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# Heat Exchanger Network Synthesis for Batch Processes by Involving Heat Storages

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The situations of streams are time-dependent which makes the heat exchanger network (HEN) synthesis of batch process much more complicated than its continuous counterpart. In this paper, a pseudo-T-H diagram approach (PTHDA) based method, in which the heat storages are employed through two methods to facilitate the heat recovery, is proposed for the synthesis of batch HEN .Two methods are investigated to use them reasonably. Total cost including cost of heat storages is calculated and HEN structure is gotten. At last an example is used for showing the application and effectiveness of the proposed methods.

## 1. Introduction

Because of the general brief that batch processes require far less energy than continuous processes, less attention has been paid to HEN synthesis. However with the shortage of energy and development of batch processes such as fine and food chemistry, more study on batch processes will be done.
Up to now, heat exchange modes are as follow: 1) direct heat exchange operation; 2)indirect heat exchange operation; 3)direct-indirect mixed operation. Direct heat exchange operation can be used between process streams which co-exist in time. However, synthesizing HEN by only direct heat operation can lead that some heat cannot be recovered. only adopting indirect exchange operation can lead to increase the total cost. So direct-indirect mixed operations is adopted in this paper.
Kemp and Deakin (1989) presented a method called a time slice model (TSM). They divided a batch process into several time intervals based on streams' start and ending time and HEN synthesis is done in each time interval according to principle of pinch technology.Besides,heat storages are added to recover more energy.However total cost is not considered when heat storages are involved in that method. Liu et al (2011) has reported a paper in which pseudo-T-H diagram approach (PTHDA) is presented to synthesize HEN of batch process based on the research of Kemp and Deakin (1989). In order to optimize HEN structure Du et al (2011) put forward three rules. However heat exchange is limited to be direct heat exchange operation in two papers. Heat storages' temperature is investigated in the paper reproted by Walmsley et al(2012).But the intergration of HEN is not drscripted.In this paper, two methods are proposed to add heat storages based on the method proposed by liu et al(2011).

## 2. Description of indirect heat exchange operation

Krummenacher and Favrat (2011) referred to a kind of indirect heat exchange operation. The heat storages are limited to be constant-temperature and variable-mass (Stoltze et al., 1995) .A group of heat storage consists of two tanks (A and B).The tanks are filled with fluid. In order to extract heat from a process stream, one low and one high-temperature tanks are required. As shown in Figure1, the temperature of tank A is higher than that of tank B. As fluid is moved from tank B to tank A, the heat is added in a heat exchanger. The only requirement to the temperature levels is that the low-temperature tank is below the lowest process temperature, and likewise for the high-temperature store. When heat is added to a stream, the tanks will have to lie above the corresponding temperatures of the process stream to be heated.

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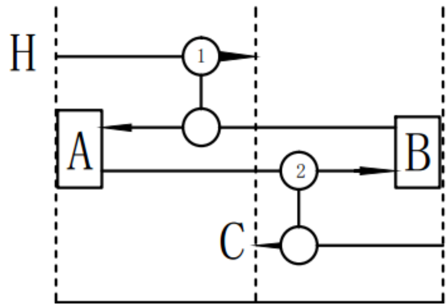



*Figure1: Model of indirect heat exchange operation*

In the paper, when the temperature of fluid inside tank B is too low to transferred heat to a cold stream, hot utilities are used to heat fluid which flows from tank A to tank B. Besides, cold utility will be used to cool fluid flowing from tank B to tank A. Figure 2 shows the model of indirect heat exchange operation with hot and cold utilities.

