EXAMPLES OF IMPLEMENTATION OF ENERGY-CONSERVATION APPROACHES IN OIL AND GAS PROCESSING

Lyubov Taranova[1], Andrey Mozyrev[1], Evgeny Zemlyansky[1],
Mikhail Zhdanovich[1], Andrei Kasperovich[2]

*[1]Industrial University of Tyumen, 38 Volodarsky St.
Tyumen, Russia, taranovalv@tyuiu.ru (L.T.);
mozyrevag@tyuiu.ru (A.M.); zemljanskijeo@tyuiu.ru (E.Z.);
zhdanovichmf@tyuiu.ru(M.Z.)*
*[2]Belarusian State Technological University, 13a Sverdlova St.
Minsk, Belarus, andkasp@mail.ru (A.K.)*

Received 05 March 2026
Accepted 25 April 2026 *DOI: 10.59957/jctm.v61.i5.2026.13*

ABSTRACT

The work is devoted to solving topical issues of energy and resource conservation (ERC) and increasing energy efficiency for hydrocarbon processing enterprises, considering the high energy intensity of industry process facilities, which is due to both objective reasons and irrational use of fuel and energy resources and direct heat losses. The goals and objectives of this work are to generalize and classify ERC approaches, proposals, methodologies and methods as applied to the hydrocarbon processing industry with an analysis of cases of their implementation, considering the "bottlenecks" of typical process facilities in the industry. The paper analyses the proposed areas and approaches to solving ERC problems in oil and gas processing, in particular, the implementation of a systemic approach, decomposition principles, thermal integration methods, including between different-level objects, the use of pinch analysis to assess the potential for heat recovery and optimize heat exchange systems, the use of digitalization methods and computer modeling technologies, etc. As an example of energy and resource conservation, a rectification unit of a gas fractionation unit with a heat pump in its composition instead of the traditional approach to creating a temperature regime in the column is considered. It has been shown that this will reduce energy costs due to heat loss to the atmosphere, the use of its own flow as a coolant with savings in water vapor resources and the cost of cooling the product in air coolers. Together, this will lead to a more rational use of the process facility's own resources.
Keywords: energy and resource conservation, oil and gas processing, systemic approach, pinch analysis, heat pump.

INTRODUCTION

Recently, much attention has been paid to issues of rational use of energy resources in all areas of human activity, especially in energy-intensive industries of extraction and processing of natural resources.

At the same time, the demand for energy resources and the extraction of fuel and energy resources (FER) continue to grow. Thus, the projected increase in energy demand in the world may be about 30 % by 2040, and in the industrial sector, the growth of energy consumption may be at the level of 11 % over 25 years with a growth rate of 0.4 % year^{-1} [1, 2]. Given the trends towards a constantly increasing demand for energy, these issues will obviously remain among the priorities for quite a long time. At the same time, not only the problems of optimizing energy consumption for production needs are being addressed, but also the currently very relevant environmental aspects, considering the priority "green" agenda.

The issues of energy and resource conservation are especially relevant in the hydrocarbon processing industries - oil and gas processing and petrochemical industry, which are characterized by high total and specific energy costs. This is primarily due to several objective reasons:

- large production capacities of enterprises for the preparation and processing of hydrocarbon (HC) raw materials and, accordingly, high energy costs;

- continuous production, which determines the presence of many complexly interconnected units of technological equipment intended for the implementation of target or auxiliary processes, as well as high energy costs for the movement of raw materials, products, semi-finished and auxiliary flows within processing facilities;

- a very wide range of changes in key parameters for conducting technological processes: variation of temperature parameters - from low negative (about minus 100°C and below) to high positive (up to 1000°C and above), and a very wide range of pressure changes - from vacuum to values of hundreds of MPa, which requires corresponding costs for their creation and maintenance of equipment operating modes;

- growing demands for deepening the processing of petroleum with the implementation of secondary catalytic processes and the involvement of various oil residues in the processing; for improving the quality of petroleum products with the satisfaction of not only operational characteristics, but also environmental requirements.

Considering the long service life of domestic industry plants for processing hydrocarbon raw materials, the reasons for increased energy consumption include the obsolescence of equipment and its high degree of wear, which dictates the need for technical re-equipment and modernization [3].

