Method for improving the liquid hydrocarbon preparation efficiency

A M Kulikov, A A Gladenko and M A Alexandrov
Tyumen Industrial University, 38, Volodarskiy str., Tyumen, 625000, Russia
E-mail: kulikovam@tuui.ru

Abstract. According to the “Energy Strategy of Russia for the Period until 2030” and Decree of the Government of the Russian Federation of November 13, 2009 No. 1715-r, oil and gas companies have to use machines and equipment in the production process, as well as methods and processes that minimize energy consumption, and eliminate negative impacts of technological processes on the environment. New methods for the design, construction and operation of oil and gas facilities and improvement of the existing equipment should be developed and implemented.

1. Introduction
The production of gas condensate - a valuable chemical raw material used to produce high-quality types of motor fuels, plastics, synthetic rubbers, fibers and resins - occupies a special place in the activities of oil and gas companies. High rates of natural gas production increase the volume of gas condensate extraction. At the same time, gradual depletion of Cenomanian gas deposits creates the need to develop gas condensate deposits.

According to the Federal State Statistics Service, in 2007-2018, the volume of production of unstable gas condensate increased by more than 90%. In Western Siberia, there are more than half of the Russian gas condensate reserves.

![Figure 1. The dynamics of gas condensate production in the last decade, million tons](image)

In 2018, the Yamalo-Nenets Autonomous District produced 11.427 million tons, which is 10% more than in 2017. This raw material is extracted by 17 enterprises in 24 fields. The leading positions are occupied by subsidiaries of Gazprom (7.424 million tons, or 65% of all condensate produced in the...
district). NOVATEK OJSC ranks second (2.811 million tons, or 24.6%), Rospan International CJSC (678.903 thousand tons, 5.9%) and Rosneft OJSC (256.439 thousand tons, 2.2%) rank third and fourth, respectively. In 2012, 12.3 million tons gas condensate were produced in the region. The growth of this indicator is associated with the development of the South Tambey gas condensate field and construction of a gas liquefaction plant.

2. Research

During field development and separation, unstable gas condensate is released from the gas mixture [2,5]. To deliver it, it is stabilized by distillation or kept at an atmospheric pressure and high temperatures to remove volatile fractions and obtain stable condensate.

The processes of preparing liquid hydrocarbons for transportation have been studied thoroughly. A number of technological units designed to prepare raw materials with a wide variety of physicochemical properties were developed. In preparing oil and gas condensate for long-distance transportation, it is necessary to isolate the dissolved gases, dehydrate and desalinate, and remove mechanical impurities, i.e., to provide the requirements for salable oil and gas condensate.

Condensate degassing is carried out at head facilities and compressor stations of the main gas pipelines. Condensation is usually degassed in several stages. The use of one-stage degassing of condensate, when the latter is sent directly to the atmospheric tank, is associated with maximum gas losses and significantly reduces the yield of commodity condensate.

Single-stage degassing is mainly used at compressor stations of gas pipelines. The two-stage degassing method is used: the condensate flows sequentially to the degassing ladder and the reservoir, reduces the loss of degassing gas and increases the condensate yield by 10-15%. An increase in the number of degassing stages over four slightly reduces the output of low-pressure gases and does not increase the yield of condensate. An increase in the number of steps increases capital investment and complicates the task of utilizing degassing gases [1].

As a result, it is necessary to develop more efficient degassing methods. Some researchers showed that the solution to this problem can be associated with the use of a vortex flow [3,4]. The swirling motion of a gas-saturated liquid forms a field of centrifugal forces, where components with different densities are separated from each other. In addition, intense mass transfer of liquid volumes with different gas saturation occurs, which inevitably leads to the formation of a gas-liquid interface with a turbulent structure, in which the gas evolution process significantly increases. Thus, ceteris paribus, the presence of a vortex should significantly accelerate degassing and increase the efficiency of the process.

The purpose of the work is to increase the efficiency of methods of preparing and separating multiphase multicomponent hydrocarbon systems by intensifying gas evolution processes.

The main objectives of the research are as follows:

1. To identify the problems of methods for condensate degassing and solving them in order to reduce or completely eliminate gas losses of degassing and environmental protection;
2. To select optimization criteria for the degassing of multiphase hydrocarbon systems;
3. To choose the optimal method for increasing the intensity of gas evolution processes and reducing the cost of commercial gas;
4. To substantiate the choice of dependences of the hydro-gas-dynamic and structural characteristics by experimental studies of the outflow of heterogeneous gas-saturated liquids in vortex chambers;
5. To develop a physical and mathematical model for the degassing of unstable condensate in vortex chambers, as well as to test the model in full-scale operating conditions.

