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INCREASING THE EFFICIENCY OF THE CONDENSATION PROCESS IN SHELL-PIPE PLANTS

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Abstract. *In the article, an experimental device for condensing water and hydrocarbon vapors in a shell-and-tube heat exchanger was created and a method of operation was developed. In the process of condensing gas condensate vapors with water in a shell pipe device, experiments were carried out along the length of the condenser pipe. In the experimental device, the transition of gas condensate with a volume of 15 liters to the vapor state and the condensation of this steam in the shell pipe experimental heat exchanger were conducted. its boiling temperature is 2.5 times lower than that of water vapor. It was determined that the heat of condensation of water vapor at 60 °C is* r_1 *=2317 kJ/kg, and when the temperature increases to 180 °C, it decreases* r_1 *=1998 kJ/kg, i.e. by 1.15 times.*

Keywords: *gasoline, water vapor, condensation, thermal conductivity, density, viscosity, temperature, heat capacity.*

In order to effectively organize the process of vapor condensation in pipelines, it is necessary to take into account technological parameters such as temperature, pressure and thermal-physical properties of the flow on the condensation surface in the pipe. Studying the effect of these technological parameters on the condensation process helps to develop the optimal design of condensation devices used in industry with high thermal efficiency [1].

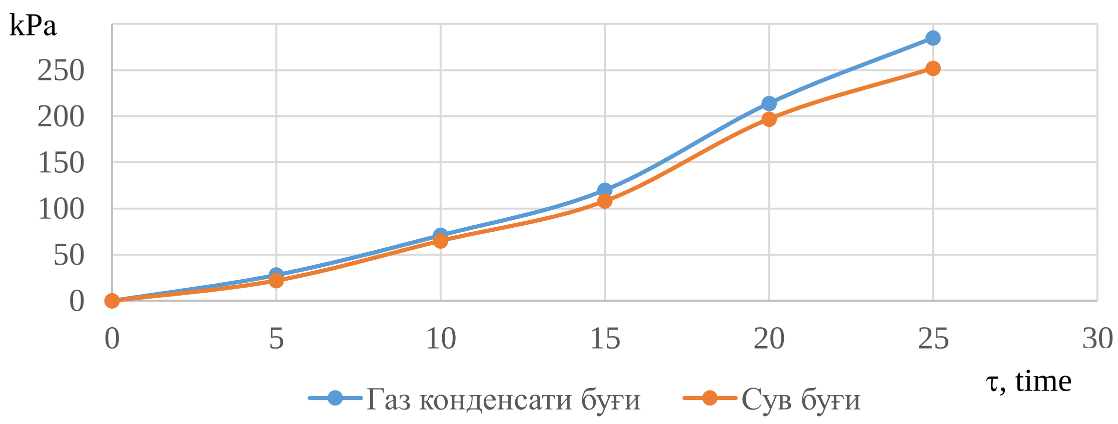

Figure 1. Variation of the pressure of the heat carriers in the steam boiler over time

Despite its wide practical application, there is little information in the literature on the study of the process of condensation of hydrocarbon vapors in tubular devices. Therefore, it is of scientific and practical importance to study the process of heat exchange during the condensation of hydrocarbon vapors in shell and pipe apparatus in order to develop recommendations for increasing the heat transfer and increasing the efficiency of industrial condensers on this basis [2].

Despite extensive practical scientific work, there is little information in the literature on the study of the process of condensation of hydrocarbon vapors in tubular devices. Therefore, it is of scientific and practical importance to study the process of heat exchange during the condensation of hydrocarbon vapors in shell-and-tube devices in order to develop recommendations for increasing the efficiency of industrial condensers on the basis of increasing heat transfer [2,3].

The purpose of determining the pressure rise in the steam boiler is to determine the time required for gas condensate and water vapor used as heat carriers in technological processes to rise to a working pressure of 250 kPa.

From the data presented in the diagram, we can observe that the pressure of water vapor changed in the range of 22÷252 kPa and increased 11 times during the period of 25 minutes, while the pressure of gas condensate vapor increased from 28 kPa to 285 kPa during this time, and we can observe that it increased more than 10 times. It took 25 minutes for water vapor to rise to a pressure of 250 kPa, and 22 minutes for gas condensate vapor.