As a result, the share of energy costs in the processing of hydrocarbons is quite significant and for highly energy-intensive oil refineries (OR) it can reach up to half of all operating costs, with up to a third of the costs directly attributable to the distillation of oil, and when implementing catalytic processes for deep processing - more than half of the energy consumption [4].

At the same time, despite the objective factors of high energy consumption, researchers of the problem note the irrational use of energy resources and high heat losses during oil and gas refining, and the presence of significant reserves of energy and resource conservation (ERC) in the industry. According to the known data, the potential for increasing energy efficiency (EE) in relation to oil refining can be estimated at 40 % [5 - 7].

The theoretical potential savings in thermal energy for oil refineries based on calculations can vary in the range of 48 - 73 % depending on the adopted temperature difference between the streams, and for optimal values of the driving force (DF), the actual savings are predicted to be around 35 % [8].

It is noted that the main reserves - up to 90 % - are directly related to technological processes (with their optimization), primarily with recuperative heat exchange systems, which will reduce energy consumption by at least 10 - 20 % with potential for values in the range of 40 - 50 % [1].

Researchers of the problem also note the rather low level of efficiently used heat in domestic practice, which in relation to oil refineries is within 23 - 26 %, and the rest is accounted for by irrationally used resources and heat losses. Losses are usually associated with heat dissipation into the environment from hot surfaces of equipment and pipelines, with flue gases from furnaces and other equipment with open flame, with the most common coolants - water and air - at the level of 8 - 12 %, 14 - 16 %, 48 - 52 % respectively [9 - 12].

Thus, it should be noted that it is important to address the ERC issues for hydrocarbon processing enterprises and improve their energy efficiency, which determined the goals and objectives of this work - generalization and classification of ERC approaches, proposals, methodologies and methods applicable to the hydrocarbon processing industry with an analysis of examples of their implementation, taking into account the “bottlenecks” of typical technological facilities in the industry.

EXPERIMENTAL

For the practical implementation of the tasks of energy and resource conservation and energy efficiency improvement (ERC and EE) of oil and gas processing facilities and the evaluation of the results, various methods and methodological approaches have been proposed:

- methods of mathematical modelling, including economic-mathematical, mathematical programming, regression analysis [13 - 15];

- pinch analysis, as well as variations of the method - construction and analysis of STEP diagrams, which have advantages over the analysis of composite curves with the ability to customize modernization options and assess the ERC potential; THE BASYC SELOOP© method, which is a development of pinch analysis, diagnostics and design methods, as well as the construction and analysis of grid (mesh) diagrams with the display of new heat exchange systems; also thermo-economic analysis, combining thermodynamic principles and data on production costs for their minimization [16];

- methods of digitalization, artificial intelligence and data management (Data mining), computer modelling; digital resource conservation considering the costs of digitalization for an oil refining enterprise can provide a reduction in energy intensity by 3.6 % [17, 18].

The tools for solving ERC problems in the conditions of their complexity and multidimensionality in the industry are the use of software packages - traditionally Aspen HYSYS, as well as more narrowly specialized ones, in particular - Pinch-2.02; Anselm DR software for collecting and processing a large array of initial data for conducting pinch analysis; Aspen One ® V9.0.

RESULTS AND DISCUSSION

Since the emergence of areas related to solving the problem of increasing the energy efficiency of industrial facilities, a large amount of experience has been accumulated in implementing proposals for energy efficiency and increasing EE, as well as theoretical justification for approaches to their implementation.

In the theory and practice of solving problems of rationalization of energy resources use, various approaches, methods, ways, directions of ERC are proposed. Traditionally several common approaches are noted, summarizing and generalizing which, the following points can be highlighted:

- optimization of the parameters and operating modes of technological equipment of production facilities from the standpoint of minimizing energy costs for the process; first, this applies to the organization of heat and mass transfer processes, as key ones in the processing of hydrocarbons and chemical processes - in the deep conversion of hydrocarbons [19];

- replacement of process equipment with more efficient types and varieties; constructive modernization of the equipment and internal elements used; use of a method of combining process operations based on various types of chemical engineering processes in one unit of process equipment;

- involvement in recovery of the maximum possible number of flows of technological objects; wider use of secondary energy resources (SER) and low-potential heat (LPH) with minimization of the use of third-party flows;

- development (synthesis) of optimal, flexible, cost-effective heat exchange systems with wider use of the principles of integration of heat flows of multi-level technological objects; at the same time, the principle of heat integration at the inter-plant level itself can provide an additional reduction in energy consumption of up to 20 - 25 %.

