EPJ Web of Conferences **318**, 03006 (2025) https://doi.org/10.1051/epjconf/202531803006
AAPM-III 2025

Study of dynamic analysis of separation devices in gas drying

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Abstract. The article considers the main types of separation equipment used at gas production and gas transportation enterprises. The most common types of separators are given. A new combined design of a gravitational cyclone separator with mesh elements has been developed. A description of the internal structure of the developed separator is given. The characteristics of the initial gas and the gas after separation are given. The effect of gas velocity on the process of separation efficiency is shown. A new direction in the field of gas separation is proposed - the implementation of gas separation in the pipelines themselves. The table shows the results of calculations to determine the rate of gas separation in vertical and horizontal pipelines. The main feature of the principle of operation of the proposed pipe separators, in contrast to the existing gravitational separators operating on the principle of jet breaking, is, on the contrary, in the continuity of the jet of gas and liquid phase.

1 Introduction

The separation process during field preparation and factory processing of gas predetermines the future unreliable operation of the gas transmission system to ensure the required quality supplied to the consumer. Our long-term studies have shown that the process of gas separation is based not only on thermodynamic laws, but even more important role in it is played by gas-dynamic factors.

At present, the thermodynamic foundations of the gas separation process have been sufficiently studied. As a result of experimental work, diagrams of phase transitions of hydrocarbon mixtures of various compositions were constructed, the equilibrium constants of individual hydrocarbons and their mixtures were determined, the limits of retrograde regions during phase transformations of hydrocarbon mixtures were established, which made it possible to establish optimal thermodynamic conditions for an effective gas separation process at various stages of development of gas condensate fields. On the basis of these thermodynamic experimental studies, a method has been developed for calculating the gas separation process using hydrocarbon equilibrium constants. These works refer only to the thermodynamic fundamentals of the gas separation process. At the same time, the movements of gas-liquid flows in the inlet pipelines and in the separation plants themselves are not taken into account.

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2 Materials and methods

As is known, thermodynamic studies of the gas separation process were carried out in the static state of hydrocarbon mixtures without taking into account the speed of their flows. In pVT devices, experimental studies on phase transformations are carried out in a complete equilibrium state of hydrocarbon systems. However, in separation plants, due to the movements of gas-liquid flows, this equilibrium is disturbed, and the gas separation process is carried out in a non-equilibrium state of the flow. Moreover, the higher the flow rate during the gas separation process, the greater the deviation of this process from the equilibrium state.

A detailed analysis of the movement of a gas-liquid flow [1-4] in the configuration of the inlet pipelines of separation plants (Figure 1), as well as in these plants themselves, carried out by us, showed the following gas-dynamic situation in them.

1. In the general case, when a gas-liquid flow moves through pipelines, depending on the speed and phase ratio in this flow, numerous (more than forty) structural forms of a gas-liquid mixture are formed. In the gas dynamics of a two-phase flow, these forms are grouped up to seven, and the speed and ratio of expressed respectively through dimensionless numbers:

$$F_r = w^2 / gD$$

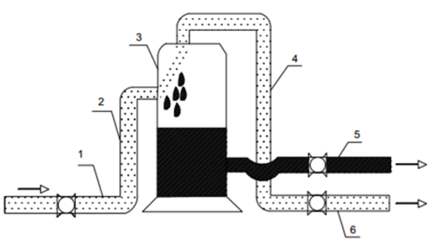
and the gas content ratio of the flow

$$\beta = Qg / \left(Qg + Ql\right),$$

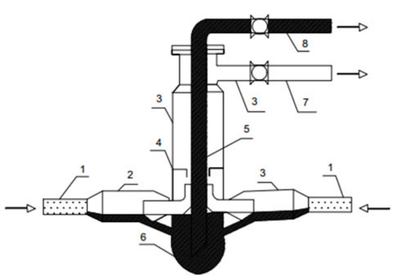
where w is the flow rate; D is the diameter of the gas pipeline; g is the free fall acceleration; Qg, Ql are the flow rates of the gas and liquid phases in the flow.

