OXERGY ANALYSIS OF THE INSTALLATION OF PRIMARY OIL REFINING

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Abstract: *The questions of thermodynamic exergy analysis of complex chemical and technological systems based on the study of the conversion of exergy in technological apparatuses and installations for the rational use of exergy circulating in the CTS are set forth . A functional approach to the selection of environmental parameters has been substantiated , which allows, indirectly, in the absence of data on the exact chemical composition of the process stream, to reliably determine the second component of exergy. An exergy analysis of the existing ELOU-AVT unit at an existing oil refinery was carried out with an increase in its productivity providing the necessary degree of oil heating.*

Keywords: *chemical-technological systems, exergy analysis, energy-technological processes, processes of primary oil refining. industrial thermodynamics.*

Introduction

The modern development of chemical and petrochemical technology is characterized by an increase in unit capacities and an increase in the efficiency of existing facilities. This is due to qualitatively new structural solutions related to the organization of interaction and processing of energy flows between individual subsystems of industrial production and the need to maximize the use of energy from technological flows within production. Chemical-technological processes of industrial production are in direct connection with energy flows, forming a single whole - a chemical-technological system or an energy-technological installation which is aimed at solving two problems: the production of finished products of the required quality and the reproduction of energy needed to conduct the process. From these tasks, the problem of the maximum use of the energy of technological flows within the system [1] follows.

The most rational way to effectively combine energy and material transformations is to find the optimal structure for the interaction of individual nodes of energy technology production. Structural optimization allows, through the introduction of additional technological connections, to maximize the use of the internal energy resources of the system, thereby increasing its economic efficiency.

A distinctive feature of energy technology industries is the variety of sources and potentials of generated energy. In this regard, it becomes necessary to use for analysis and synthesis of the optimal organization of energy technological processes the method of exergy analysis, which allows to correctly assess the quality and optimal distribution of available energy resources [2].

The statement of the problem of the analysis of the installation of primary oil refining and its solution. In this work, we consider a method for synthesizing the optimal structure of an energy-technology installation based on the use of structural-parametric optimization methods. The solution to the problem is based on the method of analyzing the efficiency of energy technological processes using the principle of thermodynamic analysis [1], which, unlike the existing ones, can be used for all classes of existing energy - technological processes, including primary oil refining processes. The technique of exergy analysis of energy-technological processes is based on the processing of exergy in technological devices. This approach allows you to objectively assess the possibilities of using the energy circulating inside the chemical-technological system [2].

Analysis of the installation of primary oil refining. Assessment of the thermodynamic efficiency of primary oil refining processes (ELOU-AT, ELOU-AVT) is based on a study of the effectiveness of each individual unit.

When assessing the thermodynamic efficiency of processes and heat transfer without taking into account heat loss to the environment and not taking into account the hydraulic resistance of the heat exchanger (which is valid due to the constant pressure in the heat exchanger equipment for oil refineries), the heat transfer process efficiency coefficients are determined as follows.

$$\eta_W = \frac{T_r(T_x - T_o)}{T_x(T_r - T_o)}, \quad (1)$$

$$\eta_W = Q_T T_o \frac{(T_r - T_x)/(T_r T_x)}{E_{вх}}, \quad (2)$$

where Q_T is the amount of useful heat transferred; Tx (Tr) - average thermodynamic temperature of a cold (hot) stream.

When assessing the effectiveness of the rectification process, it is advisable to consider separately the processes of mass transfer and thermal processes: the actual rectification, reflux, heating of the circulating stream in the furnace. The useful effect of the distillation proper for simple distillation columns can be found as the difference between the exergies of the products and the feed input stream.

$$N = E_P + E_W - E_f \quad (3)$$

Internal losses, that is, losses from irreversibility, for the mass transfer apparatus are associated with the adiabatic process in it. Internal losses are determined from the exergy balance of the distillation column.

$$\Pi = E_{w1} + E_{r1} + E_f - E_P - E_w - E_{r2} - E_{w2}. \quad (4)$$

External losses for the mass transfer apparatus will consist of the exergy of the steam and circulating streams r2 and w2 leaving it, resulting in the loss of exergy, minus the exergy of the stream r1, which returns to the column as reflux. External losses also include losses through the walls of the column, since they are small or can be neglected.

