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Heat Exchanger Network Retrofit through Heat Transfer Enhancement

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Many design methods for the retrofit of heat exchanger network (HEN) have been proposed during the last three decades. The conventional methods used to solve retrofit problems often involve too many topology modifications and are limited by the size and complexity of retrofit problems. Moreover, practical implementation of the additional area in retrofit problems can be difficult due to topology, safety and downtime constraints. Heat transfer enhancement (HTE) can increase heat transfer coefficient so as to make exchangers smaller. The application of HTE provides an opportunity to avoid high capital costs for replacing equipments and pipelines in topology modification and the difficulties of additional area implementation in retrofit design. This paper presents a novel design approach to solve HEN retrofit problems based on HTE. An optimisation method based on simulated annealing has been developed to find the appropriate heat exchangers to be enhanced and augmentation level of enhancement. The new methodology allows enhancement to be added to tube-side or shell-side or both, which depends on the heat transfer control side. The application of this new methodology can bring a significant energy saving in retrofit design without any topology modification, or investment reduction in retrofit design with topology modifications.

1. Introduction

Retrofit of HEN in an existing plant is important in energy saving. In the conventional way, by implementing additional areas, the heat load of an exchanger will increase so that energy recovery will be increased. However, in practice, implementation of physical area increase is difficult due to topology, safety and downtime constraints. Moreover, the current retrofit designs normally include many topology modifications which will increase retrofit investment significantly.

Due to these problems in heat HEN retrofit, HTE can be very attractive in HEN retrofit design. Because the implementation of enhancement devices is relative simple, which means reduced civil and pipe work cost and a short modification duration.

Pinch technology and mathematical programming are widely used in HEN retrofit. Some Pinch technology based retrofit methodologies have been proposed by Tjoe and Linnhoff (1986), Polley et al (1990). And for mathematical programming, Ciric and Floudas (1989; 1990), Yee and Grossmann (1991) have proposed some methodologies.

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However, Pinch technology based methodologies use manual procedures and require expert user, and mathematical programming based methodologies lack of interaction with users and have difficulties in solving large scale industrial problems. The network pinch approach proposed by Asante and Zhu (1997) can identify the network structural bottleneck of energy saving. However, investment of retrofit is ignored in their work. Some researches were made in applying HTE in HEN retrofit. Polley et al. (1992) first mentioned application of heat transfer enhancement in HEN retrofit, but no practical methodology was proposed. Zhu et al. (2000) have proposed a methodology based on network pinch approach, but in their methodology, enhancement and structural modification cannot be optimized simultaneously.

In this paper, a new HEN retrofit methodology is proposed. An optimisation method based on simulated annealing is developed to find the appropriate heat exchangers to be enhanced and augmentation level of enhancement. The new methodology allows enhancement to be added to tube-side or shell-side or both. The application of this new methodology can bring a significant energy saving in retrofit design without any topology modification, or investment reduction in retrofit design with topology modifications.

2. Methodology

Because the implementation of HTE is relatively simple and cheap compared with implementation of additional area, a new method of HEN retrofit can be considered without topology modification and physical area implementation. In this way, the retrofit becomes a simple task that can be achieved in a normal shut down period. That means the loss of production output in retrofit can be avoided. And the retrofit investment can be reduced significantly. Although compared with normal retrofit methodologies considering topology modifications, the energy saving of the methodology is relatively small, the simplicity of retrofit and reduced investment are very attractive.

HENs are complex systems which include intricate interactions between each of the component (Process exchangers, utility exchangers, stream splitters and mixers) in networks. A single change of one component in network may affect the performance of many other ones. And because of the complexity of HEN, those passive changes are difficult to predict. So the exchangers to be enhanced should be determined first.

Simulated annealing (SA) is a widely used optimization algorithms derived from the Metropolis algorithm (Metropolis et al. 1953). As a stochastic optimization methodology, it is easy to escape from local optima in non-convex problems. And for an infinite time scheduling, the global optimal solution is guaranteed. In SA optimization, SA moves define the search space of optimization.