It is known that the temperature is not evenly distributed along the length of heat exchangers (condenser). For this reason, steam condensation occurs at different temperatures, volume and speed along the length of the device. Therefore, the study of temperature changes along the length of the pipe is one of the main issues in choosing hydrodynamic modes to accelerate the condensation process and maintain the optimal temperature.

In addition, equal distribution of heat along the length of the pipe helps to determine the optimal length of the pipe, thereby determining the optimal heat exchange surface. This makes it possible to design capacitors with an optimal design in terms of energy.

Experiments were performed at steam pressures of 100, 150, 200 and 250 kPa in the steam boiler. During the experiment, the temperature of the cooling water at the entrance to the condenser was 20 ºC and the flow rate was 5 l/minute.

Changes in the temperature of water and gas condensate steam condensing along the length of the pipe at different pressures of the steam transmitted to the shell part of the heat exchange pipe of the experimental device are presented in Figures 2÷5.

The temperature of the steam coming out of the steam boiler at a pressure of 100 kPa at the entrance to the condenser was 100 ºC, and it rapidly decreased along the length of the pipe (3 meters). When the movement of steam reaches 2.5 meters of the condenser pipe, it is found that the condensation is complete and the temperature drops to 20 ºC. The temperature of gas condensate steam at the entrance to the shell-tube condenser was 103 ºC. As a result of the process of heat exchange in the pipe, it decreased to 20 ºC at a distance of 2.5. The difference between the initial temperatures of water and gas condensate vapors was 3 ºC, and by the end of the condensation period, it was on average 5 ºC (Fig. 2).

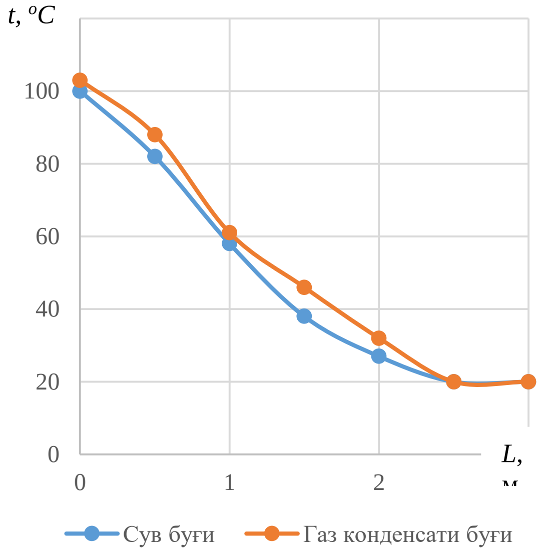

Figure 2. Distribution of steam temperature of water and gas condensate at a pressure of 100 kPa along the length of the condenser pipe

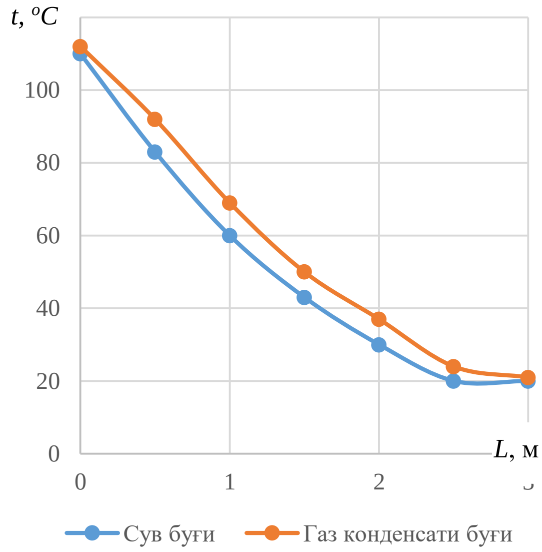

Figure 3. Distribution of steam temperature of water and gas condensate at a pressure of 150 kPa along the length of the condenser pipe

By increasing the steam pressure to 150 kPa, the temperature of water vapor increased by 110 ºC, and the temperature of gas condensate increased by 112 ºC. Water vapor was fully condensed along the length of the pipe with a velocity of up to 2.5 meters and its temperature decreased to 20 ºC. And in the gas condensate, this temperature decreased to 24 ºC along the indicated length (Fig. 3).

