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ANALYSIS OF THE EFFICIENCY OF CONDENSATION OF HYDROCARBON VAPORS IN A TUBULAR APPARATUS

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ABSTRACT
The analysis of the main results of computational and experimental studies of the heat transfer coefficient in model capacitors of horizontal and vertical design is given. It was revealed that at the average temperature of heat carriers tp = 58-76 ° C, the efficiency of heat exchange during condensation of hydrocarbon vapors in a horizontal shell-and-tube condenser is 1.5 times higher than in a vertical apparatus of similar design.

KEYWORDS: Gas condensate, hydrocarbon vapors, steam condensation, condensate, cooling, cooling agent, heat transfer coefficient, heat transfer coefficient, shell-and-tube heat exchanger, tubular condenser, thermal efficiency of the process.

At oil refineries, the process of condensation of fuel fractions and cooling of the formed process condensate is carried out in shell-and-tube heat exchangers that are part of primary oil distillation units [1,2]. The latter are large consumers of thermal and electrical energy. Due to the constant increase in energy tariffs, these installations currently do not always meet modern requirements for the efficient use of energy resources. Therefore, the priority directions of energy saving in primary oil distillation plants are rational use of energy resources, increasing the degree of use of heat from secondary energy resources and increasing the efficiency of heat transfer in heat exchangers for the thermal preparation of hydrocarbon raw materials, such as heating desalinated raw materials, condensation of fuel fraction vapors and cooling of process condensates [3].
As is known, the value of the heat transfer coefficient in the heat exchange apparatus serves as a measure of the thermal efficiency of the processes carried out in it. Based on this, the authors analyzed the efficiency of heat exchange during the condensation of hydrocarbon vapors (gas condensate) by calculating the heat transfer coefficient in horizontal and vertical tubular apparatuses.

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To calculate the heat transfer coefficient in tubular condensers, the main results of experiments conducted to study this process on a model installation were used [4]. The shell—and—tube condenser of this installation has the following geometric parameters, mm: the diameter of the casing is 50/55, the diameter of the heat transfer pipes is 10/13, the working length of the pipes is 1000 and the total number of pipes is 7 pcs. The experiments were carried out in parallel and countercurrent directions of movement of coolant flows. Steam was supplied to the inter-tube space of the condenser, and cooling water was supplied to the inside of the heat transfer pipes.

In a model installation, the nature of the condensation temperature distribution of gas condensate and cooling agent vapors over the time and length of the pipes of an experimental condenser [5] was studied under the following conditions: vapor pressure in the casing of the apparatus P = 200-250 kPa, mass vapor consumption G = 0.00122-0.00367 kg/s, gas condensate density □20 = 728-732 kg/m3, and its dynamic viscosity coefficient □20 = (0.32-0.4) 10-3 m2/s. The volumetric flow rate of cold water during the experiments was V = 5 l/min. The indicators of the properties of water, depending on its temperature, are taken from the reference literature [6].

Using the experimental results, the main thermal properties of heat carriers (gas condensate and cooling water) were determined, such as density □kn (kg/m3), dynamic viscosity coefficient □kn (m2/s) and thermal conductivity coefficient □kn (W/(m□K)) at an average temperature of: gas condensate tkn.

The criterion equation for calculating the heat transfer coefficient α2 from the wall of the heat transfer pipes to the cooling water was chosen taking into account the value of the Reynolds number [6-8]:

$$Re = \upsilon\, d_{вн}\, \rho / \mu, \qquad (1)$$

where υ = 4V/(π d2vn n) is the average water flow rate in the pipe space of the apparatus, m/s; V is the volumetric water flow rate, m3/s; dvn is the internal diameter of the condenser pipes, m; n is the number of heat transfer pipes in the apparatus, pcs; and m is the density (kg/m3) and the dynamic viscosity coefficient (Pa·s) of water, respectively.

