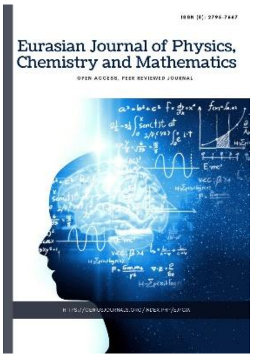

Optimization Of The Process Of Heating An Oil And Gas Condensate Mixture By Light Naphtha Vapor In Heat- Exchanger Condenser 10e04

Sakhnoza Saidanvarovna Rakhimjanova

Lecturer at the Tashkent Institute of Chemical Technology, PhD, Tashkent, Uzbekistan. 41, Mirzo-Ulugbek str. Corresponding author's. e-mail: shaku.76@mail.ru.

ABSTRACT

This study investigates the optimization of heating a 30% oil-70% gas condensate mixture in the industrial shell-and-tube heat exchanger-condenser 10E-04 at the Bukhara Oil Refinery. The mixture flow rate was 105,508 kg/h, with an inlet temperature of 96.1°C and a naphtha vapor condensation temperature of 136.6°C. A refined mathematical model accounting for temperature-dependent changes in density (768-744 kg/m^3), heat capacity (2180-2310 J/kg·°C), and viscosity (0.0032-0.0023 Pa·s) was applied, improving calculation accuracy by 20-30%. The overall heat transfer coefficient was 270 W/m^2·K. Analysis showed that at the regulated outlet temperature of 111.7°C, only 72% of the 273 m^2 heat transfer surface is effectively utilized. The optimal outlet temperature was determined as 107.3°C, corresponding to a required surface of 220 m^2. At this condition, pump power consumption is 15.4 kW and the minimum specific technological cost is 285.12 sum/kg. The optimized regime reduces effective heat transfer surface by 19% and lowers technological costs by approximately 3-4%, revealing additional thermal capacity reserves of the apparatus.

Keywords: Oil mixture, heat exchanger, process optimization, heat transfer, energy efficiency, technological cost.

INTRODUCTION

The thermal preparation of hydrocarbon feedstock prior to atmospheric distillation is one of the most energy-intensive stages in oil refining [1]. A significant share of operating costs in refineries is associated with fuel consumption, electricity use, and depreciation of heat exchange equipment [2]. Under conditions of continuously increasing energy prices and stricter requirements for resource efficiency, optimization of heat exchange processes becomes a priority task [3-4].

In conventional refinery practice, crude oil and gas condensate mixtures are heated in a block of shell-and-tube heat exchangers using hot process streams leaving the distillation column [5-8]. However, the thermal efficiency of such equipment is often limited by conservative operating regimes [9], incomplete utilization of heat transfer surfaces, and insufficient consideration of temperature-dependent changes in thermophysical properties of the heated mixture [10-11]. As a result, part of the installed heat exchange surface operates underloaded, while pumping and depreciation costs continue to grow [12-15].

An important direction for improving energy efficiency is the use of hydrocarbon vapors, particularly light naphtha vapor, as an alternative heat carrier instead of conventional steam [16]. The condensation of hydrocarbon vapors inside the annular space of shell-and-tube apparatuses allows intensification of heat transfer and more rational use of internal refinery heat resources [17-18]. At the same time, accurate modeling of the heating process requires accounting for variations in density, viscosity, and heat capacity of the oil-gas condensate mixture along the length of heat transfer tubes [19-20].

The present study focuses on the optimization of heating a 30% oil-70% gas condensate mixture in the industrial heat exchanger-condenser 10E-04. A refined mathematical model of the process is developed to determine the optimal outlet temperature, the minimum required heat transfer surface, and the corresponding specific technological cost. The results provide practical recommendations for improving energy efficiency and reducing operating costs in refinery heat exchange units.

Materials and Methods

The present study proposes a refined method for the optimal calculation and analysis of the thermal preparation process of a local oil and gas condensate mixture in a shell-and-tube heat exchanger–condenser 10E-04 operating at the Bukhara Oil Refinery. The objective of the research is to determine the energetically optimal outlet temperature and the corresponding minimum required heat transfer surface that ensures minimal specific technological cost of heating [21].