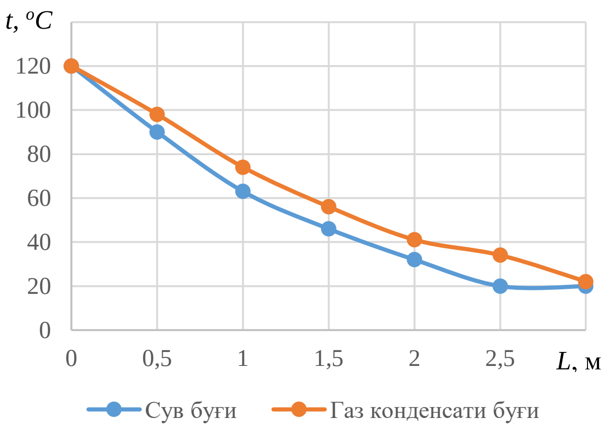

Figure 4. Distribution of water and gas condensate steam temperature along the length of the condenser pipe at a pressure of 200 kPa

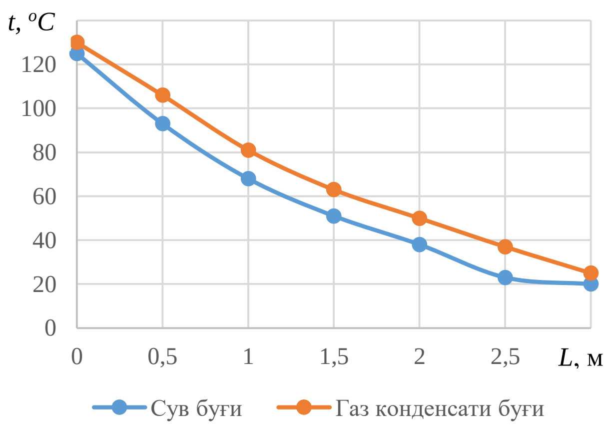

Figure 5. Distribution of water and gas condensate steam temperature along the length of the condenser pipe at a pressure of 250 kPa

As a result of increasing the pressure in the steam boiler to 200 kPa, the temperature of water and gas condensate vapors increased to 120 ºC. The temperature change along the length of the pipe decreased to 90 °C for water at 0.5 meters and 20 °C at 2.5 meters. Distribution of gas condensate steam along the length of the heat exchange pipe: 98 ºC at 0.5 meters; 56 ºC at 1.5

meters; It was found that it decreases to 34 ºC at 2.5 meters and to 22 ºC at the 3rd meter of the pipe (Fig. 4).

As the pressure of the steam entering the shell pipe of the heat exchanger increases to 250 kPa, the temperature of the water vapor at the starting point is 125 ºC and drops to 23 °C until it reaches 2.5 meters of the pipe. The temperature in the 3-meter length of the pipe was equal to 20 ºC. It was found that the temperature of the gas condensate is 130 ºC at the starting point of the pipe, and the temperature drops to 25 ºC at the end of the pipe (Fig. 5).

It can be seen from the curve diagrams presented in Figures 2÷5 that rapid condensation of water and gas condensate vapors was observed along the length of the condenser pipe up to 2 meters. Between the 2nd and 3rd meters, it was found that the condensate gradually decreases and cools down to 37÷20 ºC. In the process, the temperature change along the length of the pipe was determined using a GM530 infrared thermometer designed to measure temperatures from -50 to 530 ºC in parallel with mercury glass thermometers.

It was determined during the experiment that 15 liters of working fluid (water or gas condensate) poured into the steam generator will change from the vapor state to the condensate state within a unit of time.

In the process of condensation, the condensate output volume (V, l) of water and gas condensate steam at a pressure of 250 kPa in a unit of time (τ, min) is presented in Fig. 6.