The novelty of the research:

1. A system of criteria has been developed to optimize the degassing of multiphase hydrocarbon systems to select the most suitable method with technological and economic parameters;
2. Analytical and empirical dependencies of the main hydro-gas-dynamic parameters and geometric characteristics of the vortex chambers as condensate degassers have been established and justified;
3. A physical and mathematical model for the degassing of unstable condensate in vortex chambers has been developed. It is used to calculate parameters of separation devices depending on operating conditions.
The obtained analytical dependencies allow the calculation of parameters of the degassing stages when installing vortex chambers.

The process of degassing a saturated liquid in a vortex chamber was studied in the experimental unit. The diagram is shown in Figure 2.

**Figure 2.** The experimental unit for studying the process of degassing a liquid in the vortex chamber.

The mixing tank 1 is designed for an operating pressure of 5 MPa and has a volume of about 60 liters. A sufficiently large volume of the mixing tank allowed us to obtain 6–10 experimental points in the experiments on the outflow of saturated and undersaturated liquids from nozzles using a single charge.

The container was fixed in a special stand, allowing it to rotate around the transverse axis in order to mix the liquid during sample preparation. The need for intensive mixing of liquid and gas is caused by the fact that gas dissolution by the method of barbation, which is most often used in laboratory plants, requires a more complicated installation scheme. To circulate through tank 1, it is necessary to install either a compressor or some other way to loop the gas supply line to tank 1. The method of dissolving gas in liquid by mixing the sample makes it possible to simplify the installation scheme, because the dissolution process is much faster. The time for preparing a saturated liquid sample at a given pressure during which the container rotates around the transverse axis was determined during the experiments and was evaluated by stopping the dissolution of carbon dioxide in water. The maximum equilibrium dissolution of carbon dioxide in water is achieved after 15 minutes. In all the experiments, the rotation time of the container during sample preparation was 20 min.

The process of degassing a saturated liquid in the vortex chamber is associated with kinetics and geometrical characteristics of the chamber and mass speed of the fluid entering the chamber through the nozzle. To select the main geometric characteristics of the vortex chamber, the results of [3] were analyzed.
3. Results
The degree of liquid degassing which characterizes the completeness of this process is the main criterion for the efficiency of the vortex chamber. The degree of degassing $\varepsilon$ is the ratio of the equilibrium gas saturation of the liquid at $p$ and $t$ in the vortex chamber to its actual gas saturation in the lower part of the chamber:

$$
\varepsilon = \frac{q_{\text{in}}}{q_k}
$$

(1)

From equation (1), an expression for calculating the coefficient $n$ (the coefficient of intensity of gas evolution) can be obtained, since intensity of the degassing process depends on its value.

$$
n = \frac{1}{\tau} \ln \left( \frac{q_{\text{in}}/q_k - 1}{1 - \varepsilon} + 1 \right)
$$

(2)

where $q_{\text{in}}$ - initial gas saturation, m$^3$/m$^3$;
$q_k$ - final gas saturation, m$^3$/m$^3$

When calculating $n$ in the vortex chamber or other degasser, time $\tau$ is understood as the residence time of the liquid in the working cavity of the degasser.

The expression for determining the total amount of gas released is as follows:

$$
Q = v(q_{\text{in}} - q_p)(e^{n\tau} - 1)
$$

(3)

The total height of the chamber consists of three components: heights of rotating gas and liquid phases and liquid column in the bunker space. Only a column of the rotating liquid phase is actively involved in the degassing process. The column of liquid located below in the bunker space does not participate in the degassing process. Therefore, the main geometric characteristic of the vortex chamber is the ratio of the diameter of the chamber to the height of the working space $D/h_f$. The optimal value is in the range of 0.9 ... 1.1

$$
n = u_m \left[ a_1 (D/h_f) + b_1 D/h_f + c_1 \right]
$$

(5)

The constants in equation (5) are determined empirically from the experimental data. Numerical values of the given constants: $t = 2.9$; $A_1 = -0.242 \times 10^{-3}$; $b_1 = 0.455 \times 10^{-3}$; $c_1 = -0.129 \times 10^{-3}$. The error does not exceed 7%.