2. Inlet pipelines of separation units have a complex Z-shaped (elbowed) configuration (Figure 1(a)). In such a configuration of pipelines, a mainly structural form is usually formed, called "gas flow with liquid plugs".

3. The flow of the gas-liquid mixture into the separation plants at high speed through the inlet pipelines in a plug (liquid) structural form is accompanied by crushing and splitting of the liquid plugs, which leads to a significant entrainment of the liquid phase with the separated gas flow.



a)



b)

Fig. 1. Existing separation plant (a) and horizontal and vertical separation pipes (b): a: 1 - inlet, 2 - riser, 3 - separator, 4 - outlet, 5, 6 - liquid and gas lines; b: 1 - inlet, 2, 3 - pipe separators, 4 - liquid reflector, 5 - siphon, 6 - liquid tank, 7, 8 - gas and liquid outlets.

4. It is known that when developing gas condensate fields with constant gas extraction in the depletion mode (without reservoir pressure maintenance) with a drop in wellhead pressure in the inlet pipelines of separation units, the actual velocity $(w_{tr})_f$ of gas-liquid flows increases against its design value

$$\left(w_{tr}\right)_{pr}, \textit{i.e.}\ \left(w_{tr}\right)_f > \left(w_{tr}\right)_{pr} = 10-15m/s.$$

At such high input speeds of the separated gas inside the separation plants, a very complex gas-dynamic situation different from that provided by the existing technique on the calculation and design of separation plants based on the "particle settling model" of Stokes.

5. The high-speed flow of the gas-liquid mixture, entering the separation plants, almost retains its former high speed due to the forces of inertia and behaves like a transit flow, taking with it a significant amount of the crushed liquid phase.

6. In the currently existing methodology for calculating and designing gravity installations, the gas separation rate in the separation zone is taken w_{sep} = 0.1±0.2m/s separation time τ = 50s. These values are accepted in the existing technique for the separation (degassing) of an oil and gas flow according to the Stokes law. The use of this technique for separating gas-liquid flows with a high gas factor and for designing gas separators is illegal.

7. According to this technique, the diameter of the gravity separator is determined from the proportion rationality

$$w_{tr}\ \acute{\text{r}}\quad w_{sep} = D^2{}_{sep}\ \acute{\text{r}}\quad D^2{}_{tr},$$

where D^{2sep}, D^2_{tr}, are the diameters of the separator and the inlet pipeline. However, as mentioned above, when separating a gas condensate stream, regardless of the separator diameter, the velocity of this flow w_{tr} inside the separator is almost retains its value wtr≈const and does not decrease to w_{sep} = 0.1±0.2 m⁄s. In this case, the above inverse proportionality cannot hold.

8. The application of the existing technique for the process of crude oil degassing in natural gas separation and the use of the same type of equipment for these different processes has led to the fact that existing gravity separators operate with very low (50-80%) efficiency factors (COP).

9. It has been established that even with full maintenance of the optimal thermodynamic regime of the gas separation process in existing separation plants, due to the gas-dynamic factors of gas-liquid flows, the efficiency of these plants is sharply reduced.

Currently, in the gas supply system of the former regions of the USSR, centrifugal adjustable separators of the type TsRS-3, TsRS-5 and other designs of the Central Design Bureau of Petroleum Equipment (TsKBN) of Gazprom of the Russian Federation are used. These separation units consist of a vertical small centrifugal type separation zone with fixed and movable blades. The gap between these blades is regulated by a handwheel installed outside the separation zone. The rest of these installations is the capacity for the accumulation of the trapped liquid phase. This volume simultaneously performs the function of a separation vessel for separating water from gas condensate. The study of the operation of these installations and the revision of their internal separation zone, carried out by us, showed that under very aggressive and dynamic field conditions, these blades, designed to carry out the rotational movement of the initial flow, fail in a short period of operation, after which these installations (also like other high speed cyclone type separators) work more like a liquid plug sprayer than a separator to trap these liquid buildups.

