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ABSTRACT

of the dissertation for the degree of Doctor of Science

DEVELOPMENT OF THE BASIS OF CREATING MULTIPHASE TECHNOLOGIES IN THE PRODUCTION, GATHERING AND TRANSPORTATION OF OIL AND GAS

Specialty:	3354.01- Construction and operation of oil and gas pipelines, bases and storage facilities 2525.01 – Development and exploitation of oil and gas fields
Field of science:	Technical sciences
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Baku – 2025

The dissertation was performed at the Department of "Oil and Gas Transportation and Storage" of the Azerbaijan State Oil and Industry University.

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and the degree of development: The experience of operating offshore and onshore oil and gas fields shows that the large number of technical and technological issues and operational difficulties that occur during the extraction, accumulation, preparation and transportation of hydrocarbons, the difficulty of solving them, the excess energy costs, the consumption of human and material resources, accidents and negative impacts on the environment are mainly associated with the multiphase and multicomponent nature of well products. In these systems, gaseous oils with various rheophysical properties, as well as their mixtures, including watery, sandy, clayey, etc. in complex relief and thermobaric conditions, various technological processes are formed, often with unknown structure of flows. During the movement of multiphase and multicomponent mixtures (oil-gas, gas-condensate, oil-gas-water, gas-condensate-water, etc.), such processes as phase transformations (separation of gas from oil, "falling" of condensate from gas, formation and precipitation of the 3rd solid phase - hydrate and asphaltene- paraffin-resin (APR) compounds), as well as the formation of stable water-oil emulsions with anomalous rheophysical properties and various ballasted oil mixtures, occur precisely in the technological equipment and carrier pipelines of the "well-gathering" system.

Multiphase mixtures formed during the dilution and mixing of well products differ sharply and non-additively from the initial components, which have a very serious impact on the operation of the "well-collection" system.

Studying the effect of mixing factor and increasing water percentage on rheological and quality indicators of multiphase oils and refining rheological models for the extraction and transportation of these oils, as well as hydraulic characteristics, is required.

For a long time, at the beginning of offshore field development, associated oil gas losses were mainly explained by delays in the construction of gas collection networks, gas pipelines and gas processing facilities in the oil field economy. At the beginning of development, in the existing marine-climatic conditions, mainly joint oil and gas collection was carried out. Although the application of such a method allows us to fundamentally change the technology of in-field oil and gas collection, reduce hydrocarbon losses and costs for the construction and operation of the collection and transportation system, there have been and still are cases of increased pressure losses due to the multiphase nature of the flow during the transportation of well products to the central separation unit through water pipelines, the occurrence of harmful pressure pulsations, the formation of various sediments and blockages, and the inefficient use of reservoir energy. The solution of such problems, which are mainly related to the multiphase nature of the flow, taking into account the dynamics of field development and gas resources, is of great importance.

The abovementioned confirms that the creation and development of theoretical and experimental knowledge and scientific foundations for the creation and application of new multiphase technologies based on the study of specific properties and interaction of phases in multiphase flows and the identification of factors affecting them are considered to be the main urgent issues in order to solve problems such as improving the operational performance of hydrocarbon fields, efficient collection and transportation of well products, etc.

Based on the results of research conducted in recent years, it can be emphasized that it is now possible to solve many problems arising during the extraction, transportation, preparation and storage of hydrocarbons and significantly increase the efficiency of technological processes carried out in multiphase conditions based on multiphase technologies, which are formed taking into account the dynamics of various phase flows, hydraulic properties, and the interaction of liquid, gas and solid phases.

Object and subject of research. The object of the research is the processes of production, collection and transportation of hydrocarbons, and the subject is the development of multiphase technologies to increase their efficiency.

Purpose of the research: Increasing the efficiency of technological processes during the extraction, collection, preparation and transportation of oil and gas based on the creation of multiphase technologies.