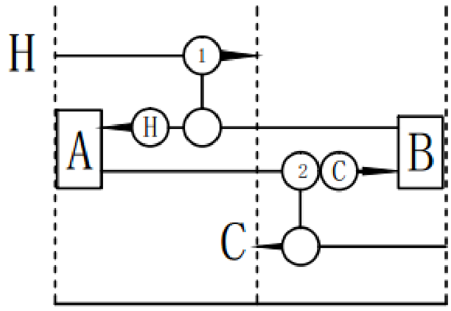



*Figure 2: The model of indirect heat exchange operation with utility*

## 3. The methods used to synthesize batch HEN by involving heat storages

Temperature and time are important factors need to be considered when dealing with batch HEN synthesis problem. The optimization of former factor is mainly reflected in PTHDA (liu et al., 2011). And the latter factor, time, which brings in some stream match restrains, causes a more complicated synthesis problem for the batch HEN than in the continuous HEN. So to obtain a target batch HEN, two methods are proposed to add heat storages. Because of different characters of different characters of two methods, both the first method together with the second method will be used in some batch processes. Firstly time intervals are divided based on streams' start and ending time. Then the two methods are used. The content of the methods is described as follow.

### 3.1. The first method

In this part, the indirect heat exchange operation with utilities will be used just as showed in the Figure 2.The stream flowing from tank A to tank B is seen as a cold stream and the stream flowing from tank B to tank A is seen as a hot stream. Firstly time intervals are divided and feasible heat cascades analysis are done (Kemp and Deakin (1989). Pinch temperatures of all time intervals are not constant; indeed it varies between a hot-end threshold and a cold-end threshold. Now on the site that there are two different pinch temperature(PT) in two time intervals, heat rejected below the pinch of one time interval can supply useful heat above the pinch of the other. Two pinch temperatures are written as PT2 and PT1 (PT2>PT1). In this paper the cold stream of heat storage is added to absorb the excess heat below the pinch and the hot stream of heat storage is used to reject useful heat. That cold stream or hot stream of the heat storage together with supply streams will be synthesized according to PTHDA in those two time intervals. Then total cost of two time intervals can be gotten. In the paper the heat can only be transferred from one time interval into the other. That is to say that heat storage can only be added between two time intervals with this method. When three or more time intervals are considered, all possible matches between two time intervals will be tried and choose the best match style so as to recover more energy. The significant characteristic of this method is that direct exchange operations together with indirect exchange operations are simultaneously considered aimed at reducing total cost of two time intervals. The unknown temperature of tank A and tank B is determined according to a C procedure. The block diagram of C procedure is shown in Figure 3. Temperature of tank A and tank B are t1 and t2 (PT2>t2>t1>PT1) which are variable quantities; Different t1 and t2 are generated and the total cost of two time intervals will be gotten through the procedure.

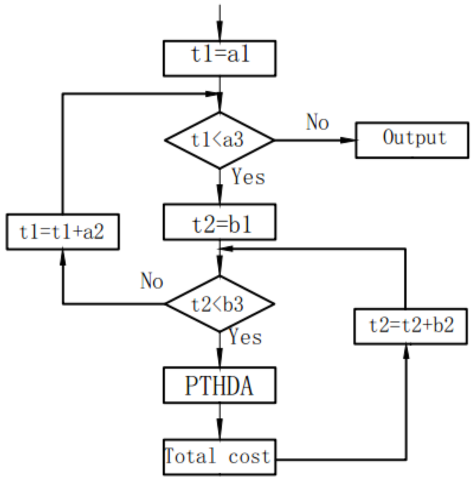



*Figure 3:The block diagram used for determining the temperature of fluid in heat storages*

**3.2. The second method**

This method is described with an example. Firstly time intervals are also divided based on streams' start and ending time.Figure 4 shows the result of time interval division. There are two hot streams and one cold stream. The specific data including the start and ending times, start and ending temperatures,heat capacity flow rate and heat transfer film coefficient can be known. minimum temperature difference is written as ΔTmin.