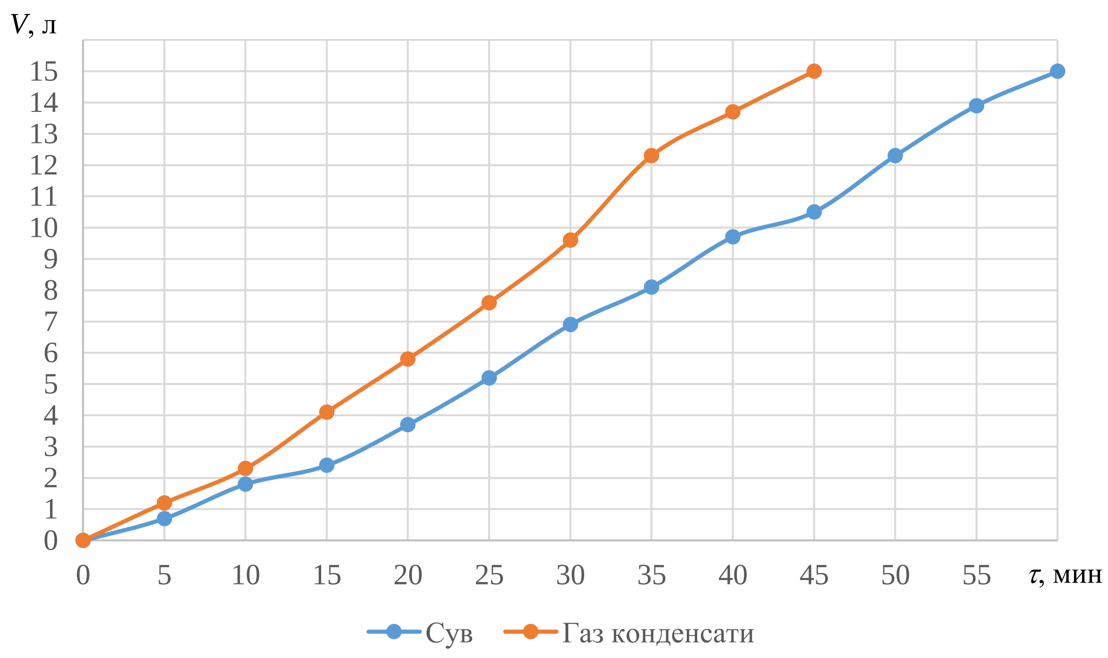

Figure 6. Volume of condensation of gas condensate steam per unit of time

As can be seen from the curve diagram, in the process of condensing the experimental samples, 15 liters of gas condensate in the steam boiler and condensing this steam in the experimental shell-and-tube heat exchanger took 45 minutes, while it took 60 minutes for this volume of water to go from the vapor state to the condensate state. time spent. The summary of the obtained results shows that the condensation of gas condensate vapor is explained by the fact that its boiling temperature is 2.5 times lower than that of water vapor. As a result, it will be possible to spend 1.5 times less time and energy on condensing hydrocarbon vapors than on condensing water vapor in production enterprises.

One of the most important thermal parameters of hydrocarbon vapors is the low condensation heat (250-350 kJ/kg) compared to water (2260 kJ/kg). This indicator makes it possible to increase efficiency in the process of condensing hydrocarbon vapors in shell-and-tube heat exchangers without additional costs.

When determining the efficiency of the condensation process in the heat exchanger by mathematical calculation, it is possible to determine by comparing the heat of condensation of water vapor and gas condensate vapor at a pressure of 200 kPa. It is known from the literature that the heat of condensation of steam is 2202 kJ/kg as a result of increasing the temperature of water vapor pressure P=200 kPa to 120 ºC in the steam generator [4,5].

The heat of condensation of gas condensate vapors can be determined using the Craig formula [4,5]:

$$r = \frac{1}{d_{15}^{15}}(354{,}1 - 0{,}3768 T_{ўр}), \quad (1)$$

where is $d_{15}^{15} = 07667$ the specific density of the gas condensate

It is known from the experiments conducted on the study of the fractional composition of gas condensate that the starting temperature of the gasoline fraction from the gas condensate is 60 ºC and the final temperature is 180 ºC. For this reason, a comparative analysis of the heat of condensation of water and gas condensate vapors in the temperature range of 60÷180 ºC was performed. The results of the experiment are presented in Table 1.

Table 1

Condensation of water and gas condensate vapors heat

Temperature, *t*, ºC	Molecular gas condensate mass	*Condensation heat of steam, kJ/kg*	
		Water r_1	Gas condensate r_2
60	73,6	2317	295
70	79,2	2298	290
80	85,4	2276	287
90	91,8	2268	282
100	98,1	2260	278
150	129,6	2120	253
160	136,4	2097	248
170	143,7	2015	239
180	156,9	1998	233

According to the data presented in Table 1, the heat of condensation of water and gas condensate vapors gradually decreases as the temperature increases. This indicator was r_1 =2317 kJ/kg for water at 60 ºC, and it was found to decrease to r_1 =1998 kJ/kg, i.e. 1.15 times, when the temperature increases to 180 ºC. The heat of condensation of gas condensate reaches 295 kJ/kg when the temperature reaches 60 ºC, and when the temperature increases to 180 ºC, this indicator decreases to 233 kJ/kg, i.e. 1.26 times.

