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CHOOSING THE OPTIMUM DIAMETER AND DISTANCE OF PIPELINES FOR NATURAL GAS TRANSPORTATİON

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ABSTRACT

The accidents arising in the collection and transportation system, as a result of complications during transportation and storage of gas and gas condensate, caused by their physicochemical and rheological properties, lead to both loss of production and damage to the ecological state of the environment. As we know, the difficulties and obstacles that arise during the collection, preparation for transportation, and storage of hydrocarbons are related to their multicomponent and multiphase nature, as well as their structural structure, the elimination of which has been investigated. The complexity and complications arising from the collection, transportation and storage of hydrocarbons in many cases due to their complexity and multiphase, as well as their structural structure. Collection and transportation of multiphase well products at offshore fields requires the selection of a reasonable pipeline diameter. The collection distance of gas condensate mixtures cannot be increased indefinitely by increasing the pipeline diameter and has a maximum limit. Increasing the collection distance beyond this limit leads to filling the gas pipeline with liquid (condensate) and deterioration of the efficient operation of the gas pipeline. To determine the hydraulic resistance coefficient, known formulas were used for a single-phase hydraulic medium using the velocity and density of the mixture, as well as its viscosity. At the same time, the use of two dependences for laminar and turbulent flows for the calculation of the hydraulic resistance coefficient was considered sufficient. At the same time, empirical formulas are used to determine the diameter and length of pipelines.

KEYWORDS:
transportation;
pipeline;
gas-condensate;
systems; diameter;
hydraulic; liquid;
separation;
hydrodynamic;
separation.

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1. Introduction

The loss of precious raw materials as a result of the accident in the collection and transportation system, during the transportation and storage of hydrocarbons, caused by their physicochemical and rheological properties and as well as environmental protection are the actual problems. If the transportation of gas condensate through a pipeline is considered, then the pipeline is calculated mainly for the gas pipeline, since gas plays a decisive role. The problems of eliminating the consequences of accidents and damage to the environment and the relevance of restoring the normal functioning of the transport system are investigated. The liquid phase separated from the gas significantly affects the transportation distance depending on the pipeline diameter. Thus, the formation of the liquid phase not only limits the transportation distance, but after a certain limitation of the belt diameter, this distance not only does not remain constant, but can even decrease. Therefore, if gas is transported with the participation of the liquid phase - condensate, depending on the gas and condensate flow rate, the values of the initial and final pressures, the maximum gas transportation distance along the pipeline should be determined. The calculation of the gas pipeline diameter was carried out on the basis of the initial data, namely, the volumetric flow rate, density and viscosity of gas and condensate, the diameter of the gas pipeline, the characteristics of its route, the initial or final pressure.

In order to determine the structural forms of the movement and flow mode of the gas condensate mixture in a given belt diameter, the difference in the specific masses of the phases and the maximum value of the pressure gradient are found and compared. Nevertheless, it is necessary to take into account the factor of condensate separation from the gas phase. Depending on the condensation pressure and the temperature, the condensate may separate from the gas in the reservoir, at the bottom hole and at the wellhead and in the collection and transportation line. The distribution of gas in condensate phase, depending on how the liquid phase moves with the gas, will change the

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hydraulic characteristics of the pipeline. That is why it is possible to choose the best option for a gas-condensate mixture, that is, energy and resource-saving transport, depending on the flow characteristics in the form of emulsions and separate phases [1-11].

Correct determination of the structural form of the mixture movement is one of the main conditions for choosing a scheme and methods for calculating pipelines. For different values of the initial data, the change in pressure loss on the pipeline, distance of transportation or amount of transported gas depending on the diameter of the pipeline was studied.

2. Materials and methods

According to the hydraulic calculations of the gas pipeline during the transportation of gas-condensate mixtures the distance of transport the gas-condensate mixture, depending on the amount of gas and condensate consumption and the initial pressure, takes certain values. Therefore, when transporting gas-condensate mixtures through pipelines, it should be taken into account the mutual influence of phases and chosen the maximum transportation distance.