The heated feedstock is a working mixture consisting of 30% crude oil and 70% gas condensate [22]. The heating process is carried out using the condensation heat of light naphtha vapors in the annular space of the apparatus. Unlike conventional steam heating, the use of hydrocarbon vapor as a coolant allows intensification of heat transfer and reduction of external energy consumption. The main design and operating parameters of the industrial heat exchanger–condenser 10E-04 used in this investigation are summarized in Table 1.

Table 1.
Design and Operating Parameters of the Industrial Heat Exchanger-Condenser 10E-04

Parameter	Value	Unit
Mixture flow rate	105,508	kg/h
Inlet temperature of mixture	96.1	°C
Regulated outlet temperature	111.7	°C
Optimal outlet temperature	107.3	°C
Condensation temperature of naphtha vapor	136.6	°C
Overall heat transfer coefficient	270	$W/m^2 \cdot K$
Heat transfer coefficient (wall–mixture)	878	$W/m^2 \cdot K$
Total installed heat transfer surface	273	m^2
Required optimal heat transfer surface	220	m^2

The apparatus has the following geometric characteristics: tube diameter d = 20/25 mm, tube length l = 6.0 m, and number of tubes n = 644. The total installed external heat transfer surface is 273 m^2. The refined calculation approach implemented in this study allows determining the effective active length of the tubes required to achieve optimal heating conditions [23].

Unlike traditional methods where thermophysical properties are assumed constant at average temperatures, the proposed approach accounts for the continuous temperature dependence of mixture properties (density, heat capacity, viscosity, and thermal conductivity). This significantly increases the accuracy of heat transfer coefficient prediction by 20-30%. The temperature dependence of the main thermophysical properties of the oil-gas condensate mixture used in the model is presented in Table 2.

Table 2.
Temperature Dependence of Thermophysical Properties of the Oil–Gas Condensate Mixture

Temperature (°C)	Density ρ (kg/m³)	Heat Capacity c (J/kg·°C)	Dynamic Viscosity μ (Pa·s)
96	768	2180	0.0032

100	760	2215	0.0029
105	752	2260	0.0026
107.3	748	2285	0.0025
110	744	2310	0.0023

As shown in Table 2, an increase in temperature leads to a decrease in density and viscosity and an increase in heat capacity, which directly affects Reynolds number, heat transfer coefficient, and hydraulic resistance of the system. The mathematical model of the heating process is based on the energy balance equation along the tube length:

$$G_0 \frac{d(ct)}{dl} = 2\alpha_2 d_{in} n(t_{st} - t)$$

where the heat transfer coefficient α_2 is calculated using the refined method considering temperature-dependent properties. Hydraulic losses are calculated through Reynolds number-based friction correlations, and pumping power is determined accordingly.

The objective function of the optimization problem is formulated as the specific technological cost of the heated mixture:

$$C_{ud} = \frac{1}{G_0} \left[C_e N + A_{ht} F + A_p N \right]$$

Where the cost includes energy consumption for pumping and depreciation deductions for heat exchange equipment and pumps.

The constraint of the optimization problem is defined by the technological limitation of outlet temperature:

$$t_{out} \le t_{lim}$$

The numerical solution of the model was carried out by iterative calculation of heat transfer surface and pumping power for various outlet temperatures within the range of 96.1–111.7 °C.

RESULT AND DISCUSSION

To select the optimal number of heat exchange apparatus for the first stage of hydrocarbon feedstock preheating, which is a system of 8 heat exchangers connected in series, a systematic analysis of the efficiency of this industrial equipment of the enterprise has been performed.

The statics of the process of heating the oil and gas condensate mixture, consisting of 30% oil and 70% gas condensate, by the heat of condensing vapors of the total naphtha fraction leaving the raw material pre-fractionation columns and the atmospheric distillation column of the Bukhara Oil Refinery primary distillation unit was studied. The industrial heat exchanger-condenser 10E-04 used for heating the operating mixture has the following design parameters. Based on the results of the study of the process on a mathematical model, a distribution curve of the temperature t of the oil and gas condensate mixture along the length of the pipes l of the heat exchanger was formed for its given productivity G_o (Fig. 1).