Much attention is paid to the issues of organizing thermal integration within a technological facility and between them, considering the energy saving reserves hidden in this with the possibility of using the underutilized potential of some facilities on others. The inter-process (IP) heat exchange capabilities and the comparison of direct integration within the plant with recovery between adjacent units showed a heat saving potential of 27 - 42 % when combining IP integration with indirect recovery within the facility through its steam system.

The literature also considers the issues of using thermal potential (including LPH as applied to refineries) for generating electric power using engines with an organic Rankine cycle (ORC), as well as the possibility of producing steam in heat pumps (MVC) with an assessment of the conditions of their applicability in different countries, or the use of a waste heat steam generator [20, 21]. An example of an integrated system for generating electric power - the integration of a turboexpander into the reboiler system of rectification columns during oil distillation with the additional possibility of generating electric power at a predictably high exergy efficiency is also described [8].

Alternative approaches to solving the ERC problem are also proposed preheating of oil before distillation using solar energy with the possibility of providing about 10 % of the required preheating [22]. When analysing the objective reasons for high energy costs discussed above, it is rational to highlight two key points in the structure of energy costs:

- costs of maintaining temperature conditions for conducting processes, which is most often achieved through heat exchange systems, including heat exchange devices and tubular furnaces and the use of appropriate heat carriers/coolants;

- costs for moving flows within facilities and creating the pressures required to implement the process; this is achieved primarily through pump and compressor equipment (PCE).

Taking this into account, approaches to the ERC will be determined. In particular, to reduce the first group of costs using more efficient varieties, it is possible to propose measures to improve operating modes, heat exchange systems, to increase the efficiency of using the heat and energy potential of installation flows, heat recovery, reduce its irrational losses, etc., as well as technical aspects of the ERC associated with the improvement of devices and their design features in order to increase the efficiency of transfer and use of energy potential. For the second group of energy costs, as ERC measures, it is possible to implement, first of all, all possible approaches to reduce hydraulic resistance when moving flows along the system of process pipelines and through devices - with a decrease in the resistance of their internal elements; the second large area here concerns the use of more energy-efficient units of PCE with the implementation of measures to reduce their energy consumption.

When considering the technical aspects of ERC measures, it is possible to note both the replacement of equipment or elements with more efficient ones, and the implementation of methods for increasing the efficiency of existing units. It is possible to propose replacing heat exchangers with more efficient plate ones, which can reduce energy consumption by 23 % or the use of devices with twisted tubes or expanded metal sheets. Among the possible modifications, it is also possible to note the application of ultra-thin graphene coatings, ultrasonic technology for protecting heat exchange surfaces from scale with an increase in energy saving indicators by 9.1 %, the use of a unit for cleaning finned tubes in ACU with an increase in EE indicators by 8.5 % [23, 24].

Considering the extreme diversity of approaches, techniques and specific proposals proposed by researchers in the field of electronic data collection, it is necessary to generalize and classify them, which will ensure a scientifically based approach when developing modernization proposals for specific objects of study.

We note the classification approaches aimed at optimizing chemical-technological systems (CHTS), which include all complex production facilities of the industry and the intensification of chemical-technological processes (CTP) occurring in them, considered at various hierarchical levels.

The main ERC method applied to the CTS is the method of best use of the driving force (DF) of processes - as a fundamental principle for ERC approaches; as well as other methods aimed at ensuring it (in particular, the most complete processing of raw materials; optimization of modes, rational use of fuel and energy resources - FER, etc.). The applicability of the specified methods is ensured using various techniques grouped as follows: mode-parametric, technological, hardware-design and organizational-technical.

Considering the extreme complexity of technological enterprises for processing hydrocarbon raw materials, it is rational to consider them from the standpoint of a systemic approach as complex and large chemical-technological systems and considering the development of energy-resource-efficient (ERE) systems, to consider industry facilities as chemical-energy-technological systems (CHETS). This accordingly requires the use of methods of the theory of analysis, synthesis (in modern conditions - automated) and optimization of CHTS, as well as engineering theory, for their analysis, study, and development.

Of the known principles of automated design, when developing ERE systems, the following varieties of decomposition principles are used: integral-hypothetical, evolutionary. The widely used decomposition approach is well suited for developing ERE CHTS as applied to the industry, allowing to reduce the dimensionality of the tasks being solved, dividing them into subtasks. In this case, the solution to the general problem of optimizing heat exchange systems and minimizing the number of heat exchange devices is carried out using transport models of mixed integer programming or a model with intermediate points.

