PROCESS INTEGRATION-EXERGY LOSES
OF THE HEAT EXCHANGER NETWORK

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Abstract. In this paper, the exergy loses of the heat exchanger network, designed by Pinch
method, is analyzed. On analytical way, the exergy changes and the exergy loses is defined,
as in standalone heat exchanger, also in heat exchanger network. The result of this work is
the fact that heat exchangers network, generated by pinch design rules and plus/minus
principle, is the solution with best performance according to minimum exergy loses.

Key words: Pinch design method, heat exchanger network, exergy loses

INTRODUCTION

Pinch design method is the widely used technology for solving the HENS (heat
exchanger network synthesis) problems[1]. In this paper we tried to analyze the
probability of generating the minimum exergy loses on appropriate heat exchangers
network, design by this method. In the other words, we tried the get the answer:"Could be
the initial solution of heat exchangers network, generated by pinch design rules and
plus/minus principle in the phase of targeting, be the solution with best performance
according to the II low statement?"

1.EXERGY CHANGES AND EXERGY LOSS OF STREAM REPRESENTED IN T-H1
DIAGRAM

As the pinch method belongs to the group of HENS sequential methods, in the first
step it would be analyzed the portion of stream exergy changes, as in the temperature
interval, also in the whole space of the problem. In the Fig. 1., the stream p is represented
in T-H diagram, from the starting temperature \( T_1 \) till the ending temperature \( T_{R+1} \), through
the R temperature intervals. For the process in heat exchangers, involving only heat

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transfer under constant pressure \((c_p=\text{const.})\), the relation between enthalpy and entropy change for one stream could be expressed as:

\[
\frac{\Delta H}{\Delta S} = m c_p \int_{T_{\text{in}}}^{T_{\text{out}}} \frac{T}{T_{\text{cp}}} \frac{dT}{T} = m c_p \ln \frac{T_{\text{in}}}{T_{\text{out}}}
\]

Simplifying the (1):

\[
\Delta S = \Delta H \left(1 - \frac{T_{\text{in}}}{T_{\text{out}}} \right) = \Delta H \left(1 - \frac{T_{\text{in}} + T_{\text{out}}}{2} \right) = \Delta H \left(1 - \Delta T_{\text{Am}} \right)
\]

exergy change of one stream, heated/cooled from the starting till the ending temperature in heat exchanger, could be expressed as:

\[
\Delta E_x = \Delta H - E_x l = \Delta H - T_o \Delta S = \Delta H \left(1 - \frac{\Delta H}{\Delta T_{\text{Am}}} \right)
\]

According to that, in the case of stream \(p\) (stream has the constant direction \(\Delta H_{p,v} / \Delta T_{\text{Am,p,v}} = \text{const.}\)), its exergy change could be got as the sum of interval's exergy changes, no matter the number or the size of interval:

\[
\Delta E_{x,p} = \Delta H_{p,v} - E_x l_p = \Delta H_{p,v} \left(1 - \frac{T_o}{\Delta T_{\text{Am,p,v}}} \right) = \sum_{r=1}^{g} \left( \Delta H_{p,r} - T_o \frac{\Delta H_{p,r}}{\Delta T_{\text{Am,p,r}}} \right) = \sum_{r=1}^{g} \Delta E_{x,p,r} = \sum_{k=1}^{N} \Delta E_{x,p,k}
\]
In the next step the composite curve was analyzed (Fig. 2). Exergy changes of all \( M \) streams in interval \( k \) could be expressed as in (5):

\[
\Delta E_{M,k} = \sum_{m=1}^{M} \left( \Delta H_{m,k} - T_o \frac{\Delta H_{m,k}}{\Delta T_{Am,k}} \right) = \left( 1 - \frac{T_o}{\Delta T_{Am,k}} \right) \sum_{m=1}^{M} \Delta H_{m,k} = \sum_{m=1}^{M} \Delta E_{m,k} \tag{5}
\]

If the HENS task involve \( P \) number of streams \((P \geq M)\), it is obvious that the exergy change of the stream which doesn't pass through the \( k \)-interval has to be equal to 0, so the (5) could be expanded:
Now, the appropriate relation for composite curve for all streams, trough the overall temperature intervals, is:

\[
\Delta E_{x_I} = \sum_{k=1}^{N} \sum_{m=1}^{M} \Delta E_{x_{m,k}} = \sum_{p=1}^{P} \Delta E_{x_{p,k}} = \sum_{p=1}^{P} \left( \Delta H_p - T_l \frac{\Delta H_{p}}{\Delta T_{Am,p}} \right)
\]

(7)

Exergy changes and also exergy losses of the all hot/cold streams involving in HENS problem are represented in table 1.