Figure 1 shows that at a given flow rate of the working mixture, Go = 105,508 kg/h, its temperature t in the apparatus rises smoothly to 107.3 °C with increasing speed in the pipe section $l \le 4.4$ m long. the length of the pipe in the initial section is 2.6 °C / m, and closer to the temperature equilibrium point - 3.5 °C / m. In the future, with the achievement of a constant temperature difference between the mixture and the heat carrier, the rate of change in the temperature of the mixture along the remaining length of the heat transfer pipes (up to 6.0 m) becomes constant.

Analysis of the curve l = f(t) shows that in order to achieve the required mixture heating temperature at the yield t_{out} = 111.7 °C, a section of the tube bundle with an active length lact = 4.4 m is sufficient, which is 72% of the total length of the heat transfer pipes in the apparatus.

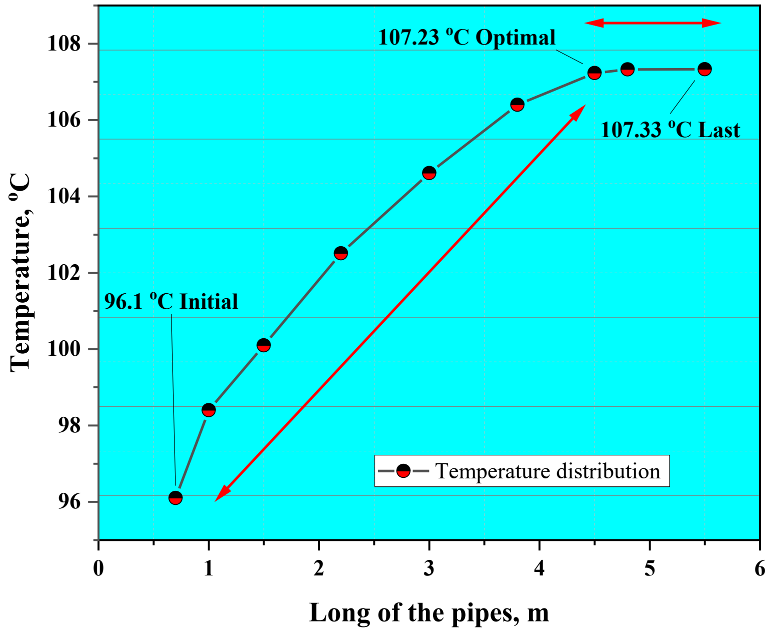

Fig. 1. Temperature distribution of the oil and gas condensate mixture *t* along the length of the pipes *l* of the 10E-04 heat exchanger-condenser at its flow rate G_o = 105,508 kg/h.

As can be seen, the main process of heating the oil and gas condensate mixture takes place in a section of the pipe with a length of l ≤ 4.4 m, and the rest of the tubes, at a given capacity of the apparatus, operate at idle (section from 4.4 to 6.0 m). It follows that for a given productivity of the apparatus, G_o = 105,508 kg/h of the mixture, its required heating surface is F_{outer2} = 220 m^2. This circumstance indicates the insufficient use of the thermal power of the apparatus, and on the other hand, the possibility of doubling the flow rate of the mixture heated in it.

Later, the objective function of the optimality criterion for the process of heating the oil and gas condensate mixture (6-11) in this heat exchanger-condenser 10E-04 was studied in relation to the operating conditions of the atmospheric oil distillation unit at the Bukhara Oil Refinery [13]. The calculation of the objective function (6) was carried out at the above values of the design and technological parameters of the process - G_o, G_d, t_{input}, t_{output} and t_{con}.

Based on the results of calculations, curves were plotted for changes in unit costs (sum/kg) - depreciation charges for a heat exchanger (curve *1*) and costs for pumping liquid by a pump (curve *2*) on the temperature of heating the oil and gas condensate mixture tout in the range of its temperature increase 96.1 ÷ 111.7 °C at a constant temperature of condensation of vapors of total naphtha t_{con} = 136.6 °C (Fig. 2).