By comparing the heat of condensation of water vapor r_1 with the heat of condensation of gas condensate r_2, the efficiency of the process can be determined using the following expression:

$$r_1/r_2 = 2317/295 \text{ kJ/kg} = 7{,}85$$

where the possible intensity level of the heat transfer process in the experimental condenser is 7.85.

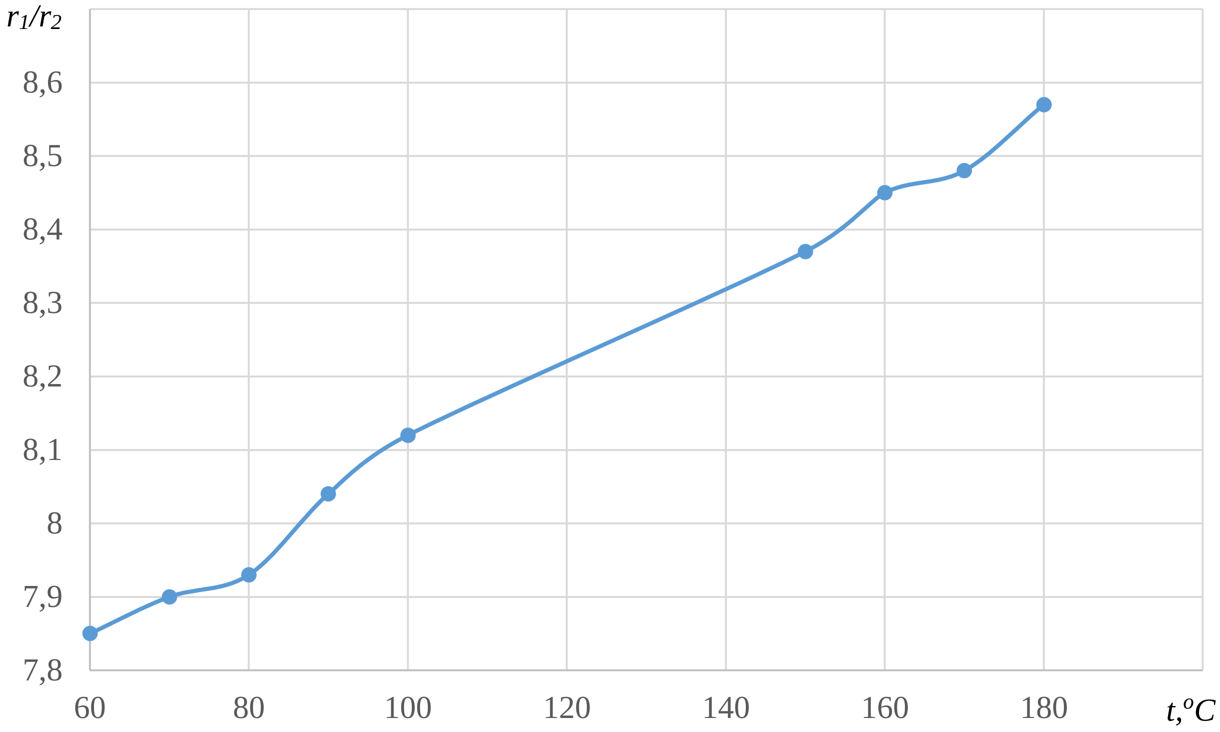

Figure 7. Specific heat of condensation of heat carriers

Figure 7 shows the comparative index of heat of condensation of the studied heat carriers r_1/r_2 depending on the ambient temperature t.

From the data presented in the given graph, we can see that the difference between the heat of condensation of water and gas condensate vapors increases from 7.8 to 8.6 times as the temperature increases from 60 ºC to 180 ºC.

Based on the results of the conducted research, it was found that the possibilities are high in the processes of primary processing (heating, cooling) of raw materials of hydrocarbon vapors.

In the shell-and-tube heat exchange experimental device, heat exchange processes during condensation were studied by calculating heat transfer and heat transfer coefficients. The consumption of saturated vapors of water or gas condensate is determined using the following equation:

$$D = V \rho_{kn} / \tau_{op}, \quad (2)$$

where V is the volume of condensate collected during stable operation of the experimental device, m3; ρ_{kn} - condensate density, kg/m3.