In addition to direct methods of assessing energy efficiency for industry enterprises, comparative assessment methods are also used, for example, the Solomon method, developed for oil refineries, used for domestic oil refineries. It is also possible to use industry benchmarking with the possibility of using the method within one company or industry. An energy efficiency index without considering heat losses, indicating the degree of perfection of the process, has also been proposed as an indicator for assessing EE.

When summarizing the literature data, it should be noted that there are a variety of approaches to solving the problems of increasing the efficiency of using energy potential at hydrocarbon processing facilities, and in order to select priority areas of ERC, first of all, it is necessary to analyse the process and equipment design of the facility under study in order to identify “bottlenecks” that require priority solutions.

To solve the problem under consideration, the authors analysed various objects of preparation and processing of hydrocarbon raw materials, in particular preparation and processing of hydrocarbon gases, deep processing of hydrocarbon raw materials, petrochemicals, concerning the optimization of their heat exchange systems [25, 26]. The following methods were chosen as research methods:

- a systemic approach and analysis of chemical and technical systems, taking into account the complexity of industry production facilities, which allows them to be structured and facilitate the tasks of ERC analysis;

- decomposition of the systems under study, which allows us to simplify the analysis of heat-technological schemes and material and energy flows of units, identify bottlenecks, energy saving reserves and search for ways of thermal integration;

- pinch analysis - as the most effective method for finding ways to save energy and optimize the use of its own energy potential within a technological facility and ways to modernize the heat exchange system.

This paper examines the potential for energy and resource conservation for the rectification unit of a gas fractionation unit (GFU) by using the heat pump principle. The gas fractionation unit (Fig. 1) is designed to separate the wide fraction of light hydrocarbons (WFLH) into individual alkanes by isolating and then separating narrow fractions.

The paper analyses the heat-engineering scheme of the unit with the identification of the areas of the ERC modernization for the unit. The initial analysis of the scheme showed that the unit is represented by six rectification units with simple columns for maintaining the temperature regime of which the traditional approach is used - maintaining the temperature of the top of the columns due to condensation and cooling of the distillate with the return of part of the flow as irrigation of the columns, and the formation of the temperature regime of the cube is ensured by installing a reboiler with heating

