exchanger network until it reaches the permitted range of the annual cost. If starting the synthesis with an incorrect cost target it may be ended up with a wrong ultimate system albeit the system itself may comply with the cost target. Moreover, if the constrained parts of the complicated process are not reflected in the target price, the system will lose its validity. Therefore, we can't overemphasize the importance of the determination of a proper target price in heat exchanger network synthesis.

Still there is another approach proposed by Linnhoff and Ahmad [1990] based on the PDM. They figured out the optimal minimum temperature difference between adjacent pinch points prior to the synthesis of heat exchanger network (cost target) by comparing the total cost based on the number of heat exchanger and heat transfer area as they change the value of the minimum temperature difference.

This study is mainly focused on the computation of appropriate cost target for the actual synthesis of optimal heat exchange network, and two examples are provided to help you understand our method.

SYSTEM SEPARATION METHOD

In our previous studies [Kim et al., 1992; Lee and Yoo, 1994; Lee et al., 1993], we showed a program designed to synthesize heat exchanger networks very close to the total cost. The program was based on the theory by Linnhoff and Ahmad [1990], and by finding the optimal minimum temperature difference we determined the total cost target for the minimum heat exchangers and heat transfer area followed by heat exchange network synthesis using the original PDM. Unlike as in the case of the network with a single pinch, we were puzzled in the synthesis about which pinch point to start with in the multiple-pinch network. Since the methods by Trivedi et al. [1989] and Jezowski [1992] were either not applicable in determining the cost target or could encounter with cases unable to define 'inverse pinch', we here suggest an applicable method shown in Fig. 1.

In heat exchanger network synthesis, we sometimes need constraints in determining streams by a user's request. For instance, there can be an accident due to the mix-ups of the hot and the cold utilities for heat exchange, of the distance between the streams are too far apart for laying pipes. Therefore, we need

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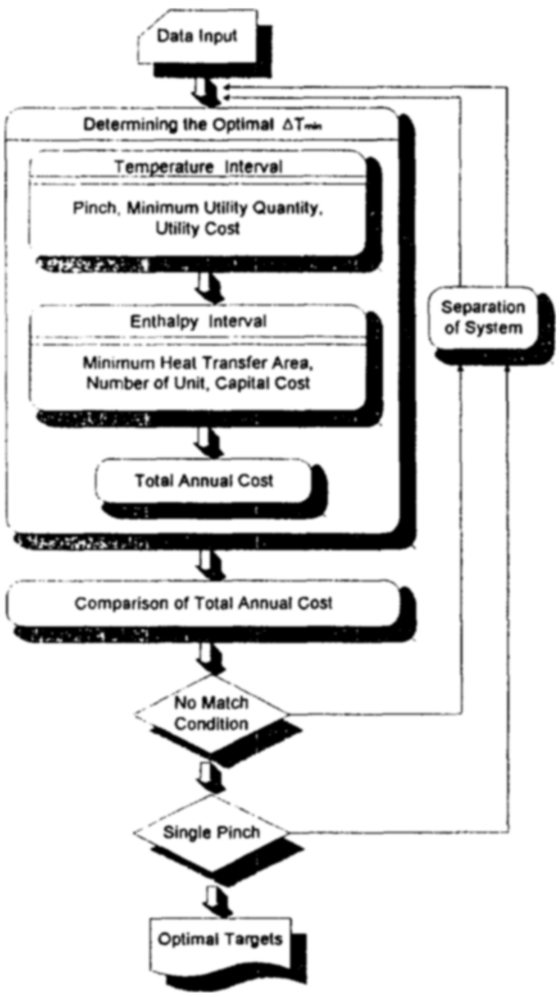

Fig. 1. Procedure of determining the optimal targets.

bestow constraints and select the best in determining streams. We therefore went over the constraints in determining cost target prior to the synthesis to enhance the reliability and the validity. Here again we separate the process stream into two subnetworks based on the constraint factors and compute the cost target for each subnetwork.

With information on network streams, we find the minimum utility requirement, pinch temperature, heat transfer area and number of units to varying ΔT within an arbitrary limit. These values are used to find the optimum ΔT with the minimum cost for the utility, unit cost and the total expenses, and the resulting costs are chosen as the target price. If the network is with multiple pinches, we must divide the stream into two subnetworks considering all the cases to compute the cost target for each case, and choose the subnetwork with a single pinch with the minimum capital cost as the optimum price. Special rules are excluded in separating streams because inconsistency in unavoidable due to the characteristics of each network, and by taking all the cases into consideration we can not only secure the reliability of optimization but also cut out the processing time with the improvement of computer efficiency.