Figure 2 shows that the behavior in the components of the unit cost of heating the oil and gas condensate mixture in the heat exchanger is the cost of pumping the mixture by a pump through the tubes and process pipes of the apparatus, including depreciation of pumping equipment $E = C_eN_p + A_pN_p$, as well as depreciation deductions for the heat exchanger $A = A_{ht}F_{ht}$, depending on the heating temperature of the mixture.

The analysis of the values of the components of the cost of the heated working mixture Sud is reduced to the following: according to the calculations, the amount of depreciation deductions for the heat exchanger $A = A_aF_a$ (curve 1), depending on the mode of its operation, intensively increases along the sloping curve from 106.66 to 134.39 sums / kg. To pump a given flow rate of the mixture G_o = 105,508.3 kg/h through the tubes of the apparatus, N_p = 15.4 kW of power will be required.

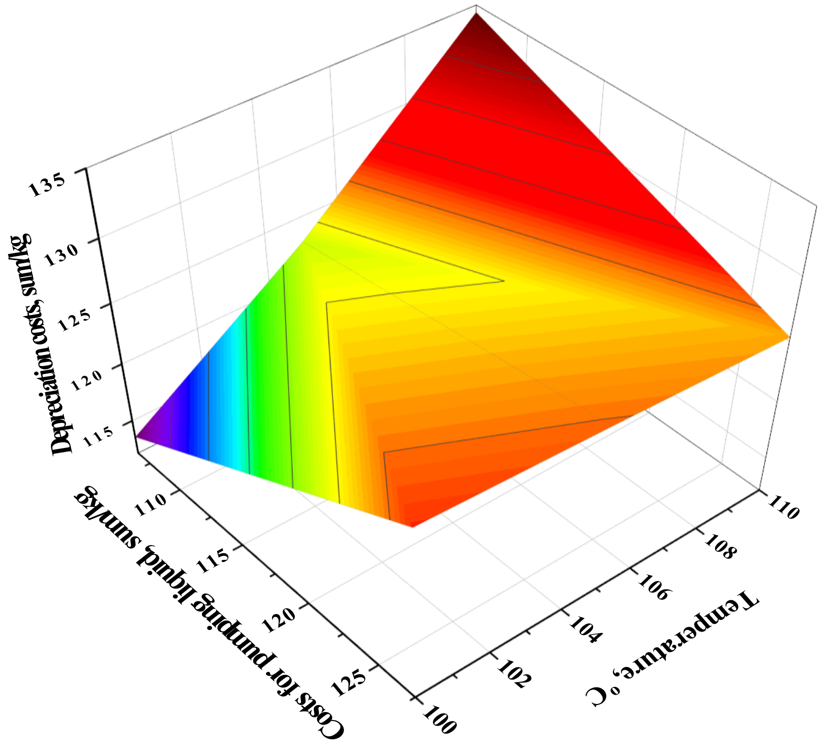

Fig. 2 Change of depreciation charges on the heat exchanger 1 and energy costs for pumping liquid 2 on the temperature of oil feedstock heating

Taking into account the cost of electricity C_e = 440.52 sum/kW (data for 2021) for refineries and depreciation of pumping equipment, the total costs for pumping a given flow rate of the mixture $C_p = N_p(C_e+A_p)$ falls in the range from 127.62 to 125.45 sum/kg (curve 2). We consider that the point of intersection of curves 1 and 2, where the value of the heat exchange surface of the apparatus F_{inter} = 220 m^2, C_p = 125.9 sum/kg, A = 127.55 sum/kg, C_{st} = 285.12 sum/kg, and temperature of the heated mixture at the outlet of the apparatus tout = 107.3 °C, characterizes the optimal operating conditions of the 10E-04 heat exchanger at its given productivity G_o = 105,508.3 kg/h in the conditions of the Bukhara Oil Refinery.

