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Benchmarking for Refinery Units

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The new Benchmarking methodology (Anselm) is based on the Pinch Analysis, statistical analysis and analysis of the best available technologies presented in this paper. Using the Pinch Analysis, 12 energy efficiency indexes were developed. The data obtained as a result of Pinch Analysis was processed by statistical methods. Dependencies that allow to identify the energy saving potential in oil refining processes without a detailed survey were obtained. An approach is proposed in which it is justified that only an economic evaluation of the proposed solutions to reduce gaps shows the most profitable way to increase the energy efficiency of enterprises. Anselm makes it possible to decompose all possible costly measures related to increasing energy efficiency or reducing emissions. This approach permits to propose a list of conditionally independent projects in different areas of activity and to propose projects according to the criterion of maximum energy efficiency or economic feasibility, in accordance with economic prerequisites. This paper gives an example of calculating the energy efficiency index (Anselm) for ten primary petroleum refining process.

1. Introduction

The welfare of citizens in the country in the 21st century is determined by the development and competitiveness of national economies, which, at a lower level, are determined by the competitiveness of individual industries and enterprises.

Competitiveness of individual enterprises is determined by the demand for output products and the expenditure of production. The reduction of expenditures is connected either with the development of new production technologies or with the improvement of existing ones. Experience shows that new technologies need to be optimized over time.

In order to manage an industrial enterprise effectively, it is necessary to know how effective it is in comparison with similar enterprises, and to represent where, how, and how much the cost of production can be reduced. Currently, the pointed problems are solved through benchmarking systems that represent the analysis methodology and tools for increasing of effectiveness and productivity of industrial enterprises.

The essence of benchmarking is the process of identifying the highest standards of excellence in the areas of production of goods, services and industrial processes, and then changing the achievement of these standards-usually called “best practice technology” (Bhutta and Hug, 1999). Saygin et al. (2011) identified Energy Efficiency Index to estimate energy consumption in public sectors of the economy and introduced the concept of energy efficiency improvement potential based on best practice technology and the best available technology. Energy efficiency index is introduced similarly by Ke et al., (2013), which is then used for benchmarking of cement industry. Benchmarking based on the best practical technologies does not provide the maximum available potential for increasing the energy efficiency of industrial enterprises. Benchmarking of Solomon Associates has been widely spread in oil refining and petrochemical industry. In this benchmarking, based on the best practice, the rating of enterprises or refinery units is established. Nevertheless, there is no constructive method for achieving the best practices. In addition, the "best practice" itself is a black box. Therefore, within the limits of one campaign, the best refinery unit in rating is defined and experience of its operation for use on similar units is studied. But it cannot be done for various companies. Benchmarking methods based on exergy analysis (Meshalkin 2009) also do not provide a constructive approach to achievement of the best practices.

A new benchmarking concept, which permits to determine the value of this potential, based on the methods of process integration and targeting techniques, is proposed in the paper by Gupta et al. (2000). The application