Main Research Objectives:

1. Technological processes occurring in a multiphase state and their analysis;
2. Necessities and scientific and experimental foundations of the creation of multiphase technologies;
3. Study of the efficient collection of associated gases, taking into account the dynamics of field development;
4. Study of the processes of preparation and transportation of petroleum mixtures;
5. Research and improvement of efficient collection and transportation of multiphase gas-condensate mixtures from offshore fields;
6. Study of rheophysical properties and dehydration of partially degassed oil emulsions;
7. Hydraulic investigation of pipeline operation during the transportation of oil-gas-water mixtures;
8. Study of the technological condition of the multiphase gas pipeline during the transportation of condensable gases;
9. Study of erosion-corrosion processes during multiphase flows;
10. Study of ballast settling during the transportation of multiphase mixtures;
11. Assessment of oil spills in a pipeline with unpressurized flow;
12. Investigation of the Bernoulli force in multiphase pipelines;
13. Study of the effect of cooling rate on the rheological properties of oil emulsions;
14. Evaluation of phase shift and gravity losses in multiphase and rail pipelines;
15. Evaluation of dynamic loads in multiphase flows;

16. Study of the effect of mixing and dilution of oils on the freezing temperature;

17. Study of pressure distribution in multiphase pipelines;

18. Study of phase separation of multiphase systems;

19. Analysis of the formation of structural regimes in multiphase vertical flows;

20. Evaluation of phase shift in risers and risers;

21. Diagnostics of stationary characteristics for multiphase flows;

22. Study of the maintenance of the dispersed state of natural gas.

Research methods: The issues raised in the dissertation were solved theoretically and experimentally, using information technology-based processing of actual data during the extraction, collection and transportation of oil and gas, as well as operational difficulties and experimental test indicators occurring in technological processes, mathematical methods, standard laboratory equipment, computers and software tools.

Scientific Novelty of the Research:

1. The necessity and scientific and practical aspects of creating multiphase technologies in oil and gas production and hydrocarbon accumulation and transportation are substantiated, and the possibility of analyzing and increasing the efficiency of technological processes formed in a multiphase state is shown:

2. The basic principles of efficient utilization of multiphase, condensable associated petroleum gases have been developed in accordance with the dynamics of gas resources;

3. Methods for estimating dynamic loads and pressure losses in multiphase, relief pipelines have been developed;

4. A concept for the efficient collection and transportation of gas-condensate mixtures from offshore fields based on multiphase technologies has been developed;

5. The role of Bernoulli force and phase shift in the formation of structural regimes in vertical pipes and fountain (gas lift) risers was evaluated;

6. A method for diagnosing stationary characteristics for multiphase flows has been developed;

The main provisions to be defended:

1. Increasing the efficiency of technological processes in oil and gas production and hydrocarbon collection and transportation based on multiphase technologies;
2. Principles of efficient utilization of associated petroleum gases based on multiphase technologies, taking into account the dynamics of gas resources;
3. Concept of efficient collection and transportation of gas-condensate mixtures from offshore fields based on multiphase technologies;
4. Methods for assessing the formation of structural regimes and phase shifts in gas lift (fountain) risers, underwater pipelines and risers during the extraction and transportation of heterogeneous well products;
5. Methods for estimating dynamic loads and pressure losses in multiphase flows;
6. Methods for diagnosing and hydrodynamic regulation of stationary operating modes and operational difficulties for multiphase flows;

Theoretical and Practical Significance of the Research.

In this work, the creation of multiphase technologies, taking into account the new physical model of flow and the interaction of phases in accordance with the gradient-velocity theory, allows for the diagnosis of operational difficulties and increased efficiency of technological processes formed in multiphase conditions during oil and gas production and the accumulation and transportation of hydrocarbons.

It was possible to create an analytical methodology for hydraulic calculation of multiphase pipelines based on the interaction of phases in multiphase flows and the consideration of a new physical model of flow.

Simplification based on a single-phase model in hydraulic calculations for multiphase gas-liquid mixtures creates such a misconception that there are no problems with their transportation. However, in such cases, the gradual filling of the pipeline with liquid, a sharp decrease in the transportation distance, and even the need to stop transportation are inevitable.