During transporting a gas-condensate mixture produced from gas-condensate fields, gas and condensate, which are two separate phases, can move on separate layers, as if moving one above the other. However, when condensate is separated from gas, the cross section of the pipe begins to shrink, which, in turn, leads to the occurrence of traffic jams and changes in the pressures of these flows. And these changes, increasing pressure in the pipeline, increase the likelihood of crashes. To prevent such crashes, the gas-condensate mixture has such an optimal transportation distance, when, due to the high probability of emergency situations at the end of this distance, there is a need for a second separation. In this case it is important to choose the optimal diameter for the transport line.

During calculating pipelines for the collection and transportation of heterogeneous systems in the form of gaseous mixtures, it is necessary to consider the separation factor on the second phase. So as for oil and gas systems, if the transport pressure is greater than the oil gas saturation pressure, then it is enough to accept the mixture as a homogeneous mixture and calculate the pipeline for one, that is, liquid phase.

If the transportation of a gas-condensate mixture through a pipeline is considered, then the calculation of the pipeline is carried out mainly for the gas pipeline, since gas plays a decisive role. However, it is necessary to take into account the state of separation of condensate from gas [12, 3-7]. Therefore, the hydraulic characteristics of the pipeline, depending on the type of distribution of condensate in the gas, as the main dispersion phase, or depending on the movement of condensate separated from the gas along with the gas, in the form of the second liquid phase, will differ significantly from each other. It is precisely depending on the type of emulsion or multilayer flow in the pipeline it is possible to choose the best option for collection and transportation, i.e. energy efficient and resource efficient transportation method of gas condensate on the fields. That is, the correct determination of the structural form of the mixture movement is one of the key conditions for choosing scheme and methods of calculation pipelines.

3. Results and discussion

Analysis of the calculation results shows that the following conditions can be accepted satisfactory for engineer-search calculations with the aim of choosing a method for calculating pipelines for gas and liquid mixtures:

- if the gas factor of the volumetric flow rate is $\beta>0.7$, the pipeline is calculated for the gas pipeline. In this case, the liquid phase is considered as a dispersion phase;
- if $\beta<0.5$, calculation of the pipeline is performed for the liquid.

In intermediate cases, when $0.5<\beta<0.7$, it is necessary to calculate the pipeline for both gas and liquid. In this case, should be accepted the result, in which the case of pressure losses along the pipeline route are low is justified.

Considering the above, the hydraulic calculation of the pipeline during transportation of the gas-condensate mixture must be performed in the following sequence:

- preparation of preliminary data; density and viscosity, volume flow rate of gas and condensate, length, diameter of the pipeline, features of the route and its initial or final pressure.
- calculation of gas volume flow based on volume flow of gas and condensate;

$$\beta=\frac{Q_g^t}{Q_g^t+Q_c} \tag{1}$$

Determination of the dispersion medium and the dispersed phase for the transported heterogeneous mixture based on the calculated value of the volumetric gas flow rate:

- if the piping diameter is unknown, it is necessary first select the diameter;
- based on the proposed or selected value of the diameter of the pipeline, it is necessary to determine the modes of movement and the structural forms of gas condensate flows.

For this purpose, the difference in their specific weights $g(\rho_c-\rho_g)$, taking into account the interaction

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of the gas and condensate phases, was compared with the maximum value of the pressure gradient $(dP/dr)_{\max}$. In this case, for $(dP/dr)_{\max}<g(\rho_c-\rho_g)$ values, when $(dP/dr)_{\max}>g(\rho_c-\rho_g)$, the arising of a layered motion of the shape of the emulsion flow was accepted.