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of this approach to Indian refineries showed the value of the potential of energy efficiency increase ~ 10% -70% of the energy consumption depending on the process.
In Andersson at al., (2018), based on the analysis of data obtained from 11 sawmills a method for calculating an energy efficiency index was developed for benchmark the energy performance of industrial small and medium-sized companies' support and production processes (Andersson at al., 2018).
Mirzakhani et al. (2017) have developed this concept for benchmarking of cement industry. Here regression relations are obtained, which permit to estimate the value of hot utilities and fuel consumption depending on the process parameters. Sardarmehni et al. (2017) using the concept of process integration, have obtained mathematical models for the evaluation of energy-saving potentials in the refrigeration cycles of olefin plants. In their work the authors (Han et al., 2015) propose an efficiency analysis method for ethylene production systems in chemical industry based on fuzzy data envelopment analysis cross-model with Fuzzy Data. Panjeshahi and Tahouni (2017) using the methods of Pinch analysis have performed benchmarking of olefin plants both for energy consumption and CO_2 emission.
This paper proposes energy benchmarking based on Process Integration methods and extensive experience in development of measures to reduce specific energy consumption in oil refineries and petrochemical plants. The basis of the benchmarking method proposed in this paper is not only the fundamental laws of Process Integration, but also the results of survey of 11 oil refineries, including the survey and integration of 170 separate units and industrial facilities. The survey was conducted in all seasons and wide climatic conditions, including the humid climate of the Balkans and the Far East, the heat of the Central Asian steppes and the frost of the Siberian taiga. Various operating modes of enterprises for different types of raw materials, which had already been used for processing, was examined.
All technological parameters of flowsheets were got, thermophysical data in all working temperature ranges were determined in the plant laboratories. For all the factory processes examined, thermodynamically valid, economically profitable and technically achievable values of the minimum specific energy consumption were received. The developed projects of energy-efficient reconstruction are currently being implemented at 23 units. The thermal-infrared survey of several tens of thousands of industrial equipment elements was performed, which made it possible to create simple expressions for calculating the power of energy emissions to the environment and to include them in the benchmarking system.
With the help of statistical data processing, the main indices of the relative internal energy efficiency of the plant units and the rating indices of specific energy efficiency, which allow comparing different installations, are determined. The parameters, which the chosen indices depend on, and the nature of their dependence are got. Sets of indices are defined for all levels of production, starting from the lower level, these are separate apparatuses, and then the level of units and processes, and the top level is the indices for the whole plant, during the development of which the Total Site Integration methodology is used.

2. Method

The innovative approach proposed in this paper is that benchmarking results not only show the energy efficiency of enterprises, but also show a roadmap for achievement of the target energy consumption. The methodology of the best available technology makes it possible to assess the potential for reducing energy consumption on each unit of equipment (for example, fired furnace or air cooler). Using the Pinch Analysis method, the effectiveness of the existing HEN was determined and the potential for reducing energy consumption was evaluated. Based on the results of the pinch analysis of the data, a list of indices was developed, which was processed by statistical methods to obtain dependencies. The following 12 indicators of energy efficiency were developed:
The indicator (parameter) of losses with waste gases determines the capacity of losses with waste gases in furnaces and boilers:

$$\xi_{gas} = \frac{t_{gas} - t_{ac}}{t_{ac}}, \tag{1}$$

where t_{gas} is the temperature of the waste gases, t_{ac} is the temperature of the acidic dew point.
The parameter for evaluate not “vertical” heat transfer, determines the efficiency of using the heat exchange surface:

$$\delta_S = \frac{S_E}{S_V}, \tag{2}$$

where SE is the existing area of the recuperative heat exchange surface, SV is the area of the heat exchange surface for “vertical” heat transfer.

The useful capacity required for the process is equal to the length of the projection of the cold composite curve to the stream enthalpy axis:

$$\Delta H_{CC} = Q_{REC} + Q_{Hmin}, \quad (3)$$

where Q_{REC} is the heat recuperation capacity in the HEN of the unit (without taking into account heat losses).
Payload index:

$$\varepsilon_{ul} = \frac{Q_{Hmin}}{\Delta H_{CC}} = \frac{Q_{Hmin}}{Q_{REC}+Q_{Hmin}}, \quad (4)$$

The indicator of regenerative load:

$$\varepsilon_{rl} = \frac{Q_{REC}}{\Delta H_{CC}} = \frac{Q_{REC}}{Q_{REC}+Q_{Hmin}}, \quad (5)$$

These indicators have the following properties:

$$\lim_{Q_{Hmin}\to 0} \varepsilon_{rl} \to 1, \quad (6)$$

$$\lim_{Q_{REC}\to 0} \varepsilon_{ul} \to 1, \quad (7)$$

$$\varepsilon_{ul} + \varepsilon_{rl} = 1. \quad (8)$$

The indicator of relative efficiency of the use of utility system useful energy:

$$\gamma_{Real} = \frac{Q_{Hreal}}{Q_{Hmin}} \quad (9)$$

Potential for reducing energy consumption:

$$\gamma_{Poten} = \frac{Q_{Hreal} - Q_{Hmin}}{Q_{CC}} \quad (10)$$

Taking into account (10), the expression can be represented in the following form:

$$\gamma_{poten} = \gamma_{Real} - 1, \quad (11)$$

With the optimum operating mode of the installation $\gamma_{poten} = 0$.
The relative loss of useful capacity in the unit:

$$\gamma_{loss} = \frac{Q_{Hloss}}{Q_{Hreal}} \quad (12)$$

All received indicators are processed by statistical methods.