The multiphase technologies proposed in this work will allow solving technological problems for the efficient collection and transportation of associated petroleum gases and gas-condensate mixtures, taking into account the dynamics of hydrocarbon field development and gas resources. These problems include ballast deposition in multiphase mining pipelines, hydrate formation, cracks and erosion-corrosion processes, pressure pulsations, and the formation and breakdown of emulsions.

The technologies and methods developed in the dissertation can be widely used by oil and gas-related project and research institutes and production enterprises engaged in the extraction and transportation of oil and gas, as well as in the educational process during the training of personnel in oil and gas-related specialties.

Approbation and application of the results of the work.

The main results of the dissertation were heard and discussed at the meetings and scientific seminars of the "Oil, Gas Transportation and Storage" and "Petroleum Engineering" departments of ASOIU, as well as presented at a number of national and international seminars and conferences:

1. Conference "Actual Problems of Offshore Oil and Gas Field Development" dedicated to the 100th anniversary of the birth of Israfil Guliyev, Baku, March 1, 2017;
2. “Achievements, problems and development prospects of the oil and gas industry” (Достижения, проблемы и перспективы развития нефтегазовой отрасли), Almetevsk, October 25-28, 2017;
3. International scientific and practical conference “Caspian oil and gas field-2017”. Baku, 2017;
4. “Modern problems of innovative technologies in oil and gas production and applied mathematics” dedicated to the 90th anniversary of Academician A.H. Mirzajanzadeh. International conference, Baku, December 13-14, 2018.

5. Scientific and practical conference "Status and prospects of exploitation of old fields" dedicated to the 5th anniversary of "KazNIPIMunaygaz", Aktau, May 16-17, 2019;

6. "10th International Conference on Theory and Application of Soft Computing, Computing with Words and Perceptions" International conference. Prague, August 27-28, 2019;

7. "14th International Conference on Theory and Application of Fuzzy Systems and Soft Computing - ICAFS-2020", International conference, 2020;

8. "International Conference on Actual Problems of Chemical Engineering, Dedicated to the 100th anniversary of ASOIU", Baku, December 24-25, 2020;

9. "11th World Conference "Intelligent System for Industrial Automation" (WCIS-2020), Tashkent, Uzbekistan, November 26-28, 2020;

10. Way science, (Integration of Education, Science and Business in Modern Environment: Winter Debates: abstracts of the 2nd International Scientific and Practical Internet Conference, – Dnipro, Ukraine, February 4-5, 2021;

11. "Рассохинские чтения" International conference, Ukhta, February 4-5, 2021.

12. Conference Proceedings "Energy Locomotives of the Turkish World" dedicated to the 100th anniversary of the National Leader Haydar Aliyev and establishment of the Republic of Turkey, Baku, October 25-26, 2023.

13. The 5th Eurasian Conference "Innovations in Minimization of Natural and Technological Risks" dedicated to the 100th anniversary of National Leader Heydar Aliyev, October 17-19, 2023.

The multiphase technologies proposed in the dissertation were applied in SOCAR's Gas Export Department and the "Umid-Babek" Operating Company and were approved by the relevant act and certificate.

Publication of work results.

The main results of the dissertation were published in 60 scientific works, including 50 articles (13 of which are conference materials), 2 monographs, 1 textbook, 5 teaching aids, 1 invention patent, and 1 methodological guide. Research work on multiphase technologies was carried out with the financial support of the ASOIU "University grant".

Structure and volume of the Dissertation.

The dissertation consists of an introduction, 7 chapters, conclusions, a list of references cited in 208 titles. The work totally includes 287 pages, 370782 symbols (including title page 464, table of contents 8025, Introduction 16761, Chapter I- 46465, Chapter II- 62386, Chapter III- 39772, Chapter IV- 55395, Chapter V- 51634, Chapter VI-707719, Chapter VII-11763, Conclusions-7681), 95 figures and graphs, 27 tables and appendices.