The coefficient of heat transfer from the coolant to the pipe wall is carried out in the following sequence [3]:

$$Q_1 + Q_2 = Q_3, \quad (3)$$

here $Q_1 = D \cdot r_{vapor}$ – heat flow from condensing steam; $Q_2 = Dc_{к}(t_{sat} – t_{kn})$ – cooling heat flux heat; $Q_3 = G_c c_c(t_{c6} – t_{co})$ – the flow of heat transferred to the cooling water; $G_{в}$ – water consumption, kg/s; $c_{кн}$ and c_c – heat capacity of condensate and water, J/(kg·K); t_{sat} and t_{kn} – saturated steam and condensate temperature, °C; t_{in} and t_{fin} – initial and final water temperature, °C.

The average temperature of heat carriers is determined using the following formula [5,6]:

$$\Delta t_{cp} = (t_{ск} - t_{cб})/[\ln(t_{sat} - t_{cб})\ (t_{sat} - t_{co})].$$

The surface area of the condenser for vapor cooling is determined using the following expression:

$$F = \pi d_{cp} L, \quad (4)$$

here L – pipe length, m; $d_{av} = 0{,}5(d_{in} + d_{out})$ – average diameter of the heat transfer pipe, m.

Based on the results of the experiment, the value of the heat transfer coefficient is calculated from the following formula:

$$K_o = Q_3/(F_{кн}\Delta t_{cp}). \quad (5)$$

The magnitude determined by mathematical calculation of the heat transfer coefficient by this formula (Vt/(m^2·K)):

$$K_p = (1/\alpha_1 + \delta_д/\lambda_д + 1/\alpha_2)^{-1}, \quad (6)$$

here α_1 and α_2 – heat transfer coefficient on the side of the cooling water and condensing gas condensate steam Vt/(m^2·K); $\delta_д$ – pipe wall thickness, m; $\lambda_д$ – thermal conductivity of the wall material, Vt/(m·K).

The coefficient of heat transfer from the condensing steam to the horizontal pipe wall is determined using the following formula [8]:

$$\alpha_{con} = 0{,}72\,[\lambda^3\rho^2 rg/\,\mu\,(T - t_1)\,d_{in}]^{0{,}25}. \quad (7)$$

1. The speed of movement of the liquid is determined:

$$v = 4G/\pi d^2_{in}\,\rho\,, \quad (8)$$

2. The regime of fluid flow, i.e. the Reynolds criterion, is determined:

$$Re_1 = \upsilon\, d_{in}\,\rho\,/\mu, \quad (9)$$

here ρ – density of liquid at calculated temperature, kg/m3; μ is the dynamic viscosity of the liquid, Pa·s.

3. Based on the fluid flow regime, the criterion equation for calculating the Nusselt criterion is selected and the heat transfer coefficient is determined.

The Nusselt criterion for the laminar regime of the liquid in the pipe is determined by the following formula [9,10]:

$$Nu_c = 0{,}17\,\mathrm{Re}_c^{0{,}33}\,\mathrm{Pr}_c^{0{,}43}\,Gr_c^{0{,}1}\left(\frac{\mathrm{Pr}_c}{\mathrm{Pr}_\partial}\right)^{0{,}25}\cdot\varepsilon_t\,. \quad (10)$$

Forced movement of the liquid in the pipe at the flow rate in the transition mode Nu_c an approximation was calculated according to the following equation [9,10]:

$$Nu_c = 0{,}008\,\mathrm{Re}_c^{0{,}9}\,\mathrm{Pr}_c^{0{,}43}\,. \quad (11)$$

The criterion equation of heat transfer for the turbulent movement mode of oil in a double-pipe device is determined by the following expression [9,10]:

$$Nu_c = 0{,}021\,\mathrm{Re}_c^{0{,}8}\,\mathrm{Pr}_c^{0{,}43}\left(\frac{\mathrm{Pr}_c}{\mathrm{Pr}_\partial}\right)^{0{,}25}\cdot\varepsilon_t\,, \quad (12)$$

here $Nu_c = d_{in}\cdot\alpha_2/\lambda$; $Pr_c = C\cdot v\cdot\rho/\lambda$ (at the average temperature of the liquid stream); $Gr_c = g\cdot d^3/v^2$ - Grasgoff's criterion at the mean temperature of the liquid stream; $Pr_\partial = C\cdot v\cdot\rho/\lambda$ - Prandtl's criterion at the average temperature of the pipe wall; $\varepsilon_t = f\,(L/d)$ - heat transfer coefficient of the size of the heat transfer pipe α_2 the coefficient that takes into account the effect on the increase [9]:

Coefficient of heat transfer from the pipe wall to the liquid α_2 defined by the following expression [9,11]:

$$\alpha_2 = \frac{Nu_c \cdot \lambda}{d_{ич}}. \quad (13)$$

The heat transfer coefficient *K* is the value of *1* m length of the pipe of the heat exchanger [9-12]:

$$K = \frac{1}{\frac{1}{\alpha_1 r_m} + \frac{1}{\alpha_2 r_u} + \frac{1}{\lambda} 2{,}31\lg\frac{r_m}{r_{ич}} + \frac{1}{r_{um}} + \frac{1}{r_{ишч}}}, \quad (14)$$

here r_{out} and r_{in} – the radius of the outer and inner pipes, m; r_{out} и r_{in}- external and internal thermal conductivity of the pollution layer in the inner pipe, W/(m^2·K).

The amount of heat passing from the heat carrier to the heated liquid is determined by the basic heat transfer equation [9-12]:

$$Q = KF\Delta t_{ўр}, \quad (15)$$

here Δt_{av} – average temperature, °C; *F* – the surface of the heat exchange pipe (for the experimental device $F=1.98\ m^2$).

The power required to drive hydrocarbon raw materials from the pipeline of the heat exchanger is determined using the following expression [13]:

$$N = G_н \Delta P / \rho_н, \quad (16)$$

here $G_н$ – consumption of raw materials at the entrance to the heat exchanger, kg/s; ΔP – hydraulic resistance of the raw material transfer path, Pa; $\rho_н$ – raw material density, kg/m^3.

Table 2 below shows the experimental and calculation results of the study of the influence of the flow speed on the thermal, hydrodynamic and energetic parameters of gas condensate vapors during the condensation process in a horizontal condenser.

Table 2

Changes in parameters during condensation of gas condensate vapors

Indicators	***Hot stream (gas condensate***				
Consumption of saturated vapors *D*, м^3/с	0,014	0,016	0,018	0,020	0,022
Initial temperature t_{in}, °C	115	115	115	115	115
Last temperature t_{fin}, °C	67	67	68	68	69
Steam pressure P_1, Pa	250	250	250	250	250
Reynolds criterion, Re	15742	15835	15985	16023	16086
Heat transfer coefficient α_1, W/m·K	502	604	689	760	831
Cooling flow (technical water)					
Flow speed ω, *м/с*	0,106	0,212	0,318	0,424	0,530
Initial temperature $t_б$, °C	20	20	20	20	20
Last temperature t_o, °C	88	86	85	84	83
Рейнольдс критерийси, *Re*	3412	6915	9317	12687	14352
Heat transfer coefficient	157	164	168	173	179

α_2, W/m·K					
Heat transfer coefficient K, W/m^2·K	119	129	135	141	147
The amount of heat transferred is Q, W	8925	9677	10124	10573	11026

From the data in Table 3.2, which shows the parameters of the heat exchange process during the condensation of hydrocarbon vapor (gas condensate) in the experimental device, the Reynolds criterion increases from 15742 to 16086 as the consumption of saturated steam varies in the range D = 0.014 ÷ ÷ 0,022 m^3/s. It was determined that the outlet temperature of the condensate increases by 2 °C in accordance with the flow rate, and the coefficient of heat transfer from the hydrocarbon vapor to the device wall increases from α_1 = 8925 to 11026 W/ m^2·K, i.e. 1.23 times. The coefficient of heat transfer from the wall of the device to the heated liquid increases by 1.14 times and is α_2 = 157÷179 W/m·K It was determined that the heat transfer coefficient K = 119 ÷ 147 W/m^2·K, the amount of transferred heat varies between Q = 8925 ÷ 11026 W.