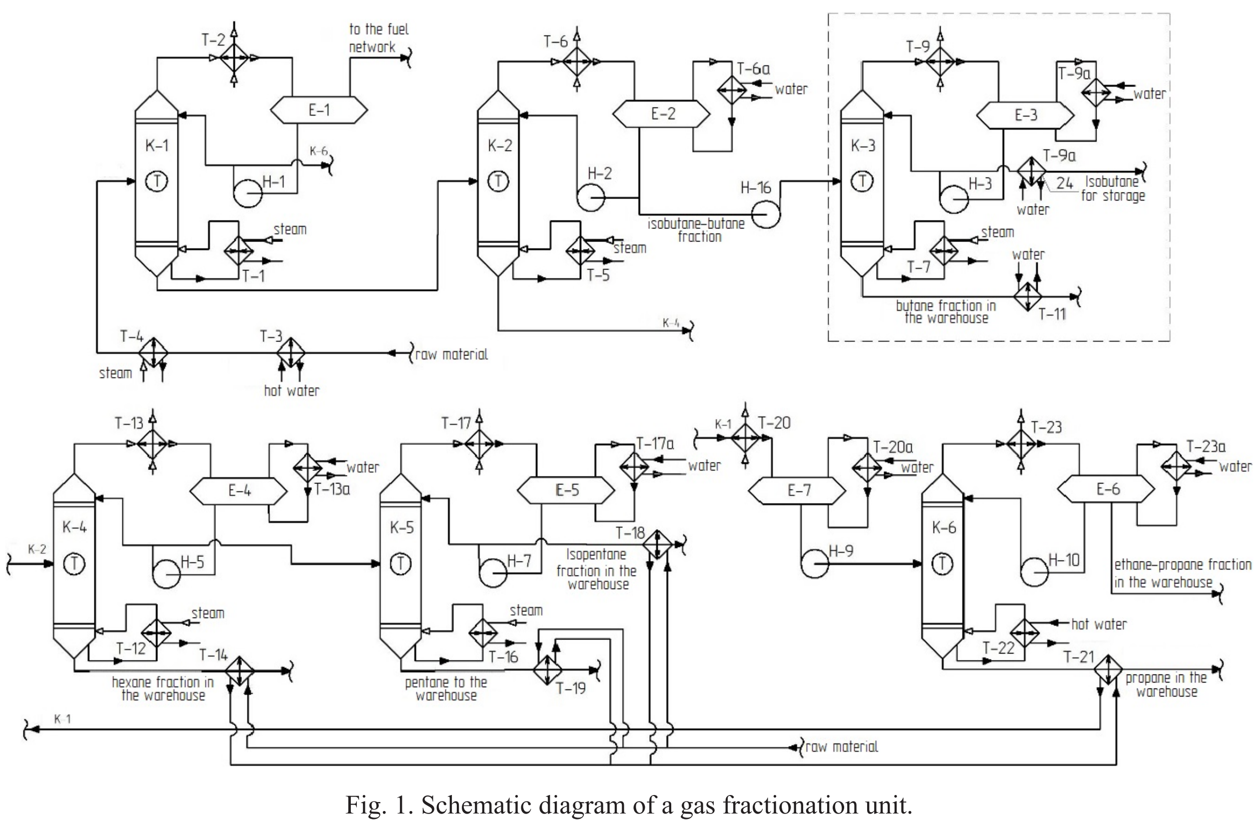

Fig. 1. Schematic diagram of a gas fractionation unit.

and evaporation of part of the bottom liquid. To ensure the operating modes, external heat carriers/coolants are involved - water vapor and air used in air coolers (ACU).

This is irrational from the standpoint of ERC approaches, since it requires energy expenditure for steam generation; for air injection into the ACU; in addition, direct heat losses of distillate flows occur in air coolers - its dispersion into the atmosphere. Analysis of the operating modes of the main apparatus of the installation - rectification columns showed a low energy potential of the unit's own flows, which does not allow for full heat recovery. In confirmation, we note the following temperature indicators:

- the temperature of the top of the columns varies within the range of 45 - 65°C;
- the cube temperature - within 60 - 128°C.

This allows only some higher temperature flows to be involved in the recuperative heat exchange.

In this case, in order to increase the degree of use of the own potential, it is rational to consider the principle of a heat pump, when it is possible to increase the flow potential due to the increase in pressure, which will naturally lead to an increase in the flow temperature with the possibility of using it as a heat carrier, which will eliminate the need to involve third-party heat carriers. The literature considers examples of using this approach for oil refining enterprises. In particular, the possibility of saving up to 11 - 12 MW of heat on hot and cold utilities during gas fractionation at oil refineries using heat pumps has been shown; in addition, the low-potential heat of distillate products can be used to heat auxiliary flows - industrial heat and friction water. The advantages of using heat pumps for rectification units over other methods with a reduction in total costs for the implementation of the process of up to 45 % have also been shown [27, 28].

To determine the possibility of using the heat pump principle, the operating parameters in the rectification units were analysed, taking into account the recommended limitations on the temperature difference of flows - no more than 30°C, and the pressures should be higher than atmospheric, but not high. Taking this into account, more suitable objects for the GFU are the columns for separating isobutane-butane (K-3) and isopentane-pentane (K-4) fractions, where the temperature difference along the column height is 21°C and 20°C, and the maximum pressure is 0.95 MPa and 0.22 MPa, respectively.

The K-3 column rectification unit was selected for consideration, implementing the process modelling with the traditional method of maintaining the column mode and using a heat pump in the Aspen HYSYS software package. The current version (Fig. 2) provides for cooling and condensation of the upper product flow in the ACU with additional cooling in a water cooler, and to maintain the temperature of the cube, part of the bottom liquid is heated with water vapor in a reboiler. The proposed version provides for the inclusion of a compressor KC-1 in the circuit on the distillate line K-3 with the provision of heating of the flow for the possibility