It is established that in the specified range of changes in water flow, the mode of its movement in the tubes of the experimental condenser is transient, since the calculated value of the number Re is in the limit of 8378-8426. For the transient mode of forced movement of water in the tubes , it is recommended to use the criterion equation [6-8]

$$Nu = 0{,}008re0{,}9pr0{,}43. \qquad (2)$$

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The calculated value of the Nu criterion was used to determine the value of the heat transfer coefficient from the cooling water a2 (W/(m2□K) [6-8]: α_2 = (Nu □in)/dvn. (3)

To calculate the heat transfer coefficient from the condensing vapors of gas condensate to the walls of heat transfer pipes a1 (W/m2□K), depending on the position of the condenser in space, the following equations are chosen [6-8]:

• for a condenser with a bundle of vertical pipes

α1 = 3.78 λ kn (pkn2dnr pt /□kn Gp)0.33; (4)

• for a capacitor with a bundle of horizontal pipes

α1 = 2.02 □p λ kn (pkn2Lt pt /□kn Gp)0.33, (5)

where dn is the outer diameter of the pipe, m; Lt is the length of the pipe, m; n is the number of pipes in the apparatus, pcs; □p is the row coefficient averaged for the entire bundle of pipes, taking into account the relative decrease in the heat transfer coefficient a1 depending on the location of the pipes and their number in the rows of the tube bundle of the apparatus; Gp is the mass flow rate of gas condensate vapor, kg/s.

With known numerical values of the heat transfer coefficients α1 and α2, the heat transfer coefficient in the experimental capacitor K (W/(m2□K)) is calculated using the well-known equation [2]:

$$K = \alpha 1\ \alpha 2 /(\alpha 1 + \alpha 2). \quad (6)$$

When calculating the heat transfer and heat transfer coefficients in a vertical tubular condenser, the temperature conditions of the process are taken into account according to one of the variants of experiments on a model installation: temperature condensation of gas condensate vapors tn1 = 174-198 ° C, temperature of the cooled process condensate (liquid) at the outlet of the apparatus tk1 = 24 ° C; temperature the water entering the condenser tn2 = 18 ° C and the temperature of the waste water at the outlet of the device tk2 = 24-34 ° C.

The results of calculations to determine the coefficients of heat transfer and heat transfer in an experimental vertical tubular condenser under different temperature conditions of its operation are given in

Table 1.

The data in Table 1 show that under the temperature conditions of condensation of gas condensate vapors tn1 = 174-198 ° C, the limiting values of thermal coefficients (W / (m2· K)) in an experimental vertical tubular condenser vary within the following limits: □1 = 2146-2238, □2 = 293-335 and K = 257-291.

Table 1 Results of calculations of heat transfer and heat transfer coefficients in an experimental vertical tubular condenser

Gas condensate temperature, °C		Heat transfer coefficient □1, W/(m2·K)	Cooling water temperature, °C		Heat transfer coefficient □2, W/(m2·K)	Heat transfer coefficient in the apparatus K, W/(m2·K)
tn1	tk1		tn2	tk2		
174	24	2146	18	34	293	257
180	24	2155	18	25	302	264
186	24	2163	18	27	311	271
192	24	2172	18	24	319	278
198	24	2238	18	24	335	291

When determining the value of the heat transfer and heat transfer coefficients in a horizontal tubular condenser, the temperature conditions of one of the winter variants of the experiments were taken into account, when the temperature of condensation of gas condensate vapors was in the range tn1 = 158-172 ° C and the temperature of condensate (liquid) at the outlet of the apparatus was in the range tk1 = 14-19 ° C. At the same time, the cooling water entered the condenser with a temperature of tn2 = 20 ° C, where it was heated to the limit of tk2 = 50 ÷66 ° C during the process.
The results of calculations to determine the coefficients of heat transfer and heat transfer in a horizontal condenser are given in