<table>
<thead>
<tr>
<th>Table 1. Exergy change and exergy loss of stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot stream</td>
</tr>
<tr>
<td>[\Delta E_{x_{I,hs}} = \sum_{h=1}^{H_s} \Delta E_{x_h} ]</td>
</tr>
<tr>
<td>Cold stream</td>
</tr>
<tr>
<td>[\Delta E_{x_{I,cs}} = \sum_{c=1}^{C_s} \Delta E_{x_c} ]</td>
</tr>
</tbody>
</table>

2. EXERGY CHANGES AND EXERGY LOSSES OF STREAMS IN STANDALONE HEAT EXCHANGER

In the next part of the paper, individual heat exchanger, with only two streams is analyzed. Target temperatures of streams could only be reached by the addition external cooling or heating. For the purpose of simplifying the problem external heating /cooling is carried out with only one utility stream of constant temperature level \(T_{ExCs}\) for cold utility and \(T_{ExHs}\) for hot utility. Exergy balance of such system (in this case only the balance of exergy losses) can be expressed as the sum of exergy losses in hot utility heat exchanger, heat exchanger, and cold utility heat exchanger:

\[\Delta E_{xl} = E_{xl_{HU}} + E_{xl_{HE}} + E_{xl_{CU}}\]

(8)

First, the energy optimal temperature levels of the streams, with maximum heat recovery and minimum hot and cold utility are presented in Fig. 2. Obviously this case was defined with \(\Delta T_{min}=0\) according to the positions of composite curves in \(T-H\) diagram. In that case the overall exergy losses can be expressed like:

\[
E_{xl_{opt}} = T_0 \frac{\Delta H_{ExCs} \min}{T_{ExCs}} - 2T_0 \frac{\Delta H_{ExHs} \min}{T_{Cs, out} + T_{Cs, HE, out}} + 2T_0 \frac{\Delta H_{HE} \max}{T_{Hs, in} + T_{Hs, R, out}} - 2T_0 \frac{\Delta H_{HE} \max}{T_{Cs, HE, out} + T_{Cs, in}} + 2T_0 \frac{\Delta H_{ExCs} \min}{T_{Hs, HE, out} + T_{Hs, out}} - T_0 \frac{\Delta H_{ExHs} \min}{T_{ExHs}}
\]

(9)

or, according to the (7) and (8), put in the simpler form:
\[ \frac{Exl}{\Delta T_{\text{min}=0}} = T_o \frac{\Delta H_{ExCs,\text{min}}}{T_{ExCs}} + Exl_{Cs} - Exl_{Hs} - T_o \frac{\Delta H_{ExHs,\text{min}}}{T_{ExHs}} \] (10)

Comprehensible representation of standalone heat exchanger with \( \Delta T_{\text{min}} = 0 \) in H-T diagram

Composite curves of the real process in heat exchanger, with respect to its finite area, are presented on Fig. 4. Coupling the (8) and (9) in (11):

\[ Exl = Exl - T_o \frac{\Delta H_{ExCs,\text{ad}}}{T_{ExCs}} - T_o \frac{\Delta H_{ExHs,\text{ad}}}{T_{ExHs}} \] (11)
exergy loses of that process could be expressed as the function of $\Delta T_{\text{min}}$

$$Exg = f(\Delta T_{\text{min}}).$$

It could be noted

$$\Delta H_{ExCs,ad} = \Delta H_{ExCs,ad},$$

and

$$T_{ExCs} < T_{ExHs}.$$
First, the energy optimal design with $\Delta T_{\text{min}} = 0$, Fig. 5, was analyzed with respect to (7) and (8), the exergy loses of the network can be as follows:

$$\Delta E_{\text{x}1_{NW, \Delta T_{\text{min}}=0}} = T_{o} \frac{\Delta H_{\text{Ex}Cs, \text{min}}}{T_{\text{Ex}Cs}} + \Delta E_{\text{x}l_{Cs}} - \Delta E_{\text{x}l_{Hs}} - T_{o} \frac{\Delta H_{\text{Ex}Hs, \text{min}}}{T_{\text{Ex}Hs}}$$

(13)
Like in the case for only one exchanger, the overall region could be divided in the three sub regions, so (11) for the heat exchangers network get the next form:

$$\Delta \text{Ex}_{\text{NW}} = \Delta \text{Ex}_{\text{MR, min}} + T_o \frac{\Delta H_{\text{ExCs,ad}}}{T_{\text{ExCs}}} - T_o \frac{\Delta H_{\text{ExHs,ad}}}{T_{\text{ExHs}}}$$

(14)

As $\Delta H_{\text{ExCs,ad}} = \Delta H_{\text{ExHs,ad}}$, and $T_{\text{ExCs}} < T_{\text{ExHs}}$ last equation clearly proved that the heat exchangers network, generated by pinch design rules and plus/minus principle, is the solution with best performance according to minimum exergy loses.

4. CONCLUSION

The question we asked in the introduction, we tried to answer through the theoretical and mathematical background in this paper. In its origin, Pinch design method was based on the second low statement, but that fact is often neglected, and put in the background position. Normally that conclusion made a lot of misunderstandings [5], especially from the scientific circle which work is based on exergy analyses as a primal method for the process integration. We hope that this work will be a little contribution in prevailing this misunderstanding.
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