Rodriguez (2005) developed a optimization approach to solve fouling mitigation problems in heat exchanger networks. In his approach, SA is used as optimization algorithm, and HEN is represented by unique nodes on each stream. Linear equations based models are solved simultaneously to calculate the node temperature. Heat duty of exchangers, splitter flow fraction and structure modifications such as re-pipe and re-sequence are considered. Chen(2008) has further developed the optimization approach proposed by Rodriguez. In her approach, a new model of HEN is developed and temperature-dependent thermal properties are considered. Based on their works, the approaches of Rodriguez(2005) and Chen(2008) are further extended to consider the application of THE.

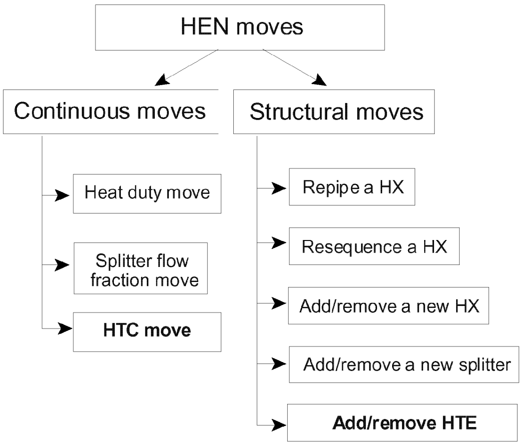

Figure 1: The detailed moves of our SA optimization

In our SA optimization, moves of adding HTE, deleting HTE and modifying heat transfer coefficient (HTC) of HTE are added. SA optimization will randomly add HTE to tube side or shell side or both of one exchanger with a random increasing ratio of HTC. The maximum increasing ratio of HTC according to enhancement devices data (Polley et al. 1992) is added as constraints. Moreover, SA optimization will randomly change the HTC value of enhanced exchangers. SA optimization will also randomly remove HTE from one enhanced exchanger. Due to the simplicity feature of our new methodology, too many implementations of HTE are not expected. So the maximum number of exchangers to be enhanced can be set by users to avoid too many modifications. The objective function is to minimize the total cost of network. When a SA move is made, the new network will be accepted if the total cost reduces, in contrary, if the total cost increases, the new network will be denied. After thousands times of move, the optimal network can be found. The SA optimization algorithm is implemented in SPRINT (v2.5) software.

As previous said, without topology modifications, the retrofit becomes a simple and low cost task, but the energy saving is relatively small. So, in those situation that a large reduction of energy saving is required, topology modification must be considered. HTE can be combined with topology modifications here to reduce the cost of retrofit and make the retrofit design more effective. In SA optimization, the moves of topology modifications such as re-pipe, re-sequence and adding a new exchanger are added to enlarge the search space of optimization. The detailed moves of our SA optimization are shown in Fig. 1.