At present, various modification works have been carried out at the Central Design Bureau for the Improvement of the efficiency of separation plants by filling their internal part with multicyclones, grids, plates, filters, cartridges and other separation elements. However, the experience of operation of various separation plants with similar elements in an aggressive environment in field practice shows their low efficiency and short-term use. It is known that gas-liquid flows also contain sand, various mechanical impurities, mineralized water with various salts. Under such polluted conditions, various elements installed inside the separators fail very quickly and do not give the expected effect of gas separation. It is very difficult to develop a generalized calculation method for these modernized separation plants.

3 Results and discussion

In engineering practice, the rule is known that when numerous improvements in a process or equipment do not lead to the required results, then it is necessary to search for radically new directions in this area. Following this, we have studied the possibility of gas separation in the pipelines themselves of various configurations. As mentioned above, when a gas-liquid flow moves in pipelines, depending on the velocity (or Fruhl number) and the coefficient β, numerous structural forms of flow movement are formed. Among them, there are forms in which the gas and liquid phases flow separately. In horizontal pipelines, the liquid phase flows along the bottom, and the gas phase flows at the top of the pipeline. Such a form in gas dynamics is called "separate-stratified". In vertical pipelines, the separate flow of phases is called "annular structural form" (2). In this case, the liquid phase moves along the walls, and the gas phase moves along the center of the pipelines. The formation of a separate-layered structural form in horizontal pipelines occurs under conditions of $Fr < 10$; $\beta > 0.95$. Based on the dependence $Fr = w^2/gD$, it is possible to determine the maximum values of separation velocities for each standard size of the pipeline that performs the function of a horizontal pipe separator [5-7].

In a vertical pipeline, the conditions for the formation of an annular structural form correspond to the criterion

$$J = w^2 \rho_r^{0.5} / \left[gD\left(\rho_j - \rho r\right) \right]^{0.5} = 9.$$

Using this formula, it is possible to establish the relationship between the separation speed and the diameter of vertical separators at various pressures of the gas-liquid flow

$$W = f / \left(D.\rho\right).$$

The separation velocity of a vertical pipeline is the velocity of the gas-liquid flow at which, in an annular structural form of motion, the liquid phase in the form of a film flows down the pipe walls - in the direction opposite to the ascending central gas flow. This reversible mode of liquid phase flow allows the separation of the gas-liquid flow in a vertical pipe separator.

The table shows the results of calculations to determine the rate of gas separation in vertical and horizontal pipelines [9-10]. The calculation for vertical pipe separators was made for a specific condition: density of the liquid phase $\rho_{zh} = 750$ kg/m^3; gas density $\rho_r = p/RT$; pressure $p = 2 \div 12$ MPa; gas constant $R = 8.314$ J (mol x K); temperature $T = 293$ K.

An analysis of the calculation results shows that, with an increase in the diameter of vertical and horizontal pipe separators, the value of the gas separation rate increases, i.e. their throughput increases. The same speed in vertical tube separators also increases at low pressures. Figure 1 (b) shows the scheme of joint operation of horizontal and vertical pipe separators.

Gas separation in these pipe separators is carried out as follows. Gas-liquid flows from different wells with different structural forms through separate plumes first enter horizontal pipe separators, where these flows acquire separate-stratified structural forms of flow. In this case, the liquid phase from each horizontal pipe separator continuously (inseparably) merges into a common pipe tank, and the gas flows separated in the horizontal pipe separators enter a common manifold installed as a vertical pipe separator. Here, the liquid phase, accidentally carried away from the horizontal pipe separators by the separated gas flow, forms an annular structural shape with a reverse mode.