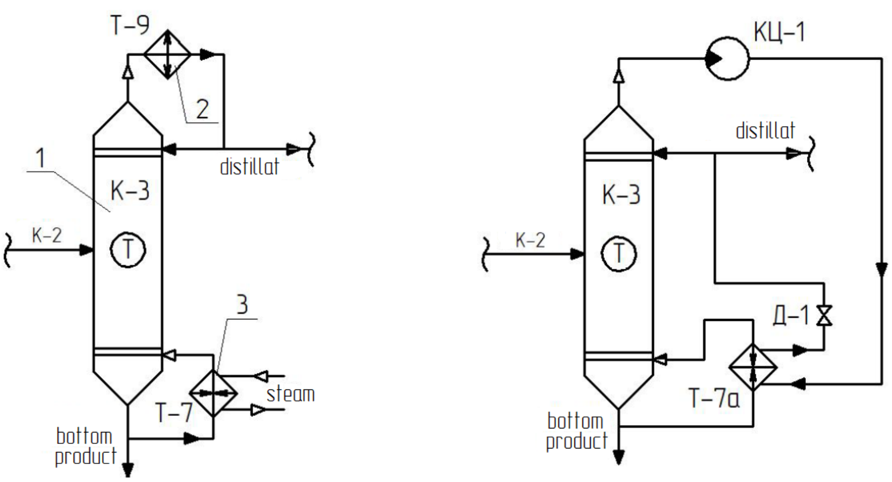

Fig. 2. Design options for the rectification unit in a traditional version and with the inclusion of a heat pump.

Table 1. Initial data for building the model.

Composition of raw materials, % wt.	Values	Operating parameters	Values
Propane	0.09	Top/feed/cube temperature, ºC	62/76/83
Isobutane	35.59	Top/Cube pressure, MPa	0.85/0.95
n-Butane	64.3	Phlegm ratio	10 - 13
Isopentane	0.02	Number of plates	119
		Mole fraction of i-butane in distillate / in bottoms product	0.99/0.01

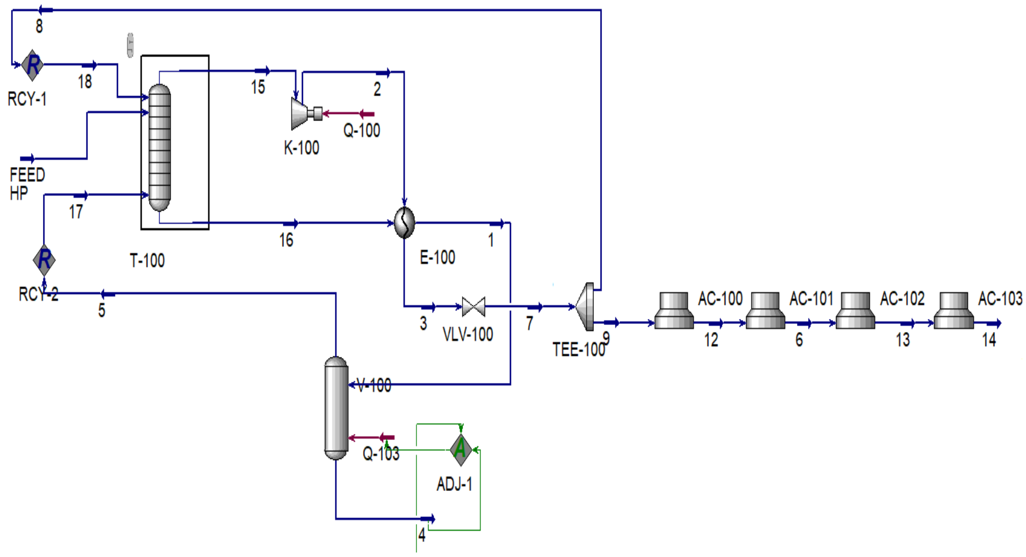

Fig. 3. Model of the rectification unit of the isobutane-butane fraction separation column with the inclusion of a heat pump.

of using it as a heat carrier instead of steam supplied to T-7. To create a K-3 reflux flow, a subsequent pressure release is provided when installing a throttle valve D-1 to obtain the temperatures necessary for the phlegm.

The modelling was based on the principles of constancy of the component composition of the raw material, product quality, and operating parameters in the corresponding parts of the column. The initial data for modelling are given in Table 1. The resulting model of the rectification unit with the inclusion of a compressor, recuperative heat exchanger, throttle, and separator in the system is shown in Fig. 3.

The process simulation demonstrates the possibility of implementing this approach and selecting a compressor, throttle and recuperative heat exchanger. Its use ensures:

- due to increased energy potential, low-potential flow of distillate product using it as a heat carrier in a reboiler instead of an external heat carrier - water vapor; with the elimination of energy costs for the generation of steam and its movement through pipelines and through the unit, as well as the elimination of steam as a material flow;

- elimination of direct heat losses during cooling of the upper product flow in air coolers; and, accordingly, energy costs for the operation of the ACU fan.