3. Case Study

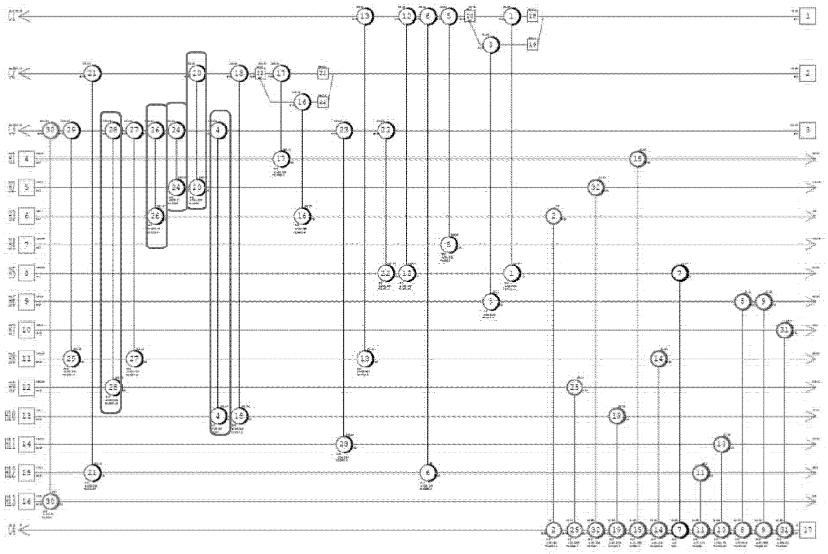

Figure 2: The existing structure of HEN

The case is an existing pre-heat train for a crude oil distillation column. The objective of this case is to find the most cost-effective retrofit design considering at most five enhancements. The original HEN before modification is shown in Fig. 2. The existing HEN is studied using SA optimization with different moves. Five HEN retrofit considerations are made to compare with each other, which are only enhancement, only physical area, physical area and enhancement, topology modifications, and both topology modifications and enhancement. The results of each retrofit strategy are shown in Table 1. The initial utility cost is 2.05E+07 GBP/y. The cost of enhancement is estimated as (Nie and Zhu 1999):

$$\text{Cost}=40*A_{\text{existing}} \tag{1}$$

The maximum number of enhanced exchangers is set to be 5 and the maximum number of adding new exchangers is set to be 3 in this case.

The table shows the results of different retrofit strategies (1 – strategy with only enhancement; 2 – strategy with only additional area; 3 – strategy with both enhancement and additional area; 4 – strategy with topology modification; 5 – strategy with both topology modification and enhancement). From the results, it can be seen that the investment of those designs with enhancement are lower than those without enhancement. The retrofit design with only enhancement can reduce 1.1 MGBP/y utility costs, which accounts for 5.4% of total utility cost. Although the energy saving is not as large as other designs, the investment of design with only enhancement is much lower than the other ones. And because of the simple implementation of enhancement, the whole retrofit can be achieved in a short time with a very small investment. From Table 1, it also can be known that the retrofit design with both topology modification and enhancement can provide a large energy consumption reduction (3.2million GBP/y) with a relatively low investment. Compared with the design with only enhancement, the design with both topology modification and enhancement cannot be done in a short time due to civil and pipe work. So the retrofit design can be an alternative design when a large energy saving is required.

Table 1: Energy cost and retrofits investment of different retrofit strategies

Retrofit strategies	Utility Cost (GBP/y)	Hot Utility saving(kW)	Additional area (m^2)	Investment (10^6 GBP)	Payback (y)
1	1.94E+07	3526	104.4	0.37	0.34
2	1.84E+07	6731	1492.0	3.03	1.44
3	1.83E+07	7051	497.8	1.35	0.61
4	1.73E+07	10256	1713.0	3.61	1.13
5	1.73E+07	10256	871.9	2.08	0.65

The enhanced exchangers in retrofit design with only enhancement are highlighted with rectangle in Fig. 2. From the figure, it can be seen that exchangers 4, 20, 24, 26 and 28 are enhanced. In these exchangers, exchangers 4, 24, 26 and 28 are on the same stream with utility exchanger 30. And exchanger 4, 24, 26 and 28 are all with a large duty. Exchanger 20 is pinching match, which is the structure bottleneck of the network(Asante and Zhu 1996).

4. Conclusion and Future Work

Heat transfer enhancement is a very attractive option for heat exchanger network retrofit. When heat transfer enhancement is applied, the retrofit investment will be reduced. In case study, application of enhancement can reduce investment significantly. For example, without enhancement, the investment of retrofit with additional area is 3.03 million GBP and the investment of retrofit with enhancement is only 0.37 MGBP. And the payback of retrofit with enhancement is very short (only 0.34 y). To consider heat transfer enhancement into optimization, SA is used as optimization algorithm and SA moves considering heat transfer enhancement are added. The optimization can search the exchangers to be enhanced automatically, and optimize the augmentation level of each enhancement. The new methodology can provide several low investment retrofit options with enhancement. In current stage, only the heat transfer performance of exchangers in a network is considered, and hydraulic performance has not considered yet. Future work will consider the hydraulic performance of enhancement.

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