Title: «Using pinch analysis technology to assess energy efficiency in oil refining technology»

Authors: E.A. Yushkova¹, V.A. Lebedev¹, A.A. Nikitin²

Affiliations: ¹Saint Petersburg Mining University, ²National Research University ITMO

St. Petersburg, Russia
The relevance of research:

The fuel and energy complex in Russia consumes a significant part of the energy produced. Improving the energy efficiency of the fuel and energy complex is an important task for the state.
Pinch analysis is one of the most effective methods for assessing and improving the energy efficiency of heat and mass transfer processes. This method allows for structural and parametric optimization of heat exchange systems. This method is based on the enthalpy approach. Indeed, the enthalpy method is most often used to study power plants for energy efficiency. The enthalpy analysis method does not determine energy from the qualitative point of view. A more complete and objective assessment of various types of energy allows us to give an exergy approach that takes into account the quality of energy. In connection with the above, it becomes necessary to develop such a method of thermodynamic analysis and improvement of systems (in particular, the oil refining industry), which would combine the advantages of the exergy method and the method of structural and parametric optimization of thermal processes based on Pinch analysis.
The heat exchange system is optimal when exergy losses tend to be minimal. This expression is represented by the formula:

$$\sum \Delta E \rightarrow \text{min},$$  \hspace{1cm} (1)

For this, it is necessary that the recuperation of the exergy of hot and cold streams is maximized, therefore, the difference in the exergy of hot and cold streams tends to a minimum. In most cases, external energy carriers are required for the heat exchange system to function. They, in turn, impose a financial burden on the enterprise. Thus, the sums of exergies of external hot and cold energy carriers (utilities) must be minimized. Taking into account the above, to optimize the heat exchange system, in addition to the convergence of the composite curves to $\Delta T_{\text{min}}$, one should use the formula:

$$\sum \Delta E = |e_h| - |e_c| + |E_{\text{UH}}| - |E_{\text{UC}}|$$

$$|e_h| - |e_c| \rightarrow \text{min},$$
$$\sum E_{\text{UH}} \rightarrow \text{min},$$
$$\sum E_{\text{UC}} \rightarrow \text{min},$$ \hspace{1cm} (2)

Where $e_h$ is the exergy of the hot compound curve,

$e_c$ – exergy of a cold compound curve,

$E_{\text{UH}}$ - exergy of external hot energy carriers,

$E_{\text{UC}}$ - exergy of external cold energy carriers,
Names E.A. Yushkova¹, V.A. Lebedev¹, A.A. Nikitin²

Affiliations ¹Saint Petersburg Mining University, ²National Research University ITMO

Keywords: exergy, increasing energy efficiency, energy, fuel

Using pinch analysis technology to assess energy efficiency in oil refining technology

\[ E_H = \left( \begin{array}{ccc} T_{r.1} & T_{r.1} & \ln \frac{T_{r.n.1}}{T_{r.1}} & CP_{r.1} \\ T_{r.2} & T_{r.2} & \ln \frac{T_{r.n.2}}{T_{r.2}} & CP_{r.2} \\ \vdots & \vdots & \vdots & \vdots \\ T_{r.n} & T_{r.n} & \ln \frac{T_{r.n.n}}{T_{r.n}} & CP_{r.n} \end{array} \right) \]

\[ T_H = \left( \begin{array}{c} T_{r.1} \\ T_{r.2} \\ \vdots \\ T_{r.n} \end{array} \right) \]

\[ H_E = (3) \]

\[ E_C = \left( \begin{array}{ccc} T_{x.1} & T_{x.1} & \ln \frac{T_{x.n.1}}{T_{x.1}} & CP_{x.1} \\ T_{x.2} & T_{x.2} & \ln \frac{T_{x.n.2}}{T_{x.2}} & CP_{x.2} \\ \vdots & \vdots & \vdots & \vdots \\ T_{x.n} & T_{x.n} & \ln \frac{T_{x.n.m}}{T_{x.n}} & CP_{x.m} \end{array} \right) \]

\[ T_C = \left( \begin{array}{c} T_{x.1} \\ T_{x.2} \\ \vdots \\ T_{x.n} \end{array} \right) \]

\[ E_C = (4) \]
The functional dependences that form the composite curve of hot flows have the form

(7):

for the first temperature range:

\[ e_h = \left( T_{r_2} - T_{r_1} - T_0 \ln \frac{T_{r_2}}{T_{r_1}} \right) \sum_{i=1}^{n_i} \frac{CP_{r_1}}{T_{r_1}}, T_{r_1} < T_{r_2}; \]

for the first and second temperature ranges:

\[ e_h = \left( T_{r_2} - T_{r_1} - T_0 \ln \frac{T_{r_2}}{T_{r_1}} \right) \sum_{i=1}^{n_i} \frac{CP_{r_1}}{T_{r_1}} + \left( T_{r_3} - T_{r_2} - T_0 \ln \frac{T_{r_3}}{T_{r_2}} \right) \sum_{i=1}^{n_i} \frac{CP_{r_2}}{T_{r_2}}, T_{r_1} < T_{r_2} < T_{r_3}; \]

for (k-1) -th temperature intervals:

\[ e_h = \sum_{j=1}^{k-1} \left( T_{r_j} - T_{r_{(j-1)}} - T_0 \ln \frac{T_{r_j}}{T_{r_{(j-1)}}} \right) \sum_{i=1}^{n_i} \frac{CP_{r_{(j-1)}}}{T_{r_{(j-1)}}} + \left( T_{r_{(k-2)}} - T_{r_{(k-1)}} - T_0 \ln \frac{T_{r_{(k-2)}}}{T_{r_{(k-1)}}} \right) \sum_{i=1}^{n_i} \frac{CP_{r_{(k-1)}}}{T_{r_{(k-1)}}}, T_{r_{(j-1)}} < T_{r_{(k-1)}} < T_{r_k}; \]

for k-th temperature intervals:

\[ e_h = \sum_{j=1}^{k} \left( T_{r_j} - T_{r_{(j-1)}} - T_0 \ln \frac{T_{r_j}}{T_{r_{(j-1)}}} \right) \sum_{i=1}^{n_i} \frac{CP_{r_{(j-1)}}}{T_{r_{(j-1)}}} , T_{r_{(k-1)}} < T_{r_k} \]
Names E.A. Yushkova¹, V.A. Lebedev¹, A.A. Nikitin²

Affiliations ¹Saint Petersburg Mining University, ²National Research University ITMO

Keywords: exergy, increasing energy efficiency, energy, fuel

Using pinch analysis technology to assess energy efficiency in oil refining technology
Algorithm for building a connection between heat exchangers

The alleged link is located above the pinch

\[ \text{CP}_{\text{hot}} \leq \text{CP}_{\text{cold}} \]

- **Yes**
  - We build a connection between heat exchangers
  - The link is close to the pinch
  - We are looking for another pair of streams to build the connection of heat exchangers
  - Communication is possible

- **No**
  - We build a connection between heat exchangers
  - The link is close to the pinch

\[ \text{CP}_{\text{hot}} \geq \text{CP}_{\text{cold}} \]

- **Yes**
  - We build a connection between heat exchangers
  - Communication is possible

- **No**
  - Communication is possible
Using pinch analysis technology to assess energy efficiency in oil refining technology

Object of study furnace of a primary distillation unit
Converted heat fluxes of the furnace in the "enthalpy - temperature" coordinate system

Converted heat fluxes of the furnace in the "exergy - temperature" coordinate system
### Hot and cold streams before building heat exchangers

<table>
<thead>
<tr>
<th>Hot streams</th>
<th>Pinch line</th>
<th>ΔE</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Radiant section</td>
<td></td>
<td>17.23</td>
<td>27.6</td>
</tr>
<tr>
<td>2. Exhaust gases in the convection section</td>
<td></td>
<td>6.05</td>
<td>27.6</td>
</tr>
<tr>
<td>3. Flue gases in the superheater</td>
<td></td>
<td>0.94</td>
<td>27.6</td>
</tr>
<tr>
<td>4. Flue gases in convection section</td>
<td></td>
<td>1.613</td>
<td>27.6</td>
</tr>
<tr>
<td>5. Exhaust gases heating oil</td>
<td></td>
<td>1.226</td>
<td>27.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cold streams</th>
<th>Pinch line</th>
<th>ΔE</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Steam in superheater</td>
<td></td>
<td>-0.86</td>
<td>6.1</td>
</tr>
<tr>
<td>2. Petroleum</td>
<td></td>
<td>-15.85</td>
<td>251.4</td>
</tr>
<tr>
<td>3. Oil</td>
<td></td>
<td>-1.14</td>
<td>34.5</td>
</tr>
</tbody>
</table>

**Keywords:** exergy, increasing energy efficiency, energy, fuel
Results

The final heat exchanger system after optimization

<table>
<thead>
<tr>
<th>Hot streams</th>
<th>Pinch line</th>
<th>ΔE</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Radiant section</td>
<td></td>
<td>17,23</td>
<td>27,6</td>
</tr>
<tr>
<td>2. Exhaust gases in the</td>
<td></td>
<td>6,05</td>
<td>27,6</td>
</tr>
<tr>
<td>convection section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Flue gases in the</td>
<td></td>
<td>0,94</td>
<td>27,6</td>
</tr>
<tr>
<td>superheater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Flue gases in</td>
<td></td>
<td>1,615</td>
<td>27,6</td>
</tr>
<tr>
<td>convection section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Exhaust gases heating oil</td>
<td></td>
<td>1,226</td>
<td>27,6</td>
</tr>
</tbody>
</table>

Cold streams

| 1. Steam in superheater     |            | -0,86 | 6,1 |
| 2. Petroleum                |            | -15,85| 231,4|
| 3. Oil                      |            | -1,14 | 34,5|
| Additional stream -         |            | -9,21 | 251,4|
| petroleum                   |            |       |     |
Conclusions

Thus, in the course of this study, we achieved that the loss of exergy became minimal. To rationally use the remaining exergy, we will bring another heat exchanger to hot stream 1, connecting it with an additional oil flow, thereby reducing the losses of the entire primary oil refining unit ELOU AT-6 to zero.

References

Thank you for your attention!

Authors: E.A. Yushkova\textsuperscript{1}, V.A. Lebedev\textsuperscript{1}, A.A. Nikitin\textsuperscript{2}

Affiliations: \textsuperscript{1}Saint Petersburg Mining University, \textsuperscript{2}National Research University ITMO

Contact details: atenoks@mail.ru, +79817126350