Additional costs when including a heat pump in the system include the costs of new equipment units, re-piping of the system, and electricity costs to operate the compressor. The approximate energy savings due to the elimination of the need for heat-transfer steam and savings in the costs of steam condensation in the ACU, according to the calculated data (according to the model), are estimated at 72 MW.

CONCLUSIONS

In the course of the work, an analysis of oil and gas processing problems was performed from the standpoint of high total and specific energy costs of the state with a generalization and classification of the ERC approaches, proposals, methodologies and methods applicable to the hydrocarbon processing industry, on the basis of which the need for a systemic approach to the study and analysis of complex industry objects was noted; their decomposition with an analysis of heat-technological schemes; identification of "bottlenecks"; determination of the heat recovery potential, including low-potential, with the definition of thermal integration options, including between process facilities of different levels.

Some examples of the implementation of ERC approaches at industry enterprises are considered, including technological and technical aspects of energy saving. An example of a possible modernization for a rectification unit using a heat pump instead of the heat exchangers traditionally used in units with the involvement of third-party heat carriers is considered. This approach will ensure the minimization of heat losses in air coolers and the costs of condensation and cooling, and will also eliminate the use of steam as a heat carrier when converting low-potential heat of a distillate product into a higher-potential one due to compression in a compressor.

Authors' contributions

L.T.: investigation, funding acquisition, project administration, writing - original draft; A.M.: conceptualization, methodology, investigation; E.Z.: writing - review & editing; M.Z.: validation, data curation, software; A.K.: visualization, resources, formal analysis.

REFERENCES

1. O.F. Glagoleva, V.M. Kapustin, Improving the efficiency of oil preparation and refining processes (review), Petrochemistry, 60, 6, 2020, 745-754, (in Russian).
2. N.I. Zakharov, I.V. Tupilko, Energy and resource saving during intensification of heat and mass transfer processes under conditions of degassing of liquid metal from nitrogen dissolved in it, Bulletin of Donetsk National University, Series G: Technical Sciences, 2, 2021, 94-99, (in Russian).
3. D.A. Lenkevich, F.R. Ismagilov, Status and directions of improving the energy efficiency of oil refineries, Oil refining and petrochemistry, Scientific and Technical Achievements and Best Practices, 11-12, 2022, 11-18, (in Russian).
4. A.S. Kozhun, D.R. Valitova, A.R. Khafizov, U.I. Safutdinova, Improving the energy efficiency of the primary oil refining unit, Bulletin of Perm National Research Polytechnic University. Chemical Technology and Biotechnology, 1, 2022, 64-76, (in Russian).
5. Y.Q. Lai, S.R. Wan Alwi, Z.A. Manan, Graphical customisation of process and utility changes for heat exchanger network retrofit using individual stream temperature versus enthalpy plot, Energy, 203, 2020, 117766.
6. S. Marton, E. Svensson, S. Harvey, Operability and Technical Implementation Issues Related to Heat Integration Measures - Interview Study at an Oil Refinery in Sweden, Energies, 13, 2020, 3478.
7. V. Seifert, J.A.M. da Silva, E. Torres, Residual steam recovery in oil refineries: technical and economic analyses, Energy Efficiency, 12, 2019, 2039-2053.
8. D.A. Sladkovskiy, D.Yu. Murzin, Integrated Power Systems for Oil Refinery and Petrochemical Processes, Energies, 15, 2022, 6418.
9. A.I. Shinkevich, Yu.Yu. Kostyukhin, D.Yu. Savon, A.E. Safronov, A.V. Aleksakhin, Optimization of energy-efficient functioning of the oil and gas sector of the economy through digitalization and resource conservation, International Journal of Energy Economics and Policy, 11, 5, 2021, 321-330.
10. E. Svensson, M. Morandin, S. Harvey, S. Papadokonstantakis, Studying the Role of System Aggregation in Energy Targeting: A Case Study of a Swedish Oil Refinery, Energies, 13, 2020, 958.
11. L.M. Ulyev, M.V. Kanischev, R.E. Chibisov, Determination of Energy Efficiency Features of Oil Refinery Units and Their Complexes, Chemical Engineering Transactions, 81, 2020, 283-288.
12. Y. Han, H. Wu, Z. Geng, Q. Zhu, X. Gu, B. Yu, Review: Energy efficiency evaluation of complex petrochemical industries, Energy, 203, 2020, 117893.