Thus, on the basis of the conducted research, the following results were obtained: in the process of condensing water and hydrocarbon vapors in a shell-and-tube heat exchanger, an experimental device was created and a method of operation was developed in order to study the normal and circulating flow of condensable steam when entering the shell part of the device. In the process of condensing gas condensate vapors with water in the shell pipe device, rapid condensation of water and gas condensate vapors was observed up to 2 meters in length of the condenser pipe. Between the 2nd and 3rd meters, it was found that the condensate gradually decreases and cools down to 37÷20 °C. It took a total of 45 minutes for 15 liters of gas condensate to pass into the steam state in the experimental device and to condense this steam in the experimental shell-and-tube heat exchanger, while it took 60 minutes for this volume of water to pass from the vapor state to the condensate state. The summary of the obtained results shows that the condensation of gas condensate vapor is explained by the fact that its boiling temperature is 2.5 times lower than that of water vapor. The heat of condensation of water and gas condensate vapors gradually decreases as the temperature increases. This indicator was r1 =2317 kDj/kg for water at 60 °C, and it was found to decrease to r_1 =1998 kJ/kg, i.e. 1.15 times, when the temperature increases to 180 °C. The heat of condensation of gas condensate reaches 295 kJ/kg when the temperature reaches 60 °C, and when the temperature increases to 180 °C, this indicator decreases to 233 kJ/kg, i.e. 1.26 times.

REFERENCES

1. Скобло А.И., Молоканов Ю.К., Владимиров А.И., Щелкунов В.А. Процессы и аппараты нефтегазопереработки и нефтехимии: Учебник для вузов. 3-е изд., перераб. и доп. - М.: ООО "Недра-Бизнесцентр", 2000. - 677 с.
2. Salimov Z. Neft va gazni qayta ishlash jarayonlari va uskunalari. - T.: Aloqachi, 2010. - 508 b.
3. Савельев Н.И. Расчет и проектирование кожухотрубчатых теплообменных аппаратов: учеб. пособие / Н.И. Савельев, П.М. Лукин. - Чебоксары: Изд-во Чувашского университета, 2010. - 80 с.
4. Ахметов С.А. Технология глубокой переработки нефти и газ: учебное пособие для вузов. Изд. 2-е, перераб.и доп. -СПб: Недра, 2013.-544 с.

5. Ахметов С.А. Технология глубокой переработки нефти и газа: учебное пособие для вузов. - Уфа: Гилем, 2002. - 672 с.
6. Исмаилов О.Ю., Хурмаматов А.М., Хайдаров Ж.А. Определение коэффициента поверхностного натяжения нефти, газового конденсата и их смесей// Узбекский химический журнал. – Ташкент, –2018. -№2. – С. 57-64.
7. Исмаилов О.Ю., Сатторов З.М. Влияние гидродинамических режимов движения нефтегазоконденсатных потоков на толщину вязкого пограничного слоя и эффективность теплообмена// Научно-технический журнал «Нефтепереработка и нефтехимия». Москва. – 2020. – №2. –С. 35-37.
8. Барулин Е.П., Кувшинова А.С., Кириллов Д.В. и др. Лабораторный практикум по тепловым процессам. Учебное пособие. - Иваново: ИГХТУ, 2009. -65 б.
9. Павлов К.Ф., Романков П.Г., Носков А.А. Примеры и задачи по курсу процессов и аппаратов химической технологии. Учебное пособие для вузов/ Под ред. П.Г. Романкова. - 10-е изд., перераб. и доп. - Л.: Химия, 1987. - 576 с.
10. Исмаилов О.Ю., Хурмаматов А.М. Повышение эффективности трубчатых теплообменников за счёт рециркуляции потоков Нефтепереработка и нефтехимия. Научно-технические достижения и передовой опыт. 2021.-№5. -С. 42-46.
11. Исмаилов О.Ю., Хурмаматов А.М., Худайбердиев А.А Влияние рециркуляции потока на интенсивность теплообмена в двухтрубчатом аппарате. Нефтепереработка и нефтехимия. Научно-технические достижения и передовой опыт. 2018. -№ 5. -С. 39-41.
12. Исмаилов О.Ю., Хурмаматов А.М. Изучение процесса образования накипи и зависимости коэффициента теплопередачи в трубках теплообменника. Булатовские чтения: материалы IV Международной научно-практической конференции (31 марта 2020 г.): в 7 т. : сборник статей / Под общ. ред. д-ра техн. наук, проф. О.В. Савенок. – Краснодар: Издательский Дом – Юг. Т. 5: Химическая технология и экология в нефтяной и газовой промышленности. – 2020. –С. 100-102.
13. Ismailov. O.Yu., Khurmamatov A.M., Boriyeva Z.R. Effect of recirculation of the hydrocarbon flow on the thickness of the viscous sublayer and the efficiency of heat transfer// Europian multidisciplinary jornal of modern science. Volume:6. 2022. Pp.328-332