The spent exergy for rectification is exergy communicated to the circulating stream in the furnace, fed into the cube of the column, i.e. E_ (ex.) = E_w1. Hence, the coefficients of intensity and exergetic losses are:

$$\eta_W = \frac{E_P + E_W - E_f}{E_{w1}}, \quad (5)$$

$$\eta_W = \frac{E_{w1} - (E_P + E_W - E_f)}{E_{w1} + E_{r1} + E_f}. \quad (6)$$

In refineries, heating furnaces are used to heat the feed streams.

The costs in the process are equal to the exergy of fuel E_t and the exergy of enriched air E_b, necessary for complete combustion of the fuel. The intensity function is determined by the sum of the exergy of the flows exiting the furnace minus the sum of the exergy of the flows entering the furnace:

$$N = E_{c_2} + E_{c_4} + E_{\Pi_2} - E_{c_1} - E_{c_3} - E_{\Pi_1} \quad (7)$$

The intensity factor for the process of heating oil petroleum products in the furnace will look like:

$$\eta_W = \frac{E_{c2} + E_{c4} + E_{\Pi 2} - E_{c1} - E_{c3} - E_{\Pi 1}}{E_т + E_b} \quad (8)$$

The process of heating streams in furnaces is accompanied by both internal and external losses. Internal losses, that is, losses from the irreversibility of the process, are associated with two phenomena: irreversible combustion of fuel and irreversible heat transfer. They can be estimated from the exergy balance of the furnace

$$\Pi^1 = E_т + E_b + E_{c2} + E_{c3} + E_{п1} - E_{c2} - E_{c4} - E_{п2} - E_{g2} \quad (9)$$

External exergetic losses are determined by the exergy of flue gases E_ (dg)

The exergy loss coefficient is estimated by the equation:

$$\eta_п = \frac{E_т + E_b - (E_{c2} + E_{п2} + E_{c4} - E_{c1} - E_{c3} - E_{п1}}{E_т + E_b + E_{c1} + E_{c3} + E_{п1}} \quad (10)$$

Based on the exergetic analysis methodology under consideration, an exergy balance was calculated and the effectiveness of the existing ELOU-AVT-6 unit was calculated to identify reserves for increasing production efficiency and determining the optimal level of productivity. The calculation results are presented in tables I, 2.

It should be noted that, as shown by the calculation results (Table 2), the second component of exergy makes a significant contribution, and for the light fraction, since it is necessary to bring less energy to it than to heavy fraction, the first component rises. It follows that the light fractions have greater specific working capacity. This indicates the need to take into account the second component of exergy [5].

Table 1

Heat exchangers		Distillation the columns			Tube furnaces		
		К - I	К-2, К-6 К-7, К-9	К-8	П-1	П-2	П-3
η_N η_n	0,536-0,882 0,02 - 0,46	0,09 I 0,425	0, I63 0,380	0,I28 0,667	0, I68 0,723	0, I65 0,736	0, I6I 0,758

Furnaces with recovery boilers: η_N = 0, I70, η_n= 0,604.

The coefficient of thermodynamic efficiency of the system η_c= 0,069.

K as seen from the table, exergy efficiency analyzed.

Table 2

Process flow	E_I, $kcal / kg$	E_2, $kcal / kg$	E, $kcal / kg$
Raw oil	0,077	60, 27	60,347
Couple fr. НК-180 из К- I	90,74	108,12	198,86
Topped oil from К- I	46,02	45,62	91,64
Couple fr . 85-180 из К-2	86,43	101,06	187,49
fr . 180-220 из К-6	11,37	80,77	92,14
fr . 220-280 из К-7	21,28	61,88	83,16
fr 280-350 из К-9	40,13	42,52	82,65
Fuel oil К-2	67,33	29,67	97,00
Stable gasoline from К-8	20,49	87,10	107,59

Devices have rather high values, since exergy estimates for chemical and energy-technological processes are characterized by small values. Only tube furnaces have large exergy loss ratios. This is due to the process of irreversible combustion of fuel and the irreversibility of heat transfer during heat transfer by the feed stream through the walls of the coils. As an additional analysis showed, the use of the heat of the exhaust flue gases for heating the waste heat boilers does not significantly increase the intensity coefficient. The coefficient of exergy losses is reduced by 15-20%

Analysis of heat transfer processes showed that they have the highest intensity coefficients and the lowest exergy loss coefficients. At the same time, heat exchangers in which heat transfer occurs at a high temperature level have higher efficiency indicators. As can be seen from the results, heat exchangers operate with different thermodynamic efficiency, which is explained by the irrational organization of the heat exchange system. Thus, an exergy analysis of the heat exchange system revealed the possibility of increasing its efficiency by changing the structural organization of flows.