The comparable cost of C_p and A is explained by the high price of imported pumps used at refineries

In the world on improvement and optimization of a technological stage of oil distillation researches are constantly conducted. Namely in the field of development and introduction in manufacture of technology of application of the alternative hydrocarbon heat carrier instead of water steam, effective use of heat of hot technological streams leaving a rectification column, development of energy-saving technologies of heat preparation of hydrocarbon raw materials for distillation, increase of efficiency of heat exchange apparatuses and optimization of their mass-size parameters. In particular, such scientists as S.A.Akhmetov, O.F.Glagoleva, A.K.Manovyan, A.I.Skoblo and many others worked on solving a wide range of problems on improvement of technology and equipment of oil preparation for refining. At the same time, research work on creation of energy-saving technology of thermal preparation of raw materials for distillation by steams of dehydrated distillate fractions, uniform distribution of a stream of oil on tubes of heat exchangers in a field of centrifugal forces, heating of raw materials at condensation of a rotating stream of steam and designing of a surface of heat exchangers on the basis of distribution of temperature of raw materials on length of heat-transfer tubes of heat exchanger are presently conducted. In the work of the author Ismailov O.Yu. the results of research on the influence of hydrodynamic modes of flow of liquid hydrocarbons in the process of scale formation, on the efficiency of the process of heating raw materials in tubular heat exchangers were given. Regimes were developed to reduce energy costs by preventing scale formation in a tubular heat exchanger. According to the above methodology, by a similar method of system analysis, using the developed algorithm for implementing a mathematical model, the statics of the heating process of all eight heat exchangers of the primary oil refining unit were calculated. The technological parameters at different technological and hydrodynamic regimes of the process were revealed. So, for heat exchangers 10E05; 10E07;10E08 the specified method did not optimize the heat transfer surface, but revealed the dependence of the heat transfer coefficient on the length of heat transfer tubes. The higher the heat transfer coefficient, the shorter the length of heat transfer tubes of the heat exchanger. The technical and economic evaluation of the economic feasibility of using these heat exchangers is investigated.

Conclusion.

Thus, the analysis of the results of the study on the model of the statics of heating the oil and gas condensate mixture showed that with a regulated apparatus capacity G_o = 105,508 kg/h and a mixture temperature of 111.7 °C, the effective length of the heat transfer tubes of the shell-and-tube heat exchanger-condenser 10E-04 is l_{act} = 4.4 meter, at which the optimal heating surface of the apparatus is F_{inter2} = 220.2 m^2. Comparison of the values F_{inter2} = 220.2 m^2 and F_{inter1} = 273 m^2 indicates the insufficient use of the thermal power of the apparatus, and in terms of technology - the possibility of further doubling the consumption of the heated mixture in the apparatus. The results of the study of the objective function of the criterion of optimality of this process in the conditions of the Bukhara refinery made it possible to identify the optimal values of the technological parameters of the process in the heat exchanger 10E-04: F_{inter1} = 220 m^2, C_p = 125.9 sum/kg, A = 127.55 sum/kg, C_{st} = 285.12 sum/kg and $t_{opt.}$ = 107.3°C.

REFERENCES

1. Akhmetov S.A. Technology of deep processing of oil and gas: a textbook for universities. Ed. 2nd, revised. and additional - St. Petersburg: Nedra, 2013. - 544 p.
2. Glagoleva O.F., Kapustin V.M., Gyulmisaryan T.G. etc. Technology of oil processing. In 2 parts. Part I. Primary oil refining / Ed. O.F. Glagoleva and V.M. Kapustin. - M.: Chemistry, Kolos, 2006. - 400 p.
3. Manovyan A.K. Technology of primary processing of oil and natural gas: a textbook for universities. 2nd ed. - M.: Chemistry, 2001. - 568 p.
4. Skoblo A.I., Molokanov Yu.K., Vladimirov A.I., Shchelkunov V.A. Processes and apparatus of oil and gas processing and petrochemistry: a textbook for universities. 3rd ed., revised. and additional - M.: Nedra-Businesscenter LLC, 2000. - 677 p.
5. Akhmetov S.A., Serikov T.P., Kuzeev I.R., Bayazitov I.M. Technology and equipment for oil and gas processing processes: textbook / Ed. S.A. Akhmetov. - St. Petersburg: Nedra, 2006. - 868 p.
6. http://www.ecomet.ru/equipment/heat-exchangers.
7. Analytical portal of the chemical industry, http://www. newchemistry.ru/index.php. Report of the Academy of Industrial Market Studies: the market of shell-and-tube heat exchange equipment in Russia, 2008-12-10. www.akpr.ru
8. Khudaiberdiev A.A., Khudaiberdiev Ab.A. Analysis of the design of heat exchangers of oil refineries // Problems of formation and implementation of innovative technologies in the context of globalization: Collection of scientific articles of the international research and production complex. Part II. - Tashkent, TSTU im. Beruni, 2010. - S.72-74.
9. Khudaiberdiev A.A. Intensification of the process of heating oil feedstock. Monograph. - Tashkent: Navroz, 2019. - 213 p.
10. Babkin V.A. et al. Increasing energy efficiency in the process of atmospheric distillation of oil. Bulletin of the Tomsk Polytechnic University. Chemistry and chemical technologies, 2014. - V.325, No. 3. - P.56-63.
11. Khudaiberdiev A.A., Rakhimzhanova Sh.S. Modeling the statics of the process of heating the oil and gas condensate mixture during the condensation of naphtha vapors in a horizontal shell-and-tube apparatus // Universum magazine: technical sciences. - Moscow, 2022. - No. 4(97). - S. 17-21.
12. Hudayberdiev A.A. Study of the static of the process of heating hydrocarbon raw materials