Consequently, when each subnetwork has a single pinch with optimal minimum expense, we can determine the final cost target by combining the expenses of the two subnetworks, and by synthesizing to contend with the target price we can easily apply the original PDM thus obtaining the ultimate system which has the composite network of the two subnetworks.

The method to compute the target price proposed by us are described in previous studies [Kim et al., 1992; Lee and Yoo, 1994; Lee et al., 1993], and here we will go over examples for multiple-pinch networks with given constraints for heat exchanger streams on the basis of our theory.

Table 1. Stream and design data for example 1

(a)

Stream type & number	Supply temp. (℃)	Target temp. (℃)	Heat capacity flowrate (MW/℃)	Heat transfer coefficient (MW/m²·℃)
Hot 1	327	40	0.10	$.50\times10^{-3}$
Hot 2	220	160	0.16	$.40\times10^{-3}$
Hot 3	220	60	0.06	$.14\times10^{-3}$
Hot 4	160	45	0.40	$.30\times10^{-3}$
Cold 1	100	300	0.10	$.35\times10^{-3}$
Cold 2	35	164	0.07	$.70\times10^{-3}$
Cold 3	85	141	0.33	$.50\times10^{-3}$
Cold 4	60	170	0.06	$.14\times10^{-3}$
Cold 5	141	300	0.20	$.60\times10^{-3}$

(b)

Hot utility
- Temperature: 330-250(℃)
- Heat capacity flowrate: 1.0(MW/℃)
- Heat transfer coefficient: 0.50×10^{-3}(MW/m²·℃)

Cold utility
- Temperature: 15-30(℃)
- Heat capacity flowrate: 1.0(MW/℃)
- Heat transfer coefficient: 0.50×10^{-3}(MW/m²·℃)

Cost data
- Exchanger capital cost($) = 10000 + 350·area(m²)
- Plant lifetime: 5(year)
- Rate of interest: 0(%)
- Annual cost of unit duty of hot utility : $60000.0/MW·year
- Annual cost of unit duty of cold utility : $6000.0/MW·year

EXAMPLE 1

This example is to explain our system separation method for the network with multiple pinches. Here we varied the temperatures of cold stream 1, 3 and 5 arbitrarily so that the network raised by Linnhoff and Ahmad [1990] can have two pinches. Process streams and design data are shown in Table 1. The network consists of 4 hot and 5 cold utilities, and temperature intervals are shown in Fig. 2(a). The optimum ΔT of 5-35℃ was 24℃, and the network was found to be multiple-pinch network where the pinch is present at both 124℃ and 160℃. When we computed the target prices for each case by separating systems, we found that network had the single-pinch with minimum expense when hot utility 3, 4 and cold utility are subgrouped in subsystem-1 and hot utility 1, 2 and cold utility 1, 2 and cold utility 1, 2 and 5 into subsystem-2; they are shown in Fig. 2(b). The target cost for each subsystem and the total cost of these two subsystems are shown in Table 2(b).

As a result, we found that subsystem-1 does not have a pinch,

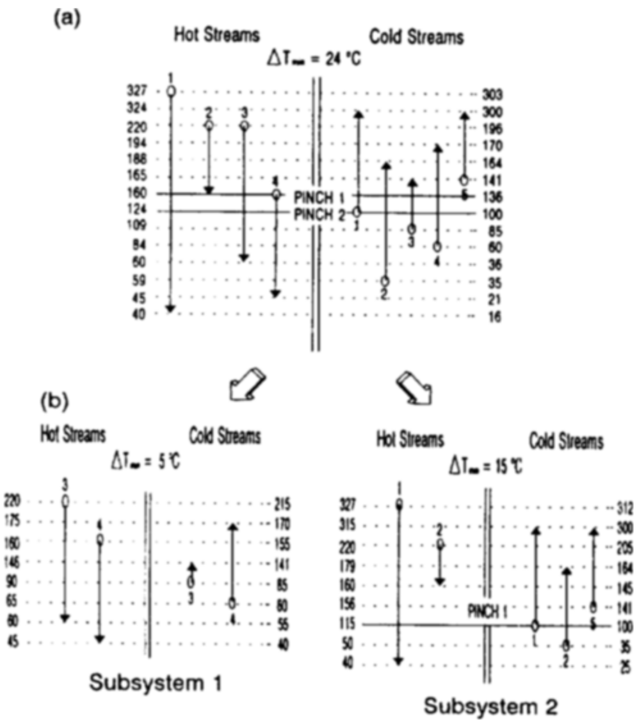

Fig. 2. Temperature-intervals for example 1.
(a) the conventional method
(b) the suggested method