A comparative evaluation of the efficiency of distillation colonies shows that the K-2 complex column with side stripping - sections K-6, K-7, K-9 is most efficient. This is explained by the non-adiabaticity of the separation process in a complex column due to heat removal by the 1st and 2nd circulation irrigation. The intensity coefficient of the K-8 gasoline stabilization column is quite high due to the fact that the lighter fractions taken from this column have a higher specific exergy. At the same time, stabilization columns have large exergy losses, which is explained by a large reflux ratio.

When analyzing the possibilities of increasing the plant productivity, we proceeded from the invariance of the fractional composition of the selected products, which allows us to analyze the operation of the columns with an increase in the load, regardless of the heat exchange system, and then organizing the thermal subsystem accordingly, to achieve the required thermodynamic operating modes.

In the mathematical description of the rectification processes of oil and oil products, a technique was used that is currently used both in the calculation of existing production facilities and in design calculations. The calculation procedure is based on a sectional representation of the rectification process with the determination of the effective temperature in each section, which characterizes the distribution of fractions between the upper and lower products based on absorption and stripping factors.

In order to verify the adequacy of the adopted mathematical model of the rectification process and correctly set the free information variables of the systems of equations of material and energy balances, an industrial experiment was carried out, which consisted in determining the flow rates of products, pressure in the columns, temperature on the upper plates of the columns. An analysis was also made of the composition of the separation products in the columns.

In fig. I presents the results of the analysis of the columns when the load changes. It can be seen from the graphs that, when the load changes, the column intensity factors remain approximately constant up to a capacity of 8 (million tons) ⁄ year, after which they decrease. At the same time, the exergy loss coefficients are reduced. This is because the costs and benefits increase approximately proportionally, while the input exergy grows faster than the absolute magnitude of the exergy losses due to both exergy and phlegm exergy. With an increase in the load of more than 8 (million tons) ⁄ year, the beneficial effect decreases, since with an increase in the reflux ratio the amount of the upper product with the highest specific exergy decreases, which leads to an increase in the exergy coefficient of distillation columns [6].

A decrease in the exergy loss coefficients indicates an increase in the load, but since a decrease in the loss coefficient reduces the unit cost of fuel. On the graph, the area of plant productivity is highlighted that is most preferable from a thermodynamic point of view.

Exerget analysis of energy technological installations. The modern [2] development of chemical and petrochemical technology is characterized by an increase in unit capacities and an increase in the efficiency of existing facilities. This ILA qualitatively new structural solutions relating to the organization and interaction of the processing of energy flow between different subsystems of industrial production and the need to maximize the energy in the production process streams [1] . Chemical-technological processes of industrial production are in direct connection with energy flows, forming a single whole - a chemical-technological system or an energy-technological installation that is aimed at solving two problems: the production of finished products of the required quality and the reproduction of energy necessary for the process. From these tasks arises the problem of maximizing the use of the energy flow of technological flows within the system.

The most rational way to effectively combine energy and material transformations is to find the optimal structure for the interaction of individual nodes of energy technology production. Structural optimization allows, through the introduction of additional technological connections, to maximize the use of the internal energy resources of the system, thereby increasing its economic efficiency.

A distinctive feature of the power technology of production is in the variety and sources of generated energy potentials. In this regard, it becomes necessary to use the method of exergy analysis for analysis and synthesis of the optimal organization of energy technological processes , which allows one to correctly assess the quality and optimally distribute the available energy resources [2].

Statement of the problem and the decision. In this work, we consider a method for synthesizing the optimal structure of an energy-technology installation based on the use of structural-parametric optimization methods. The solution is based on the method of analyzing the effectiveness technological processes using the principle of thermodynamic analysis [1], which is the first in contrast to susche stvuyuschih can be used for all classes of existing energy -technological processes, including primary refining processes. The technique of exergy analysis of energy-technological processes is based on the processing of exergy in technological devices. This approach allows you to objectively assess the possibilities of using the energy circulating inside the chemical-technological system [2].

Using the techniques of structural optimization pre dpolagaet knowledge of the value of exergy uu process streams characterizing its potential for use in ehnergotehnologicheskoj system.