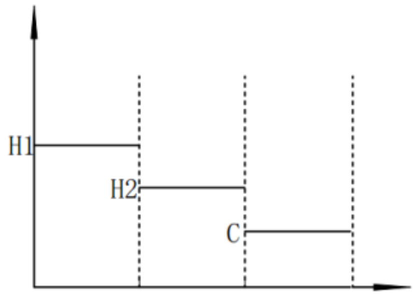
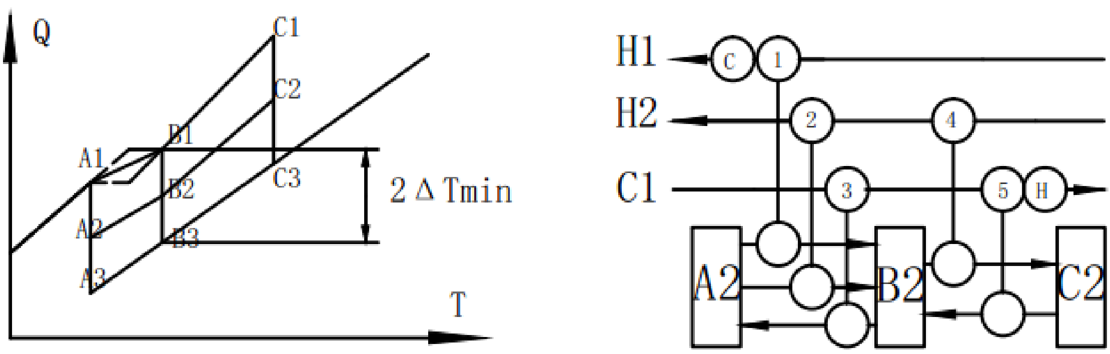



*Figure 4:The result of time interval dividion of the example*




*(a)* *(b)*

*Figure 5: The model of graph method used to synthesize HEN(a) and the structure of HEN(b)*

In this paper, a graphical method is proposed to synthesize sub-network. Figure 5(a) shows this graphical method. X-axis represents for energy (Q) and Y-axis represents for temperature (T). Represent those streams with Hot and Cold Composite Curves in T-Q diagram. Make the vertical lines of X-axis over inflection points and endpoint of Hot and Cold Composite Curves. Line segments between Hot and Cold Composite Curves are formed. Ensure that the length (ΔT) of line segments are more than 2ΔTmin. The location and the temperature of tanks are determined in those line segments. The step is described as fellow. Make points (A2,B2,C2) on those line segments. Ensure that the vertical distances between points and Hot or Cold Composite Curves aren't less than ΔTmin.Then the temperature and the location of heat storages are determined through those points. One point represent for a tank and adjacent tanks consititude a heat storage.The temperatures of tanks are gotten through making vetical line of Y-axis over those points. The folw velocity of fluid between two tanks can be adjusted. The locations of heat exchanger can be determined through the graph intuitively. The result is shown in Figure 5(b). The characters of the methods are that ΔTmin is consided and the result of this method can only generate indirect heat exchange operation. The significant character of this method is that it can be used in three or more time intervals. If cold and hot streams coexist, this method is not used because the result of this method can only have indirect heat exchange operation in this paper.

### 3.3. The combination of the first and the second methods

If there are some time intervals in which cold and hot streams coexist and other time intervals only having one kind of streams in a batch process, time intervals are divided into two groups. Cold streams and Hot streams coexist in the time intervals of first group. When Hot streams and Cold streams do not coexist, the time intervals are distinguished into the second group.

If time intervals can be distinguished two groups, methods will be combined to synthesize the HEN and one total cost can be gotten. Besides, the first method is used alone to get one total cost. Two total costs are compared to choose a better method. If time interval cannot be distinguished, only the first method is used. Figure 6 is used to describe the overall thought. Firstly, time intervals are divided. Judge whether time intervals can be distinguished into groups. The content of YES is that time intervals can be distinguished. The content of NO represents that time intervals cannot be distinguished. The detail content of method 3 includes two parts. 1) HEN of time intervals in the first group is synthesized with the first method; HEN of time intervals of the second group is synthesized with the second method. 2) Parts of time intervals in the second group are synthesized with the second method and the rest time intervals are synthesized with the first method.