3. Results and discussion

The advantages of using the Anselm method are shown in the calculation example for ten primary petroleum refining process. First, the current specific energy consumption was determined. Based on the analysis of statistical data for 3 years of operation work for ten primary petroleum refining processes, specific energy consumption diagram was drawn up (Figure 1).
As already mentioned, Anselm permits to not only determine the energy efficiency of processes and compare them with each other, but also to offer a roadmap for achievement of the target energy consumption.
Based on the analysis of statistical data, the current of energy consumption in primary petroleum refining process was defined. The results are presented in the form of the Sankey diagram. The Sankey diagram was drawn up of energy consumption structure for a typical process (Figure 2).
Based on the analysis of the Sankey diagram (Figure 2), it can be concluded that primary petroleum refining processes under consideration consume mainly heat energy. Consequently, the greatest potential for increasing the energy efficiency of the considered processes is in the increase of the efficiency of the heat transfer system.

Statistical processing on the basis of data obtained as a result of the Pinch Analysis was carried out. The revealed dependencies make it possible in the future to do without a detailed survey of plants, to determine the potential for energy conservation and to estimate the current energy efficiency. Comparison of the potential for reduction energy consumption calculated with the use of the Pinch Analysis method and data obtained as a result of statistical processing is shown in Figure 3.