Exergy spent on conducting the process is distributed on the beneficial effect (N), expressed in units of exergy , and exergotic losses (P).

$$E_{for\ m\ p} = N + P \qquad (11)$$

where $P = P^{I} + P^{II}$, P^{I} - internal exergy losses associated with the irreversibility of the processes occurring within the system; P^{II} - external exergetic losses associated with the conditions of interaction of the system with the environment.

A decrease in exergy losses for a given element does not mean an increase in its effectiveness, since a useful effect may be reduced. In accordance with this, to assess the effectiveness of individual processes, the following characteristics are used: intensity coefficient (η_N) and exergy loss coefficient (η_N):

$$\eta_N = \frac{N}{E_{замр}} = \frac{N}{N+П}\ , 0 \leq \eta_N \leq 1 \qquad (12)$$

$$\eta_П = \frac{П}{E_{вх}}, 0 \leq \eta_N \leq 1 \qquad (13)$$

Thermodynamic efficiency HTS may be evaluated using sivity thermodynamic efficiency , which is a function and its individual elements, and is defined as the ratio of the amount of exergy designated target products from the system to the exergy spent raw materials and energy. In other words,

$$\eta_c = \frac{E_{отв\ ц}}{E_{людь}} = f(\eta_N \eta_П), 0 \leq \eta_N \leq 1. \qquad (14)$$

When calculating exergy in energy-technological processes , two components of exergy are distinguished : (E_I), which is the result of a mismatch of the temperature and pressure of the substance in question with the temperature and pressure of the “ environment ” and exergy (E_2), which is associated with establishing the equality of chemical potentials between the corresponding components the flow in question and the " environment " since when analyzing chemical and petrochemical processes, these two components of exergy are most important .

To determine the exergy, it is necessary to set the parameters of the "environment". For the calculation of the first component exergy of the environment taken medium with P_0 = I e t and m, and T_0 = 273 K. In determining component exergy arising due to differences in the compositions accept an environmental ideal gas medium is hypothetical substance TO- fraction composition lacking molecular bonds.

The expression for determining a first component exergy records follows:

$$E_1 = \Delta_0 I - T_o \Delta_o S, \qquad (15)$$

wherein $\Delta_0 I,\ \ \Delta_o S$ – - entail and entropy , the state defined by the pressure P_{on} and the temperature T_{of} the environment, to the current state.

For processes elapsed levels at constant pressure (which is the case and a primary refining processes), i.e. are isobaric, to calculate the enthalpy and entropy, the following equations are used:

$$\Delta_0 I = \int_{T_o}^{T} C_p dT \qquad (16)$$

$$\Delta_o S = \int_{T_o}^{T} \frac{dQ}{T} = \int_{T_o}^{T} \frac{C_p dT}{T}, \qquad (17)$$

where C is the true mass heat capacity at constant pressure; T is the temperature of the process stream in K.

When evaluating the second component of exergy, an ideal gas is taken as the environment, i.e. Hypothetical Vefth of the composition of the fraction, devoid of molecular bonds. An ideal gas composition fractions eq with yorgia is determined, meets all three requirements exergetic analysis: has minimal or no thermodynamic potential, the potential is unchanged and depends only on the molar composition at P=Idem and T=Idem; It has minimal energy value compared with regarded Vai substance and does not interact with the analyzed system, since it is only abstraction.

Thus, the work of aligning the chemical potentials of the substance in question is measured by the sum of the energy necessary to carry out the reversible transfer of the substance into equilibrium with the environment, i.e. in perfect condition and exergy of the ideal substance [3].

This transfer can be carried out in the following steps. First: the transfer of a substance from a liquid state to a vapor state with unchanged parameters, then the transfer of fluid vapors to an ideal state, which corresponds to the removal of molecules by a sufficient pain distance in the process of vapor expansion, and the work of separation of an ideal substance.