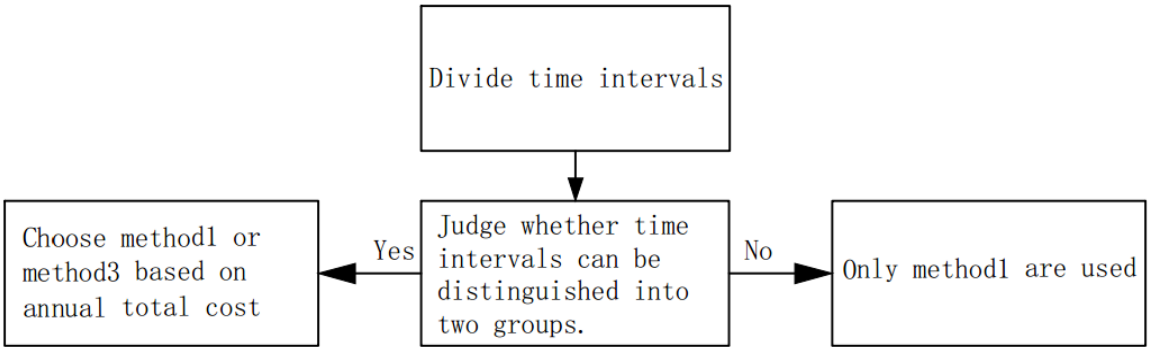



*Figure 6: The overall idea*

## 4. Example

The example is used to demonstrate the performence of the proposed method. The data of the example including 5 hot streams and 3 cold streams are shown in the Table 1. Formula of calculating the cost of heat exchanger is: 802[A $(m^2)]^{0.71}\$\cdot y^{-1}$. The formula of calculating the cost of heat storage is: 1,504 [V$(m^3)]^{0.71}\$\cdot y^{-1}$. The unit prices of hot utility and cold utility are 160,000 \$.$[W.h.y]^{-1}$ and 10,000 \$.$[W.h.y]^{-1}$.

For comparison, two kinds of methods are used in this example: Method I is proposed by Liu et al (2011); Method Ⅱ is proposed in this paper. Figure7 and Figure 8 are the network structure of method Ⅰ and method Ⅱ. When the method in this paper are used,7 time intervals are divided and time intervals can be distinguished into two groups. There are no heat storages in time interval 3,4 and 5, because when the heat storages are added in that time intervals ananual total cannot be reduced and the network structure is complicated. Cost results of two methds are presented in Table2. From Table 2, we can see that compare with method Ⅰ annual equipment cost is 2.8 % higher due to new heat exhangers and heat storages. However annual total cost of method Ⅱ is 3.5 % less than that of mehtod Ⅰ as more heat is recoveried through heat storages .

*Table 1: The data of example*

| Stream | Supple Temperature K | Target Temperature K | Heat capacity Flow rate $W.K^{-1}$ | Start time h | Ending time h |
|---|---|---|---|---|---|
| H1 | 383 | 313 | 3,000 | 1.5 | 4.5 |
| H2 | 353 | 333 | 7,000 | 1.5 | 4.5 |
| H3 | 353 | 352 | 160,000 | 1 | 4.5 |
| H4 | 403 | 393 | 20,000 | 2 | 4 |
| H5 | 413 | 313 | 5,000 | 2 | 5 |
| C1 | 313 | 368 | 10,000 | 1 | 4 |
| C2 | 383 | 384 | 160,000 | 1 | 4.5 |
| C3 | 323 | 363 | 8,000 | 0 | 3 |
| Cold utility | 283 | 284 | | 0 | 5 |
| Hot utility | 464 | 463 | | 0 | 5 |