Acknowledgment: The applicant expresses her deep gratitude to Doctors of Technical Sciences, Professors G.G.Ismayilov and E.K.Iskandarov for their advice, recommendations, and attention in the formation of scientific directions and the discussion and systematization of the results obtained during the process of completing the dissertation work.

The applicant also expresses her gratitude to the employees of the "Oil, Gas Transportation and Storage" and "Petroleum Engineering" departments of the Azerbaijan State Oil and Industry University, where the dissertation was completed, for their technical and moral support.

CONTENT OF THE WORK

In the introduction part of dissertation the relevance of the work is justified, the purpose and main issues solved are given, the scientific novelty, practical significance, main provisions defended are noted, and the content of the work is briefly explained.

The first chapter of the dissertation work is devoted to the scientific and experimental foundations of the creation of multiphase technologies in the extraction and transportation of oil and gas. A brief analysis of the characteristics and calculations of technological processes formed in a multiphase manner in oil and gas extraction was carried out, and the rheological description and flow characteristics of multiphase systems were explained.

There are a large number of theoretical and experimental scientific research works devoted to the filtration and movement of multiphase and multicomponent heterogeneous systems in reservoir conditions and pipes in oil and gas production and hydrocarbon transportation processes. Among the prominent scientists of Azerbaijan who have made significant contributions to the development and improvement of theoretical and experimental works devoted to multiphase systems are academicians A.K. Mirzajanzadeh, M.T. Abbasov, G.N. Jalilov, corresponding members of ANAS E.E. Ramazanova, A.M. Guliyev, N.C. Tahirov, Z.Y. Abbasov, R.S. Gurbanov, G.I. Jalalov, G.I. Kalbaliev, B.A. Suleymanov, T.Sh. Salavatov, G.M. Panahov, professors R.M. Sattarov, A.M. Mammadzadeh, G.G. Ismayilov, F.H. Valiyev, F.B. Naghiyev, S.R. Rasulov, H.F.Miralamov, A.A. Suleymanov, V.M., E.K.Iskandarov, Fataliyev, N.M. Safarov, etc. Among the foreign scientists who have made special contributions in this field, Z.S.Aliyev, R.S.Andriasov, A.A.Armand, V.A.Arkhangelsky, K.S.Basniyev, J.Q.Belov, K.B.Vinagradov, A.I.Guzhov, V.Q.Gron, O.V.Klapchuk, A.P.Krylov, Q.S.Lutoshkin, V.A.Mamayev, I.T.Mishenko, M.A.Mokhov, I.M.Muravyov, G.E.Odishariya, N.N.Repin, V.A.Sakharov, P.I.Tugunov, R.A.Brot, S.E.Kutukov, N.M.Baykov, A.I.Grichenko, M.V.Lurye, A.M.Shammazov, A.X.Shakhverdiyev, M.M.Xhasanov, P.M.Bakhtizin, V.T.Sitenkov, D.Chisholm, etc. In solving the problems of filtration of heterogeneous systems in oil reservoirs and hydrodynamic problems related to pipeline hydraulics, the invaluable services of academician A.K.Mirzajanzadeh and representatives of the scientific school he created were provided. Scientists and researchers who have contributed to the development and improvement of theoretical and experimental work on risers for the extraction of heterogeneous well products have proposed various methods and technologies to regulate the flow structure and movement modes and generally increase the efficiency of gas-liquid risers, each of which has certain advantages and disadvantages.

This chapter explains the phenomenon of multiphase transport, shows the importance of a new physical model of flow and the interaction between phases. The possibility of creating an analytical methodology for calculating multiphase pipelines and fountain (gas lift) risers based on the new physical model of flow is shown.

Recent studies[1] show that the existing physical model of flow (constancy of static pressure) implies an uneven distribution of energy potential in the cross section. Thus, the existence of energy transfer in the direction away from the flow axis (to the pipe wall) has not been observed. The currently newly created active boundary layer model1 is based on the fact that the flow is not static along the cross section, but on the stability of the total pressure, and the change of static pressure depending on the flow velocity. It is no coincidence that since the theory of not only multiphase, but even single-phase flows itself was developed by empirical methods based on experimental data, the accuracy of the calculations performed does not meet the requirements of engineering practice, and in some cases the results are significantly different. Therefore, taking into account the new flow model, adapting hydraulic calculations and schemes to

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[1] Sitenkov, V.T. Theory of a gradient velocity field./ V.T. Sitenkov. Moscow: - VNIIOENQ, - 2004. - p.308.

the new model is very important for increasing the efficiency of oil and gas production and transportation processes.