in tubular apparatus // International scientific and technical journal Chemical technology. Control and management, 2019, No. 1 (85). - pp. 63-67.
13. Technological regulations for the installation of atmospheric distillation of a mixture of oil and gas condensate and fractionation of hydrotreated naphtha at the Bukhara Oil Refinery. - TR 16472899-001, 2009.
14. Khudayberdiev A.A., Rakhimjanova Sh.S. Technique for refined calculation of heat exchange during condensation of vapors of fractions of oil and gas condensate mixture in the shell and pipe apparatus //Scientific and technical journal of Namangan institute of engineering and technology/ -Namangan, 2021. -Vol. 6 Issue (4) 2021. - p.126-133.
15. Grigoriev B.A., Bogatov G.F., Gerasimov A.A. Thermophysical properties of oil, oil products, gas condensates and their fractions / Ed. ed. prof. B.A. Grigoriev. - M.: MPEI Publishing House, 1999. - 372 p.
16. Khudaiberdiev A.A. Comparative analysis of the properties of heat carriers for heating oil // Uzbek chemical journal. - Tashkent, 2012. - No. 4. - S. 57-60.
17. Khudaiberdiev A.A. Influence of temperature on the density of oil, gas condensate and their mixtures // Vestnik TSTU. - Tashkent, 2013. - No. 2. - S. 128-133.
18. Boyarinov A.I., Kafarov V.V. Optimization methods in chemical technology. Ed. second, revised and additional - M.: Chemistry, 1975. - 576 p.
19. Khudaiberdiev A.A., Artikov A., Rakhimjanova Sh.S., Shomansurov F.F. Optimization of the process of heating the oil and gas condensate mixture with naphtha vapor in the heat exchanger-condenser 10E-03 of the primary oil distillation unit // Universum magazine: technical sciences. - Moscow, 2022. - No. 4(97). - S. 10-17.
20. Pavlov K.F., Romankov P.G., Noskov A.A. Examples and tasks in the course of processes and apparatuses of chemical technology. Textbook for universities / Ed. P.G. Romankov. - 10th ed., revised. and additional - L.: Chemistry, 1987. - 576 p.
21. Khudaiberdiev A.A., Ismailov O.Yu., Sayidmurodov M.M. Study of the viscosity of oil, gas condensate and their mixtures // Chemical technology, control and management. - Tashkent, 2012. - No. 6. - S. 50-53.
22. Ismailov O.Yu. Influence of hydrodynamic regimes of hydrocarbon flows on the efficiency of tubular heat exchangers for scale formation. Author's abstract of thesis Doctor of Technical Sciences, Tashkent, 2023, p. 58.
23. Khudayberdiev A.A., Rakhimjanova Sh.S. Technique for refined calculation of heat exchange during condensation of vapors of fractions of oil and gas condensate mixture in the shell and pipe apparatus// Manufacturing technology problems. Scientific and technical journal of NMTI. Uzbekistan. Namangan, 2021. Issue (4) Vol 6. ISSN 2181-8622.