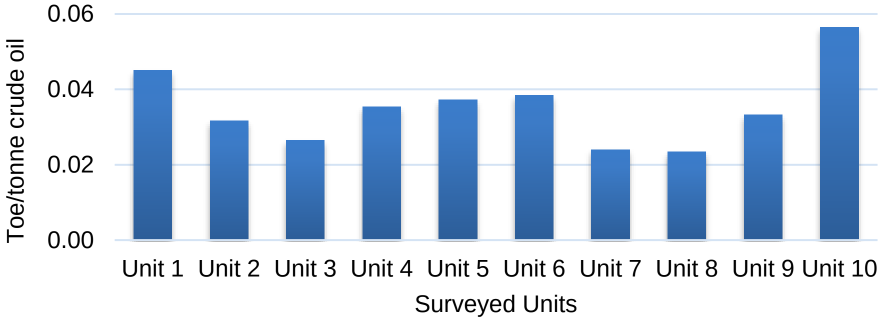

Figure 1: The current energy consumption

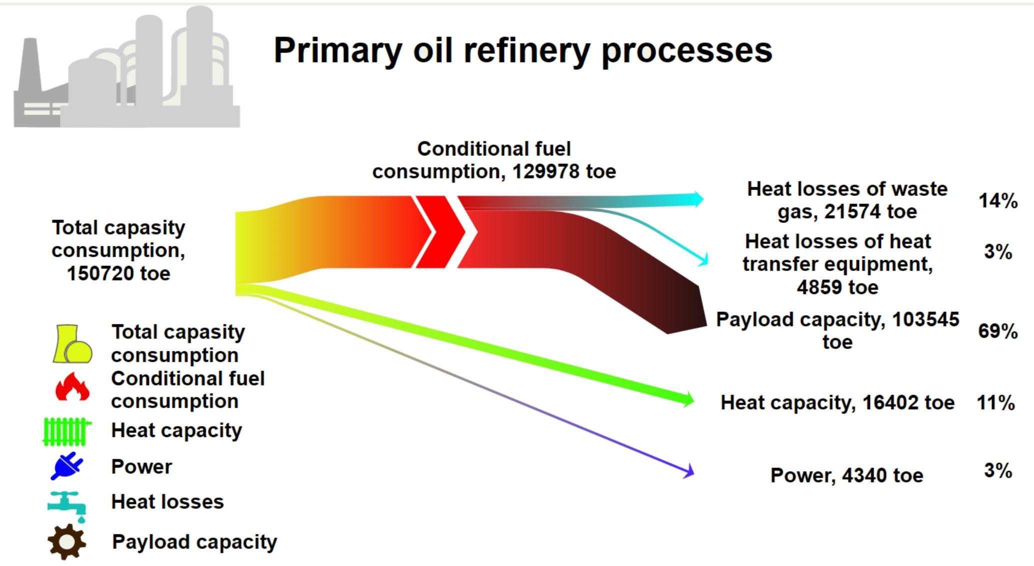

Figure 2: Energy consumption structure for a typical primary petroleum refining process (for 3 years of operation work)

The values obtained as a result of statistical analysis showed good convergence with the data obtained as a result of the Pinch Analysis. The error was 0.24 %.

With the help of indices from Section 2, the gap between the existing and ideal process for each unit was defined. The example of analysis of the heat transfer system presents the results of calculating the gaps between the existing precession and the process with a thermodynamically grounded minimum of energy consumption. The results of the calculations are shown in Figure 4.

Comparing the data in Figure 1 and Figure 4, shown that, while unit 10 has the highest energy consumption, it is in the sixth place in terms of the potential for reducing energy consumption. Consequently, the specific energy consumption is not always sufficient to assess energy efficiency.

The proposed methodology is based on the principle that the reduction in energy consumption cannot be an end in itself but should be economically justified. It is also necessary to take into account various economic restrictions (Ulyev at al., 2017).

The developed methodology permits to estimate the economic parameters of the project to reduce energy consumption without a detailed survey of the Unit.