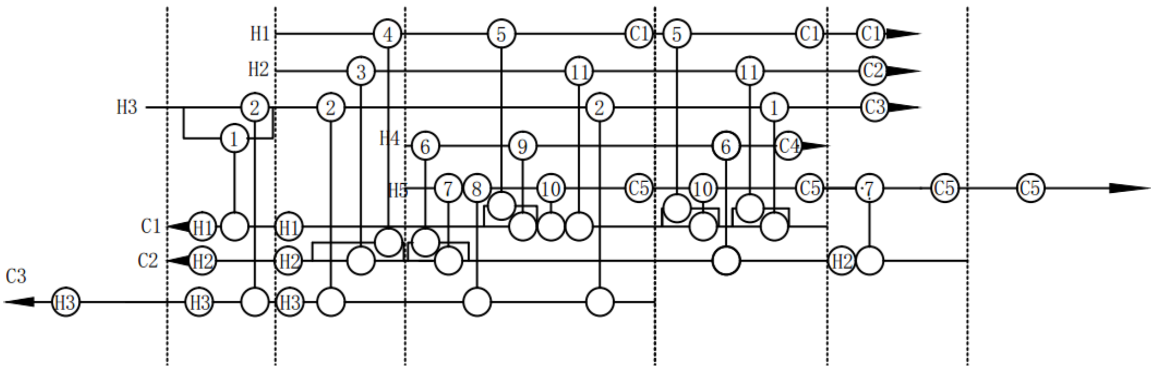



*Figure 7: The network structure of method Ⅰ*

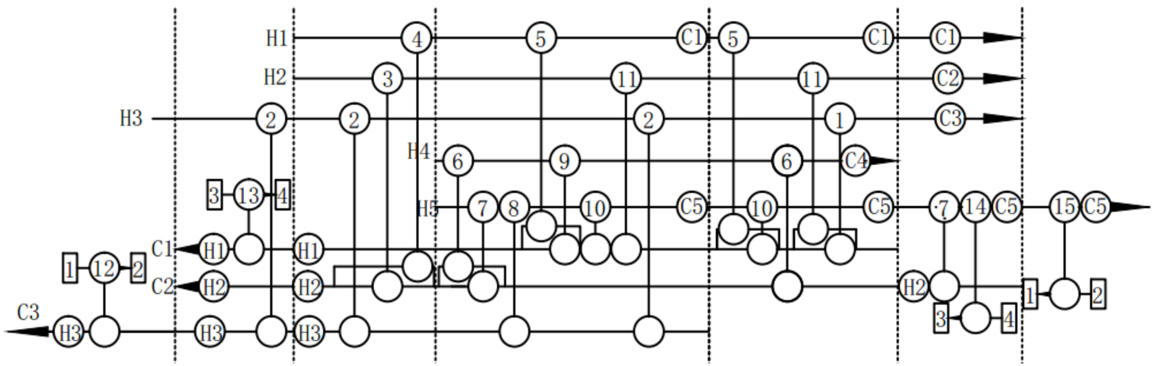



*Figure 8: The network structure of method Ⅱ*

*Table 2: The comparison of two methods*

| | Annual equipment cost | Annual operating cost | Annual total cost |
|---|---|---|---|
| Method Ⅰ | 139,165 $. $y^{-1}$ | 18,5319 $. $y^{-1}$ | 324,484 $ .$y^{-1}$ |
| Method Ⅱ | 177,919 $ .$y^{-1}$ | 135,169 $ .$y^{-1}$ | 313,088 $ .$y^{-1}$ |

## 5. Conclusions

Based on the Time Slot Model,two different methods are proposed and combined to synthesize HEN by involving heat storages.It has been demonstrated that the method proposed by Liu et al (2011) for heat intergration of batch process can be improved in order to achieve higher heat recovery by involving heat storages between different time intervals.When two different methods are aopted in different situation,the total cost can be reduced to some degree and the method for adding heat storages can be simplified.

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