The equation characterizing the energy of the substance under consideration at F $_{of}$ and T $_{of}$ the form:

$$E_2 = E_P^{ж} + E_p^{n} + E_N, \tag{18}$$

where $E_P^{ж}$ is the energy of the transition from liquid to vapor with a constant composition and parameters

((P=Idem, T= Idem, $\sum_1^0 n_i = idem$);

$E_p^{П}$ – - the energy of the transition of the fluid vapor to an ideal state with a constant composition and parameters (P = I dem , T=I dem ,); - exergy of an ideal gas of vapor composition of a liquid

The value is calculated empirically with the only difference being that the process of transition from a liquid state to steam occurs at a boiling temperature T $_{bales}$, and then the energy expended on evaporation is brought to the level of the standard state of the substance T $_{about.}$

The value when considering the process of isothermal expansion is calculated as follows:

$$E_P^{n} = I_{вх} - I_{вых} + T_{o\Delta} S_{небр} \tag{19}$$

Loss from irreversibility for imperfect vapors in a real isothermal process is defined as.

$$T_{o\Delta} S_{необр} = T_{oln} \, {}^{P_o}\!/_{p_{nd}} \left(1 - {}^{\eta_{из}}\!/_{\eta_{из}}\right), \tag{20}$$

where P $_o$ = 760 mm Hg , P $_{id}$ = 0 mm Hg , is the isothermal efficiency

To determine the enthalpy difference at the input and output (I $_{Rin}$ - I $_O$) empirical relationships.

The value is the minimum work that needs to be spent on reversibly separating the ideal vapor mixture:

$$E_N = -RT_o \sum_i x_i ln x_i \tag{21}$$

Thus, exergin, arising due to the difference in the compositions of the substance in question and the environment, during the separation process will be determined by the equation:

$$E_N = K\frac{T_o}{M} + I_{вх} - I_{вых} + T_{o\Delta} S_{необр} + (-RT_o \sum_i x_i ln x_i) \tag{22}$$

A distinctive feature of the conclusion that the methods for calculating the second component of exergy are considered is that it can be successfully used with the unknown exact chemical composition of the process stream based only on its physicochemical properties.

This circumstance is especially important in the analysis of oil refining processes, since it is not possible to establish the exact composition of oil and oil products. The technique allows the analysis refining product operate fractional composition of process streams.

Thus, the energy analysis of complex chemical-technological systems makes it possible to evaluate the effectiveness of both individual technological processes and the technological installation as a whole. When calculating the exergy of oil and oil products, it is advisable to calculate the second component of exergy based on the choice of an ideal gas as the environment. This approach allows you to indirectly carry out its calculations without having the exact composition of the analyzed technological parameter.

Conclusion

As follows from the results of the exergy analysis, there is the possibility of increasing the efficiency of the heat exchange system due to the rational organization of its structure, which will reduce fuel costs for heating oil or increase plant productivity. Based on the methodology of structural optimization of thermal subsystems, a search was made for the optimal structure of a heat exchange system that provides a given temperature of oil at the entrance to the topping column at a capacity of 8 (million tons) ⁄ year.

The task of finding the optimal heat transfer system was solved for a given total heat transfer surface, taking into account the reserve production capacities.

The optimal structure of the thermal subsystem is shown in Fig. 2 and can be selected as a heat exchange system for ELOU-AVT-6.

In contrast to the initial scheme of the thermal subsystem, the calculated optimal scheme has a three-stream structure for crude oil, which is associated with an increase in productivity. However, even greater crushing of the oil flow is obviously impractical, since this leads to a decrease in the linear velocity of the process flows and, as a consequence, to a deterioration in the heat transfer process.

An exergy analysis of the reconstructed unit for primary oil refining showed that the efficiency of both individual units and units, and the entire unit as a whole, increased. Thermodynamic efficiency The perfection of the reconstructed installation is 0.072. Increasing the thermodynamic efficiency of the installation by reducing exergy losses brings to a decrease in specific fuel consumption by 5.5%.

Thus, the structural optimization of energy-technological processes using the method of resolving terms of linear programming makes it possible to determine the structures of heat exchange systems that are optimal from the thermodynamic point of view.

An exergy analysis of energy-technological processes allows us to evaluate the effectiveness of individual processes, and allows us to evaluate the effectiveness of both individual processes and the entire installation. The calculation of the second component of exergy is based on the choice of the ideal gas model as the environment, which allows indirect calculation of it, without having the exact composition of the process stream.

Assessment of the thermodynamic efficiency of typical processes of oil refineries based on the use of intensity factors and exergy losses.

In order to identify production reserves and adjust mathematical models, an industrial balance experiment was conducted on the existing ELOU-AVT-6 installation. Exergy analysis of the current installation ELOU-AVT-6 indicates the possibility of increasing its productivity. An optimal version of the heat exchange system for the installation is proposed with an increase in its productivity, which provides the necessary degree of oil heating.

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