13. K. Yang, S. Liu, C. He, B. Zhang, Q. Chen, M. Pan, Improving energy saving of crude oil distillation units with optimal operations, Journal of Cleaner Production, 263, 2020, 121340.
14. A.A. Ryzhova, I.I. Emelianov, N.N. Ziyatdinov, R.V. Semin, Decomposition approach to the analysis and synthesis of the heat exchange system of the primary oil distillation unit, Mathematical Methods in Technology and Engineering, 4, 2021, 87-91, (in Russian).
15. V.I. Bobkov, V.A. Chibisov, M.V. Kanishchev, Features of process data analysis to improve the energy efficiency of the ELOU-AVT-3.5 unit, Modern Science-Intensive Technologies, 11, 2022, 14-18, (in Russian).
16. M.S. Svistun, L.M. Uliev, M.V. Kanishchev, Pinch analysis of a catalytic reforming unit with preliminary hydrotreating, Advances in Chemistry and Chemical Technology, 36, 2, 2022, 113-116, (in Russian).
17. V. Markov, A. Fedyukhin, I. Sultanguzin, B.G. Matisov, N.V. Nikitkov, V.V. Izrantsev, V.G. Knorring, G.A. Konrashkova, L.R. Mukhametova, Improvement of energy efficiency of motor fuel production at oil refinery, IOP Conference Series: Earth and Environmental Science, 337, 2019, 012080.
18. V.P. Meshalkin, Current theoretical and applied research on engineering of energy-saving highly reliable chemical-technological systems, Theoretical Foundations of Chemical Technology, 55, 4, 2021, 399-427, (in Russian).
19. A.A. Ryzhova, Optimal thermal integration of oil refinery units, Bulletin of the Technological University, 25, 3, 2022, 67-71, (in Russian).
20. N. Gangar, S. Macchietto, N. Markides Recovery and Utilization of Low-Grade Waste Heat in the Oil-Refining Industry Using Heat Engines and Heat Pumps: An International Technoeconomic Comparison, Energies, 13, 2020, 2560.
21. M. Karimi, A. Kargari, S.A. Behbahani-nia, H. Sanaeepur, Heat recovery and optimizing design of furnaces in the gasoline-kerosene units of Tabriz Oil Refining Company, Applied Thermal Engineering, 161, 2019, 114136.
22. K. Altayib, I. Dincer, Analysis and assessment of using an integrated solar energy based system in crude oil refinery, Applied Thermal Engineering, 159, 2019, 113799.
23. F.-R. Jia, W.-T. Jing, G.-X. Liu, Q. Yue, H.-M. Wang, L. Shi, Paraffin-based crude oil refining process unit-level energy consumption and CO2 emissions in China, Journal of Cleaner Production, 255, 2020, 120347.
24. T.S. Silkina, N.F. Lyamina, Improving the energy efficiency of an air cooling device for the utilization of associated petroleum gas at oil fields, Oil and Gas Technologies and Environmental Safety, 1, 2023, 51-58, (in Russian).
25. L.V. Taranova, G.P. Klevtsov, A.G. Mozyrev, Optimization of the heat exchange system of the gasoline fraction hydrotreating unit, News of higher educational institutions. Oil and Gas, 1, 2022, 81-95, (in Russian).
26. A.L. Shurayts, D.A. Korobchenko, A.P. Usachev, A.V. Rulev, Development and calculation of energy efficiency of heat pumps operating on zeotropic hydrocarbon mixtures and intended for drying various materials, International Technical and Economic Journal, 3, 2022, 62-72, (in Russian).
27. A.V. Fedyukhin, A.V., A.G. Zvonchevsky, Promising directions of using heat from low-potential sources of chemical production, News of Higher Educational Institutions. Problems of Energy, 24, 3, 2022, 15-27, (in Russian).
28. A.V. Frolkova, D.S. Logachev, T.E. Ososkova, Diethyl mixture separation ether + hexane + ethyl acetate + ethanol using extractive rectification, Izvestiya Vuzov. Chemistry and Chemical Technology, 63, 10, 2020, 59-63, (in Russian).