The abovementioned requires proper investigation and consideration of velocity-gradient fields based on new approaches for both mono- and multiphase flows with different rheological properties in different motion regimes. The practice (Figure 1.) that asserts that the static pressure in the flow cross-section is constant and is common in hydraulics courses has already been proven to be incorrect.

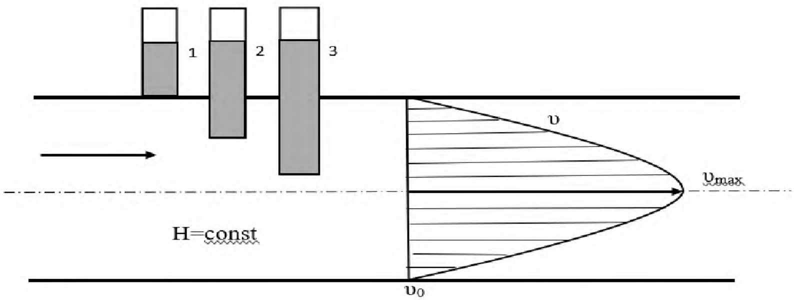

Figure 1. Measurement of pressure with piezometers in cylindrical flow

As can be seen from Figure 1, the height of the liquid column in all three stationary glass tubes (piezometers) is the same. That is, the pressures measured by the glass tubes are the same, even though they have different cross-sections. In hydraulics textbooks, this is interpreted as the static pressure in the flow being independent of its local velocity and the static pressure gradient being dP/dr=0.

Studies (including the author's results)[23] have shown that the prevailing idea that the cross-sectional area of the flow does not obey

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[2] Ismayilov, QQ Transmission phenomenon. Textbook. / QQ Ismayilov, EX Iskenderov, FB Ismayilova – Baku: Azerbaijan State Oil and Industry University, - 2021, - 212 p.

[3]Ismayilov GQ, Ismayilova FB, Zeynalova GA, Gulubayli AP. Interaction of phases in multiphase gas pipelines and technological difficulties. // KhazarNeftGasYataq-2022 International Scientific and Practical Conference, - Baku: -6-7 December, - 2022, - pp. 27-34.

the Bernoulli equation is incorrect. The currently used physical model of the flow of viscous fluids in a pipe does not correspond to the true shape of the flow, which has become a very serious obstacle to the implementation of analytical calculation methods .

From this perspective, the gradient-velocity theory developed by Professor V.T.Sitenkov is more interesting[1]. Thus, the possibility of constructing simple mathematical models that allow solving engineering problems without making large errors based on the proposed theory and applying them to analyze and increase the efficiency of multiphase technological processes in oil and gas production has been shown in this dissertation work.

According to the gradient-velocity field theory, the physical model of a real fluid can be described as shown in Figure 2.

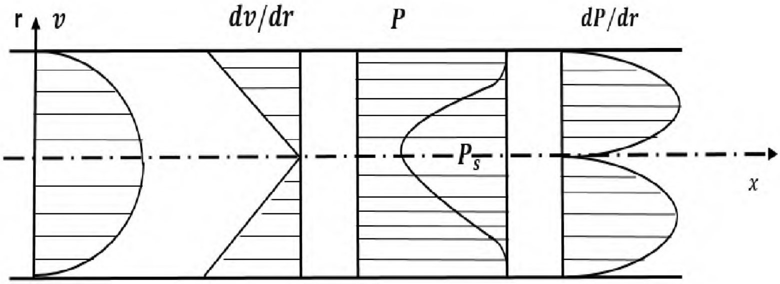


Figure 2. New physical model of flow

As can be seen from Figure 2, according to the new physical model, the static pressure (P) in the flow is not constant, but a variable quantity. The total pressure (P+Ps), which is the sum of the static and velocity pressures, remains unchanged along the flow cross-section and creates a constant energy potential. This distribution of the energy potential corresponds to the stability condition of the parameters of the working fluid. Because in this case, no energy transfer occurs along the flow cross-section. One of the main characteristics of this model is that it reflects the distribution of the static pressure gradient along the cross-section:

$$dP/dr = -\ 8\rho_m u^2 \alpha\,(1-\alpha^2)/R \qquad (1)$$

Here, u-average flow velocity in the pipeline, m/s; R-radius of the pipe, m; ρ_m -density of the dispersed medium, kg/m^3; α-relative coordinate of the studied point (α=r / R).

The main problems that arise when calculating pipelines are the stratified transportation of gas-liquid systems, that is, separated into separate phases, which occurs when the maximum static pressure gradient $(dP/dr)_{\_max}$ along the cross section is smaller than the difference in the specific gravity of the phases $(\rho_{d.p} - \rho_l)g$. For clarity, let's look at the displacement of the dispersed phase particle along the cross section towards the center during the flow of a dispersed medium (for example, oil) and a dispersed phase (for example, mechanical particles and water droplets) in a pipe.

The density of the particle is greater than the density of the dispersed medium (gas). Under the influence of the gravitational force, the particle is located on the lower surface of the pipeline. When the movement along the pipeline begins, a gradient-velocity field is created. When the tension of the r coordinate of the field is low, it is located below the level of the center of mass of the particle $dP/dr = (\rho_{d.p} - \rho_l)\, g$. Three forces act on the particle: gravity, Archimedes and Bernoulli forces. Due to the low Bernoulli force, the direction of the equivalent of these forces is initially the same as the gravitational force, and the particle remains under the influence of gravity at the bottom of the pipeline. When the tension of the gradient-velocity field is sufficient, the direction of the equivalent force is directed towards the axis of the gas flow due to the increase in the Bernoulli force. Since the static pressure is the lowest in the flow axis, the Bernoulli force is always directed towards the point with the maximum velocity value, that is, towards the flow axis. Since the pressure gradient is variable, the momentum is also variable and does not remain constant. When an object (mechanical particle or water drop) starts moving towards the axis of the flow, it falls from the small gradient area into the area of a larger pressure gradient. This means that the object starts moving with a changing (increasing) acceleration. Such a movement continues until the object reaches the point corresponding to the maximum pressure gradient. Then the object starts moving towards the axis of the pipeline with a decreasing acceleration. This situation continues until the axis of dynamic equilibrium is reached. At this point, the counterforce is zero. However, since the object has a high velocity, its movement continues by inertia and falls to the area above the axis of the flow. At this point, the Bernoulli force is already in the same direction as the gravitational force, so the movement of the object weakens. As a result, due to the alternating action of the gradient-velocity fields, the particle begins to move in a damped oscillation around the axis of dynamic equilibrium, moving down and up. After several oscillations, the mechanical particle seems to calm down and settles on the axis of equilibrium. Thus, the particle begins to move in the core of the gas flow.

Such transfer phenomena, characteristic of multiphase flows, occur due to the Bernoulli force, which causes the interaction of phases in both horizontal and gravitational flows. Thus, particles moving with acceleration from the edges of the flow towards its axis have a much lower speed when they reach the center. Nevertheless, their stable movement occurs in the core of the flow.

The currently available theory of mono-phase flows, since it is developed empirically based on experimental data, cannot be applied to multiphase flows. The accuracy of calculations performed in this area does not meet the requirements of engineering practice, and in some cases the results are many times different. In this regard, taking into account a new flow model for multiphase flows, adapting hydraulic calculations and schemes to the new model is very important for increasing the efficiency of hydrocarbon extraction, preparation and transportation processes. Since technological processes are formed in a multiphase state during the movement of these systems compared to mono-phase flows, new approaches are required. In turbulent flows, the transfer of matter and energy across the cross section does not occur only due to molecular diffusion. This process is also caused by the directed movement of the medium. Such transfer phenomena, characteristic of multiphase flows, occur due to the Bernoulli force, which causes the interaction of phases in both horizontal and gravitational flows. Thus, particles moving with acceleration from the edges of a cylindrical flow toward its axis have a much lower velocity when they reach the center, and their steady motion occurs in the core of the flow.