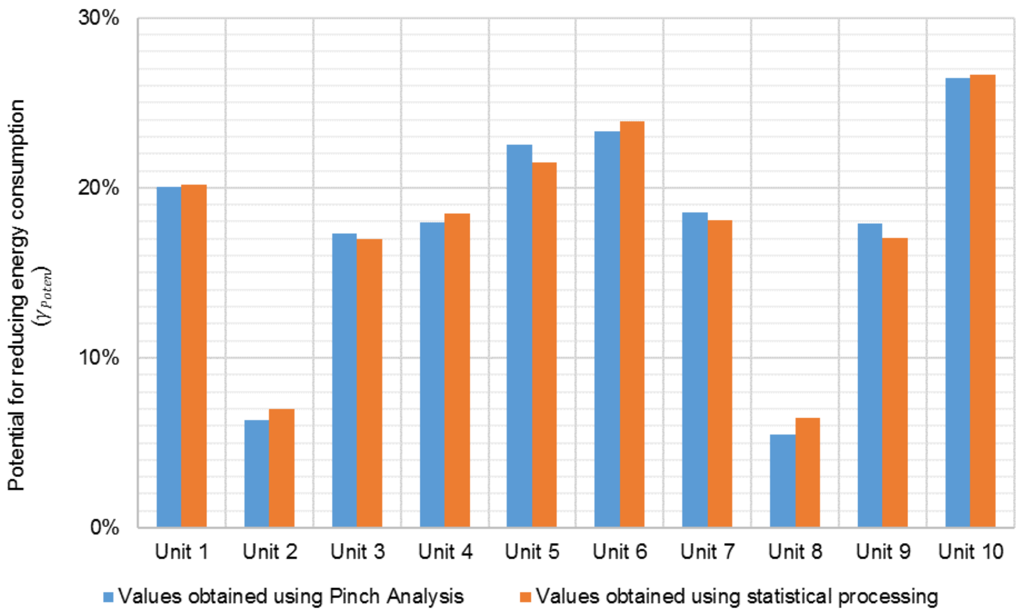

Figure 3: Potential for reducing energy consumption

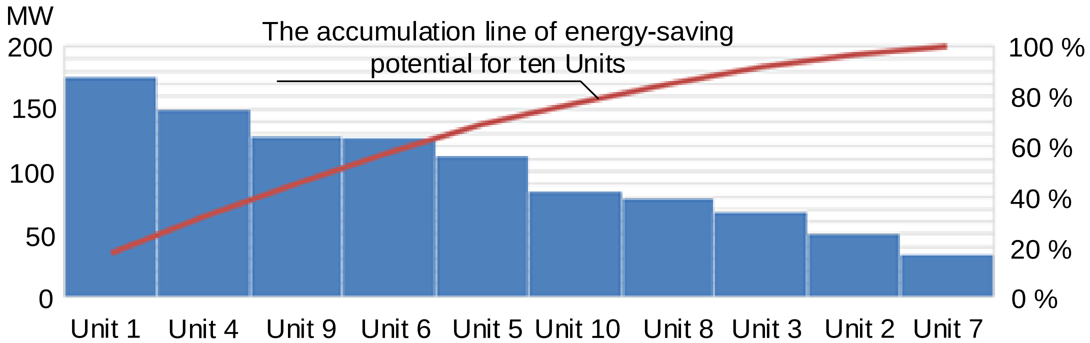

Figure 4: Gap of energy efficiency for heat transfer systems

The estimation of the economic efficiency of the investment project was made according to international practice by two indicators - net present value of discounted cash flows (NPV) and internal rate of return (IRR). Conservative economic assumptions were used in the calculation:

- The implementation period is 2 years after the commencement of work.
- To achieve the targets, the possibility of using existing equipment is not taken into account.

When carrying out an energy audit and determining the actual possibility of the use of the existing equipment, an economic index can be improved.

The results of calculating the economic efficiency of projects to achieve energy consumption targets are presented in Figure 5.

The analysis of the data from Figure 4 and Figure 5 shows that the profitability of projects for reducing energy consumption does not always coincide with the energy potential for reducing energy consumption. This is due to the different cost of equipment and energy in different regions and different companies. Therefore, only the economic evaluation of the project gives a realistic idea of the feasibility of reducing the energy consumption gap.

The dependencies presented in Figures 4 and 5 can be calculated for other types of energy, for example, for electric energy. Further development of the methodology is to improve the way to determine capital costs when achieving energy consumption targets.

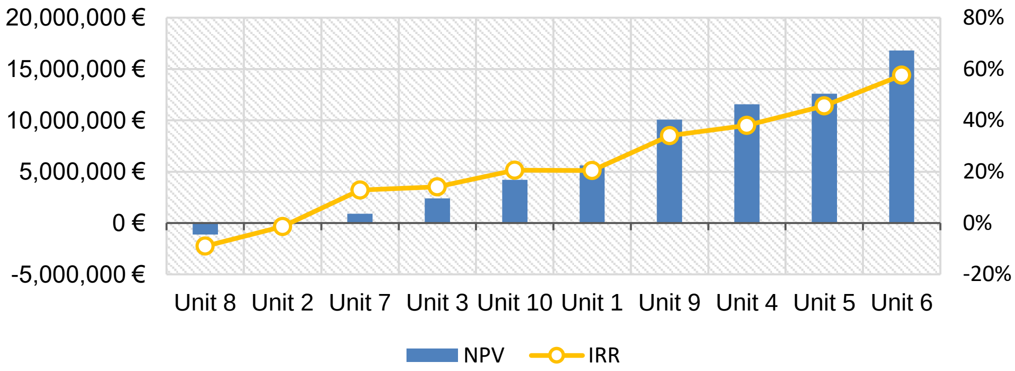

Figure 5: The economic efficiency of projects

4. Conclusions

The Benchmarking methodology of enterprises (Anselm) is proposed, which permits to define a roadmap for achieving energy consumption targets. The energy efficiency index (Anselm) for ten primary petroleum refining process is calculated. It is shown that specific consumption cannot be a determining criterion in the assessment of energy efficiency. An approach is proposed in which it is justified that only an economic evaluation of the proposed solutions to reduce gaps shows the most profitable way to increase the energy efficiency of enterprises.

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