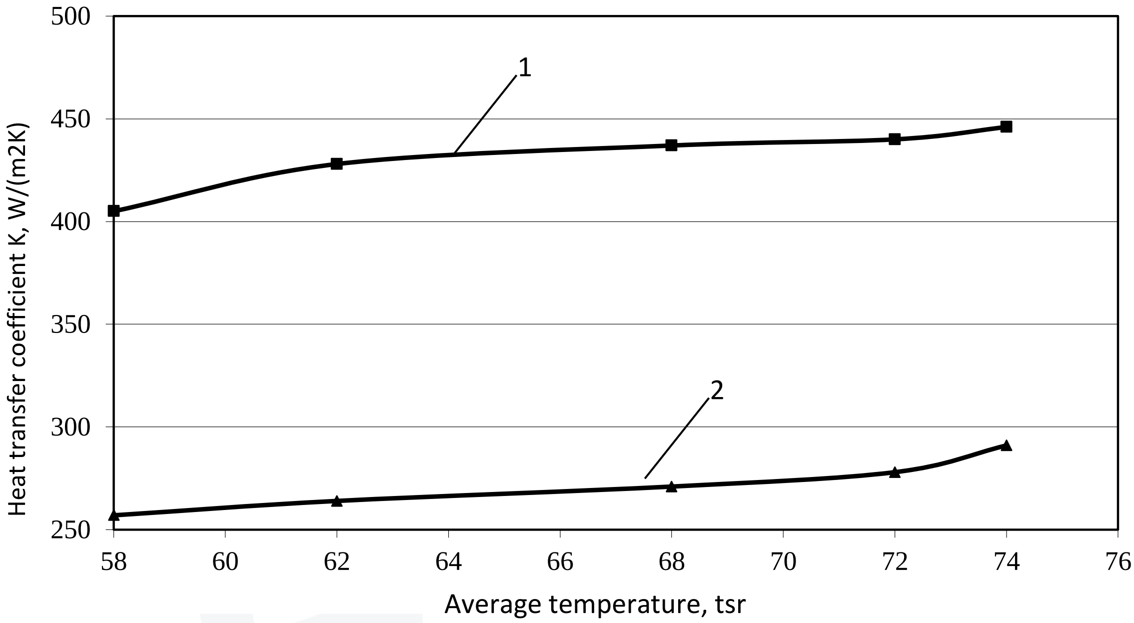
Table 2.
As can be seen from the data in Table 2, at the temperature conditions of condensation of gas condensate vapors of 158-172 ° C, the values of the heat transfer and heat transfer coefficients (W /(m2· K) in the experimental horizontal tubular condenser are in the range □1 = 7820-9687, □2 = 428-468 and K = 405-446.

Table 2 Results of calculations of heat transfer and heat transfer coefficients in an experimental horizontal tubular condenser

Gas condensate temperature, °C		Heat transfer coefficient □1, W/(m2·K)	Cooling water temperature, °C		Heat transfer coefficient □2, W/(m2·K)	Heat transfer coefficient in the apparatus K, W/(m2·K)
tn1	tk1		tn2	tk2		
158	17	7820	20	66	428	405
160	19	8931	20	63	450	428
165	15	9460	20	61	459	437
168	14	9519	20	56	462	440
172	14	9687	20	50	468	446

Comparison of the data in Table. 1 and 2 indicate that as the difference between the temperature of the heat carriers at the entrance to the apparatus and the exit from it increases, the values of the heat transfer coefficients in its inter-tube and tube spaces increase, respectively, and the values of the heat transfer coefficients in the apparatus increase.

The figure shows the curves of the dependence of the heat transfer coefficient K on the average temperature of the tcp heat carriers during condensation of gas condensate vapors in horizontal and vertical tubular apparatuses, constructed according to the data of the above tables. 1 and 2.



The dependence of the heat transfer coefficient K on the average temperature of the heat carriers tp during condensation of gas condensate vapors in tubular condensers of horizontal (1) and vertical (2) design

As can be seen from the figure, the curves of the dependence of the change in the heat transfer coefficient K on the value of the average temperature of the heat carriers tp in the horizontal (curve 1) and vertical (curve 2) condensers are characterized by a smooth and gradual increase. It is obvious that with an increase in temperature tp from 58 to 74 ° C, the values of the heat transfer coefficient in a horizontal condenser increase by 41 W /(m2· K), and in a vertically located condenser - by 34 W /(m2· K).

Thus, a comparison of the results of determining the values of the heat transfer coefficient in experimental devices shows that the efficiency of heat exchange during condensation of hydrocarbon vapors in horizontal shell-and-tube condensers is on average 1.5 times higher than in vertical condensers of a similar design. Therefore, the use of horizontal shell-and-tube heat exchangers for condensation of vapor fractions

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of hydrocarbon raw materials is appropriate in the aspect of efficient use of thermal energy at oil refineries.

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