The equation for the expiration of gas-saturated liquid (mass velocity):

$$
u = \left[ (1 - 0.8 k) e^{-(0.06 \Delta q^{1/10} + 0.8k)} \right] \mu 2 \rho \frac{\sqrt{p_1 - p_2}}{l/d}
$$

(6)

where $k = (k / k_0)0.2$ — function of the ratio of the solubility coefficient of gas in the liquid to the solubility coefficient of carbon dioxide in water;
$\Delta q = q/q_p$ — degree of saturation of liquid with gas;
$l/d$ — the ratio of the length of the cylindrical nozzle to its inner diameter;

Figure 3. The solubility of carbon dioxide in a liquid: 1 - carbon dioxide in water; 2 - carbon dioxide in diesel fuel; 3 - natural gas in condensate
Figure 4. The dependence of degassing degree $\varepsilon$ on mass speed of the outflow of raw materials through the nozzle at $D/h_f = 0.5 \ldots 1.0$

The best degassing value is achieved at mass flow rates of less than $14.0 \times 10^3$ kg / (m$^2$ s).

The experimental studies of the vortex effect in gas-saturated liquids revealed possibilities for using vortex chambers for degassing oil and gas condensate and primary processing of hydrocarbon feedstocks. To identify all the possibilities of the vortex effect in liquids, much more effort is required.

Thus, the analysis allows us to identify the following advantages of the vortex chamber compared to other separation equipment:

1) simplicity of design, manufacture, installation and maintenance;
2) the absence of moving parts and mechanisms, the use of flow energy;
3) high unit power (productivity of one unit);
4) the ability to optimize the process of equipment operation under various operating conditions;
5) more complete use of the inner cavity of the vortex chamber and intensification of the degassing process (reducing the residence time for the gas-saturated liquid in the vortex chamber compared to other separators);
6) environmental friendliness, efficiency and manufacturability of equipment, making it possible to utilize gas-saturated mixtures, while eliminating the loss of light fractions of hydrocarbons, as well as the possibility of separation of light fractions by components by applying the step-by-step degassing method;
7) smaller dimensions for locating this equipment on offshore platforms and bulk sites in wetlands of Western Siberia;
8) lower metal consumption (mass of the vortex unit, comparable in its technological parameters with separators like NGS is 10 ... 13 times less).

As a result of the experimental study of the degassing of a saturated liquid in the vortex chamber, the influence of various factors on the efficiency of this process was specified.

4. Conclusion
1. The analysis of structural and operational characteristics of the vortex chambers confirmed their advantages over vertical and horizontal separators, as well as hydrocyclones.
2. An algorithm for calculating basic geometric, technological and technical and economic parameters of the vortex chambers was developed as condensate degassers depending on operating conditions.
3. As a result of the theoretical testing of the design calculation algorithm, the relative error in measuring the flow rate of saturated liquid, gas saturation and mass flow rate was determined, confirming the possibility of practical application of the algorithm.

References
[1] Trivus N A and Seidali-zade B M 1974 Optimum modes of condensate degassing step and its effectiveness, B Sat. : Development and exploitation of gas and gas condensate fields VNIIEGazprom 6 17-22
[2] Dudin S M, Zemenkova M Yu and Shabarov A B 2005 Modeling of hydrodynamic processes in the pipeline transportation of hydrocarbons Interstroimekh –2005: Proceedings of the International Scientific and Technical Conference 1 79-82

[3] Sinai E G, Lapin E A and Zaitsev Yu V 2002 Separation of multiphase multicomponent systems (Moscow: Nedra)

[4] Bakhmat G V 1981 Use a vortex effect for degassing of crude condensate Oil and Gas Problems Tyumen 49 15-18

[5] Zemenkov Yu D, Markova L M, Prokhorov A D and Dudin S M 2009 Collection and preparation of oil and gas (Moscow: Academy)

[6] Kulikov A M, Petryakov V A and Seroshtanov I V 2015 Optimization of separation processes of multicomponent multiphase systems Business magazine Neftegaz.RU 11-12 36-40

[7] Kulikov A M and Komarova E A 2010 To the question of preparation of unstable gas condensate Problems of functioning of transport, International scientific-practical conference pp 188-189

[8] Smulsky I I 1992 Aerodynamics and processes in the vortex kamerah (Novosibirsk: Nauka)

[9] Suhovich E P 1987 Turbulence models for describing the anisotropy of turbulent transport in swirling flows. Methods of vortex flows with heterogeneous chemical. responds. sredoy (Moscow: Nauka)

[10] Dudin S M, Zemenkov Yu D, Maier A V and Shabarov A B 2016 Research and Design of Thermophysical Gas-Liquid Mixture Parameters in Product Pipelines IOP Conference Series: Materials Science and Engineering DOI: 10.1088/1757-899X/154/1/012021