The maximum value of the pressure gradient is determined based on the following known expression [13]:

$$(dP/dr)_{\max} = 6.158 \cdot \rho_{mix} \cdot \vartheta_{mix}^2 / D \tag{2}$$

The density of the gas condensate mixture is defined as follows:

$$\rho_{mix} = \beta \cdot \rho_g + (1-\beta)\rho_c \tag{3}$$

To determine the mixture flow rate ϑ_{mix} was used the following pipe hydraulics expression:

$$\vartheta_{mix} = \frac{4 \cdot Q_{mix}}{\pi \cdot D^2} \tag{4}$$

If the flow of gas condensate is layered, a phase shift will occur, i.e. the gas phase will move faster than the liquid phase. In this case, the diameter of the cross section in which the gas moves, the diameter of the core can be calculated as follows [14]:

$$D_c = \left[\frac{2.772 \cdot \vartheta_g^2 \cdot \rho_g \cdot D^4}{g(\rho_c - \rho_g)}\right]^{0.2} \tag{5}$$

Determination of the coefficient of hydraulic resistance λ_{mix} for gas-condensate mixtures.

For this purpose, for single-phase flows, for the laminar mode of motion (Re<2300), which is known from hydraulics of liquid, the Stokes formula (Re>2300) was used, and for the turbulent flow (Re<2300), the Blasius formula was used.

Designing underwater pipelines in offshore oil and gas fields requires a significant revision of some traditional design rules on the land. Such an approach should be primarily related to the degree of dehumidification of natural gas prior to transportation on offshore stationary grounds (OSG). Exploitation practice shows that the depth of gas drying is determined - not only by the temperature on the seabed along the pipeline route, but also by its initial pressure, length, diameter and flow rate, as well as the hydraulic losses occurring on the pipeline. The initial pressure of the pipeline is determined depending on the distance of the OSG from the shore and the pressure at the wellhead.

The practice of operating underwater pipelines in the Caspian basin confirms that when transporting oil, gas or gas-condensate mixtures through a one-pipe scheme located between the OSG, on shorter distances (up to 10 km) or on the coast (the several kilometers), the normal operation of the gas transmission system broke and is accompanied by various specific complications and pressure pulsations. During the movement of gas condensate systems, liquid accumulates in gas pipelines and the transport pressure rises. The slower the mixture, the greater the accumulation of fluid in the pipeline and the higher the transportation pressure. Therefore, the collection of multiphase products of wells requires the choice of an accurate and reasonable diameter of the pipeline [9-11, 15]. Thus, the adoption of a large diameter leads to additional consumption of metal and corrosion damage on the pipeline, while the choice of a smaller value, as is well known, limits the collection of production of the well and increases the pressure losses in the system.

The actual loads and hydraulic characteristics of the existing gas transmission system were considered at the example Umid gas condensate field that at a distance of 40 km from the coast of the Caspian Sea. The gas-condensate mixture of one well under the wellhead pressure is transported through an underwater gas pipeline, after a choke with a diameter of D=0.2 m, the flow rate of gas and condensate is 600 m^3/day, and 100 m^3/day respectively.

Based on the above database and given that the gas phase plays a dominant role, that is, it is an active dispersion medium (the gas content of the mixture does not exceed 0.7 and β=0.99), the pipeline calculated using known gas formulas (for a gas pipeline) [14].

$$P_b^2 - P_e^2 = 561.2 \cdot \frac{Q_g^2 \cdot \lambda \cdot L \cdot \rho_g \cdot T_{av} \cdot Z}{D^5} \tag{6}$$

where L and D – respectively the length and diameter of the pipeline, m; P_b and P_e – pressure at the beginning and end of the pipeline, Pa; Q_g – gas consumption in standard conditions, m^3/day; λ – hydraulic resistance coefficient; ρ_g - gas density under standard conditions, kg/m^3; T_{av} – average gas temperature, K; Z – gas compression ratio; the unit of measurement of the coefficient 561.2 is Pa/K.

Taking into account data P_b=6·10^5 Pa, P_e=2·10^5 Pa, T_{av}=283 K, Z=0.92, Δ~1.5 on formula (6) the gas collection distance was calculated dependence on gas flow and diametere of gas pipeline. The results of the calculations and the dependence of the gas collection distance on the diameter of the gas pipeline are shown respectively in table 1 and in figure 1.

As can be seen from figures 1 and 2, the gas collection distance for a single-phase gas pipeline increases with increasing pipe diameter, and with increasing flow rate, on the contrary, decreases. Hydraulic calculation of the investigated underwater gas condensate pipeline and, as indicated above, the calculated diameter of the pipeline were adjusted taking into account for the mutual influence of the phases, depending on the distribution of gas and condensate along the pipeline route.