The return downward film flow of liquid along the walls of the vertical collector (i.e. vertical pipe separator) merges into a common container for the accumulation of liquid and from there is discharged through a siphon tube to the liquid outlet line. The separated gas flow from the vertical pipe separator is fed into the main gas pipeline.

Table 1. Determining the efficiency of horizontal pipe separators.

W_{sep}, m/s								
P, MPa	**D, mm**							
	100	150	200	250	300	350	400	450
Vertical pipe separator								
2.0	2.52	2.79	3.0	3.17	3.32	3.45	3.56	3.67
3.0	2.27	2.51	2.70	2.85	3.0	3.10	3.21	3.31
4.0	2.11	2.34	2.52	2.66	2.78	2.89	2.99	3.08
5.0	1.99	2.23	2.36	2.50	2.61	2.72	2.81	2.89
6.0	1.89	2.10	2.25	2.38	2.50	2.59	2.68	2.76
7.0	1.82	2.00	2.17	2.29	2.40	2.79	2.58	2.66
8.0	1.75	1.99	2.08	2.20	2.31	2.40	2.48	2.65
9.0	1.70	1.88	2.02	2.14	2.24	2.32	2.40	2.47
10.0	1.65	1.83	1.96	2.08	2.17	2.26	2.39	2.49
11.0	1.61	1.78	1.91	2.02	2.11	2.19	2.27	2.34
12.0	1.57	1.74	1.87	1.97	2.06	2.15	2.22	2.29
Horizontal tube separator								
-	3.13	3.83	4.43	4.95	5.42	5.86	6.26	6.64

The experimental work carried out to determine the efficiency of horizontal pipe separators shows that at slightly lower actual flow rates than the calculated ($w_{av}<w_{sep}$) the gas separation efficiency increases even more (Table 1). In this case, the vertical pipe separator, after the horizontal ones, only performs the function of an "insurer" to catch the entrainment of the liquid phase in cases of a sharp increase in productivity or the flow rate of gas-liquid mixtures in well plumes.

The main feature of the principle of operation of the proposed pipe separators, in contrast to the existing gravitational separators operating on the principle of jet breaking, is, on the contrary, in the continuity of the jet of gas and liquid phases. Therefore, pipe separators can be called gas-dynamic separators.

Pipe separators can be manufactured in-house from pipe materials without factory orders. They are part of pipelines. The combination of gas separation and transportation processes makes it possible to simplify the technological schemes of field gas treatment. The specific metal content of pipe separators is ten times less than that of existing separators, and their throughput is much higher.

Of great importance is the use of pipe separators in offshore gas condensate fields. The implementation of the gas separation process along the way on sea loops and risers when collecting gas at low temperatures of deep sea waters frees the expensive working areas of offshore platforms and racks from cluttering up with existing separation plants and allows gas separation at lower temperatures on the seabed.

4 Conclusion

A gas-dynamic analysis of the gas separation process in existing separation plants was carried out and the reasons for their low efficiency were indicated.

Structural forms of gas-liquid flows in pipelines are considered and separate-stratified and annular structural forms of two-phase flows are identified, in which it is possible to carry out the process of in-line gas separation in horizontal and vertical pipelines.

A method for calculating pipe separators based on gas-dynamic criteria for the formation of separation modes in horizontal and vertical pipelines is given. The results of calculations to determine separation velocities in pipe separators for various pipe diameters are presented.

The low efficiency of existing separators, upgraded with various separation elements, is noted.

A scheme of joint operation of several horizontal and one vertical pipe separators is proposed and the principles of their operation are described.

The advantages of pipe separators in comparison with modern installations are indicated. The importance of using pipe separators in offshore gas condensate fields is shown.

We thank SOCAR management and the oil and gas administration, as well as the engineering and operational staff who, with their work and advice, made a significant contribution to our research. With their help, experiments were carried out and the results of our research were successfully applied.

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