The second chapter of the dissertation reflects the main problems and solutions related to the utilization and transportation of multiphase condensable associated petroleum gases. Thus, the problems of utilization of associated petroleum gases, justification of their transportation technologies and methods, and the importance of taking gas resources into account in this case are shown, and the main principles of efficient collection and transportation of multiphase gases are developed.

The issues that need to be resolved during the design of multiphase gas pipelines have been investigated and their solutions have been shown. If we compare the transportation of natural and associated petroleum gases, it is clear that natural gas can be transported over long distances by pipeline in a single-phase state, while associated gas can be transported in a multiphase state with only two phases. Multiphase transportation requires more energy consumption than monophase. The ratio of energy consumption for multiphase and monophase transportation of gas is 2-4, and in some cases even 5-6.

When choosing the diameter of a gas pipeline, it is important to take into account the dynamics of gas flow. If the maximum gas flow rate is given as the initial data, then when the flow rate decreases, gas transportation will be possible only under high pressure conditions. Therefore, when choosing the diameter of a gas pipeline, the minimum gas transport pressure cannot be taken as a basis. Unlike a single-phase flow, any decrease in gas flow in a pipeline for a multiphase flow will lead to an increase in pressure at its inlet. From this we can conclude that when choosing the diameter of a pipeline, the possibility of a certain decrease in gas flow rate should also be taken into account.

It was determined that the main problem of efficient utilization of associated petroleum gases is related to their multiphase nature.

During the transportation of these gases, the condensation of the propane-butane fraction and its deposition in the pipeline significantly increase the pressure losses, which prevents their efficient utilization. The feasibility of taking into account gas resources when selecting technological equipment for gas utilization has been shown.

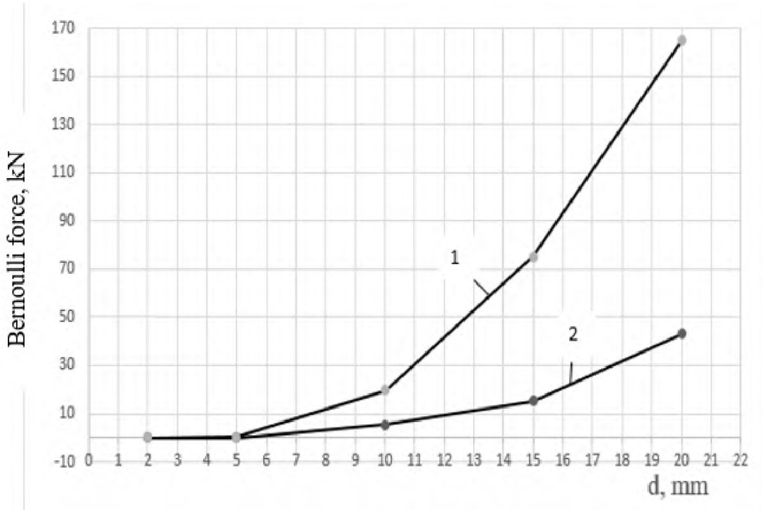
The third chapter of the work is devoted to the issues of assessing dynamic loads and pressure losses in multiphase pipelines, taking into account the relief. Based on the transport phenomenon for multiphase flows, if we consider the variation of velocity (υ) and velocity gradient (dv/dr) across the cross section, we obtain the following expression for calculating the Bernoulli force:

$$F_B = 8.39\rho d^3 u^2 \alpha\,(1-\alpha^2)/D \qquad (2)$$

Here, u- is the average flow velosity; d- is the diameter of the dispersed phase particle (this can be a mechanical particle, water droplet, gas, etc.); R and D- are the radius and diameter of the pipeline, respectively, ρ - is the density of the dispersed medium. $\alpha = r/R$;