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Table 1
The consumption of gas collection distance and the gas pipeline dependence on diameter

Flow of gas, Q_g, $\frac{\text{min.m}^3}{\text{day}}$	Collection distance, L, km			
	Diameter of pipeline, D, m			
	0.3	0.5	0.7	1.0
10	2.9	37.9	-	-
20	0.7	9.5	51.0	-
30	0.3	4.2	22.7	134.9
40	0.2	2.4	12.7	76.0
50	0.1	1.5	8.2	48.6
60	-	1.1	5.6	33.7
70	-	0.8	4.2	24.8
100	-	0.4	2.0	12.1

Table 2
Calculation formulas for determining the gas collection distance for different diameters

D, m	$L = 121452340 \dfrac{D^5}{Q_g^2}$
0.2	$L = 38864 / Q_g^2$
0.3	$L = 295129 / Q_g^2$
0.4	$L = 1238814 / Q_g^2$
0.5	$L = 3795385 / Q_g^2$
0.7	$L = 20412494 / Q_g^2$
1.0	$L = 121452340 / Q_g^2$
1.2	$L = 302173421 / Q_g^2$

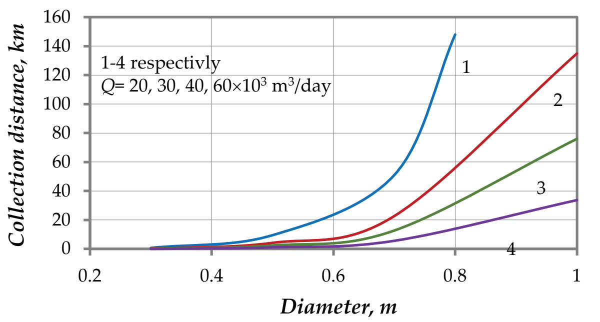

Fig. 1. The dependence of the collection distance on the diameter for a low-phase gas pipeline

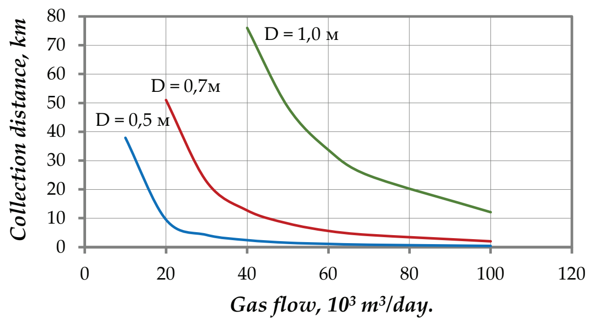

Fig. 2. The dependence of the collection distance from the gas flow at different diameters of pipelines

To determine the coefficient of hydraulic resistance were applied well-known formulas for hydraulic single-phase medium using the speed and density of the mixture, as well as its viscosity. In addition, in engineering calculations, it is considered sufficient to use two dependences of the hydraulic resistance coefficient for laminar and turbulent flows.

Each time after the choice of the initial diameter of the pipeline, based on a comparison of the densities of the condensate and the mixture (γ_{con}-γ_{mix}) at a maximum pressure gradient $(dP/dr)_{\max}$ were determined the gas-condensate regimes flow and the structural forms. However, the layered form exists, as a rule, under the condition $(dP/dr)_{\max} < \gamma_{con}$-$\gamma_{mix}$ in horizontal pipelines and pipelines with a small slope [3,14,16-18]. Previously, taking into account the change in the diameter of the pipeline according to (6), the following computational formulas were obtained for calculating the collection distance:

$$Q = A\sqrt{\frac{\left(P_b^2 - P_e^2\right)D^5}{ZT_{av}\,\lambda\, L\,\Delta}}; \quad A = 0.0385(m^2 c\sqrt{K})/kg \qquad (7)$$