Table 2. Example 1-output for targets of heat exchanger network : (a) the conventional method, (b) the suggested method

(a)

Minimum temperature difference : 24.0℃	
Pinch temperature : 160.0℃, 124.0℃	
Requirement of hot utility : 23950.0 kW	
Requirement of cold utility : 31940.0 kW	
Total number of exchangers : 16 EA	
Total area	: .173E+05 m^2
Energy cost	: \$ 1.629×10^6/year
Capital cost	: \$ 1.243×10^6/year
Total cost	: \$ 2.872×10^6/year

(b)

	Subsystem 1	Subsystem 2	Total
Minimum temperature difference	5℃	15℃	
Pinch temperature	-	115.0℃	
Requirement of hot utility	0.0 kW	25480.0 kW	25480.0 kW
Requirement of cold utility	30520.0 kW	2950.0 kW	33470.0 kW
Total number of exchangers	4 EA	7 EA	11 EA
Total area	9.62×10^3 m^2	6.31×10^3 m^2	1.59×10^4 m^2
Energy cost	\$ 1.831×10^5/year	\$ 1.546×10^6/year	\$ 1.730×10^6/year
Capital cost	\$ 6.814×10^5/year	\$ 4.559×10^5/year	\$ 1.137×10^6/year
Total cost	\$ 8.645×10^5/year	\$ 2.002×10^6/year	\$ 2.867×10^6/year

Table 3. Stream and design data for example 2

(a)

Stream type & number	Supply temp. (℃)	Target temp. (℃)	Heat capacity flowrate (MW/℃)	Heat transfer coefficient (MW/m^2·℃)
Hot 1	327	40	0.10	$.50\times10^{-3}$
Hot 2	220	160	0.16	$.40\times10^{-3}$
Hot 3	220	60	0.06	$.14\times10^{-3}$
Hot 4	160	45	0.40	$.30\times10^{-3}$
Cold 1	100	300	0.10	$.35\times10^{-3}$
Cold 2	35	164	0.07	$.70\times10^{-3}$
Cold 3	85	138	0.35	$.50\times10^{-3}$
Cold 4	60	170	0.06	$.14\times10^{-3}$
Cold 5	140	300	0.20	$.60\times10^{-3}$

(b)

Hot utility
Temperature: 330-250(℃)
Heat capacity flowrate: 1.0(MW/℃)
Heat transfer coefficient: 0.50×10^{-3}(MW/m^2·℃)
Cold utility
Temperature: 15-30(℃)
Heat capacity flowrate: 1.0(MW/℃)
Heat transfer coefficient: 0.50×10 ³(MW/m^2·℃)
Cost data
Exchanger capital cost(\$)=10000+350·area(m^2)
Plant lifetime : 5(year)
Rate of interest : 0(%)
Annual cost of unit duty of hot utility : \$ 60000.0/MW·year
Annual cost of unit duty of cold utility : \$ 6000.0/MW·year
※No-match condition : Hot 1 ↔ Cold 2

and subsystem-2 has a single pinch at 115℃ (temperatures based on hot utility). When compared to cost target without system separation, we found that utility expense increased while the total cost decrease of heat transfer area. Moreover, by switching a multiple-pinch network into a single-pinch network, we could utilize the original PDM.