$$L = \frac{A^2\left(P_b^2 - P_e^2\right)D^5}{ZT_{av\,\lambda\,\Delta}Q_g^2} = \frac{A^2(P_b^2 - P_e^2)}{ZT_{av}\Delta}\cdot\frac{D^5}{\lambda Q_g^2} = B\frac{D^5}{\lambda Q_g^2} \qquad (8)$$

$$B = \frac{A^2(P_b^2 - P_e^2)}{ZT_{av}\Delta} = \frac{0.0385^2\cdot(36-4)\cdot 10^{10}}{0.92\cdot 283\cdot 1.5} =$$
$$= 1214523.4,\ \text{m}^2/\text{s}^2$$

$$L = 1214523.4\frac{D^5}{\lambda Q_g^2},\ \text{m}$$

If we take λ=0.01, then

$$L = 121452340\frac{D^5}{Q_g^2},\ \text{m}$$

Source data for gas condensate mixtures:

- Gas consumption Q_g=104 m³/day=2.7777 m³/h
- Fluid flow rate 5 m³/day=0.0014 m³/h
- Gas density $\rho_g^{st} = 2$ kg/m³
- The density of the condensate $\rho_c^{st} = 800$ kg/m³

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- Gas pressure at the beginning of the pipeline P_b=6·10^5 Pa
- Gas pressure at the end of the pipeline P_e=2·10^5 Pa
- Gas compression ratio Z=0.92
- Gas viscosity μ_g=2·10^{-5} Pa·s
- Viscosity of condensate μ_c=0.05 Pa·s
- Average transportation temperature T_{av}=283 K

The pressure and temperature of the transportation conditions were taken in accordance with 2·10^5 Pa and 283 K, respectively.

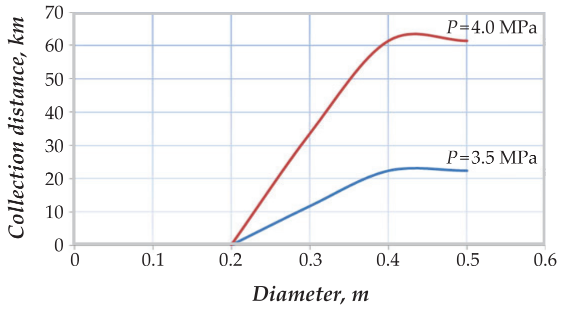

Fig. 3. Dependence $L=f(D)$ on different values of the initial pressure

The parameters in the conditions of transportation are calculated in the following order:

- gas density in transportation conditions

$$\rho_g^{tc} = \frac{\rho_g^{st}\ P_e\ T_{st}}{T_{av}\ Z\ P_{st}} = \frac{2\cdot 2\cdot 293}{283\cdot 0.92\cdot 1} = 4.5\ \text{kg/m}^3$$

- gas consumption in transportation conditions

$$Q_g^{tc} = \frac{Q_g\,T_{av}\,P_{st}}{P_e\,T_0} = \frac{2.7777\cdot 283\cdot 1}{2\cdot 273} = 1.44\ \text{m}^3/\text{s}$$

- flow of gas-liquid mixture

$$Q_{glm} = Q_g^{tc} + Q_c = 1.44\ +\ 0.0014\ =\ 1.4414\ \text{m}^3/\text{s}$$

The research results show that for the collection and transportation of single-phase production of wells requires the choice of a reasonable diameter of pipelines. The collection distance of gas-condensate mixtures cannot be infinitely increased with an increase in the diameter of the pipeline and has a maximum limit. Increasing the collection distance above this limit results in filling the pipeline with liquid and impairs the effective operation of the pipeline (fig. 3).

Conclusions

Thus, based on the analysis of the problems of hydrodynamic corrosion in low-phase gas pipelines, the following conclusions can be drawn:

1. Filtration of mechanical particles (fractions with a diameter greater than 1.0 mm), leading in most cases to corrosion, at the beginning of pipelines to prevent corrosion damage in local pipelines during the collection and transportation of natural gases contributes to a significant reduction in corrosion rate.
2. One of the ways to protect gas pipelines from destruction is the choice of such a hydrodynamic regime in which the gas velocity ensures the transportation of mechanical particles by the gas flow.

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