EXAMPLE 2

This example is to explain a case of networks when constraint conditions are given for the selections of streams to exchange heat, based on the problem suggested by Linnhoff and Ahmad [1990], and we arbitrarily determined constrained conditions for hot utility 1 and cold utility 2. Process streams and design data are shown in Table 3. Temperature-enthalpy graphs not considering the constrained conditions for stream determinations are shown in Fig. 3(a); the curve for all the mixed streams of the hot and the cold are indicated in solid lines, and the hot 1 and the cold 2 are shown in dotted lines. However, since two streams, of which heat shouldn't be exchanged between them, are lain perpendicular to each other and can cause error in target price computation, we tried to solve these problems by separating the streams into two subsystems. First of all, we placed hot utility 1 and cold utility 2 in different subsystems, and searched for the case of a network having the minimum cost with a single pinch by considering all the factors, for varying ΔT of 5-35℃ and arranging streams of subsystems. The minimum cost for

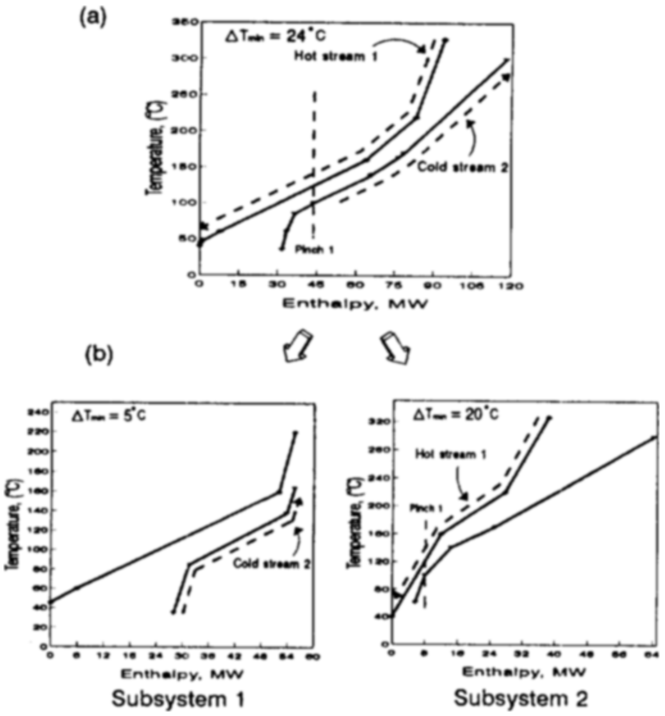

Fig. 3. Temperature-enthalpy diagrams for example 2.
(a) the conventional method
(b) the suggested method

single pinch was achieved when hot utility 3, 4 and the cold utility 2, 3 are grouped into subsystem-1 and the rest of the streams into subsystem-2; this is shown in Fig. 3(b) and Table 4. When compared to target price without consideration of constrained parts, the total cost was increased slightly but we found the more reliable cost target by considering all the constraints.

CONCLUSION

The advantages of our system separation method are to solve the problems we meet in applying original PDM in networks with multiple pinches, make the applications of original PDM much easier and find the more reliable cost target by considering all the constraints, whereas 'inverse pinch' concept and 'simultaneous synthesis method' only consider actual synthesis steps. Our study on actual synthesis is near to completion and will be reported soon.

NOMENCLATURE

ΔT : temperature different [℃]
ΔT_{min} : minimum temperature difference on the composite curves [℃]

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Table 4. Example 2-output for targets of heat exchanger network : (a) the conventional method, (b) the suggested method

(a)

Minimum temperature difference	24.0℃
Pinch temperature	124.0℃
Requirement of hot utility	23920.0 kW
Requirement of cold utility	31640.0 kW
Total number of exchangers	15 EA
Total area	1.72×10^4 m^2
Energy cost	\$ 1.625×10^6/year
Capital cost	\$ 1.235×10^6/year
Total cost	\$ 2.860×10^6/year

(b)

	Subsystem 1	Subsystem 2	Total
Minimum temperature difference	5℃	20℃	
Pinch temperature		120℃	
Requirement of hot utility	0.0 kW	25900.0 kW	25900.0 kW
Requirement of cold utility	28020.0 kW	5600.0 kW	33620.0 kW
Total number of exchangers	4 EA	7 EA	11 EA
Total area	8.43×10^3 m^2	7.17×10^3 m^2	1.56×10^4 m^2
Energy cost	\$ 1.681×10^5/year	\$ 1.588×10^6/year	\$ 1.756×10^6/year
Capital cost	\$ 5.984×10^5/year	\$ 5.162×10^5/year	\$ 1.115×10^6/year
Total cost	\$ 7.665×10^5/year	\$ 2.104×10^6/year	\$ 2.870×10^6/year