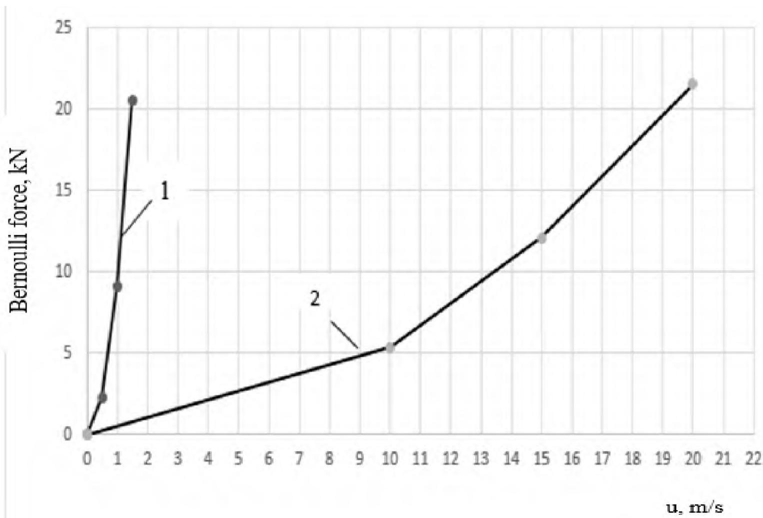
The case of presence of mechanical mixtures of different sizes as a dispersed phase in gas and oil pipelines has been investigated. It has been established that the variation of Bernoulli force along the cross section in multiphase flows for both oil and gas pipelines has the same character.

The dependence of the Bernoulli force on the size of mechanical particles was investigated and it was determined that for both the oil pipeline and the gas pipeline, the Bernoulli force begins to increase intensively starting from the value of the size of mechanical particles d=8-10mm and this intensity gradually increases. At this time, this increase is greater in the oil pipeline than in the gas pipeline. Then, how the flow velocity affects the resulting force was also studied. The Bernoulli force increases monotonically depending on the flow velocity. This increase is more characteristic for the oil pipeline (Fig. 3, 4).



1-oil pipeline; 2-gas pipeline

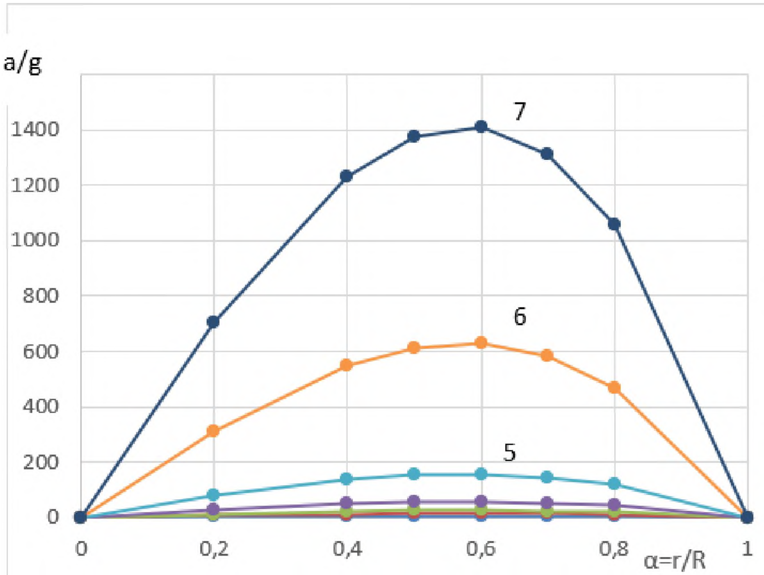
Figure 3. Dependence of Bernoulli force on the diameter of the dispersed phase particle (D=0.3m)



1-oil pipeline; 2-gas pipeline

Figure 4. Dependence of Bernoulli force on the velocity of the dispersed medium (flow) (D=0.3m, d=0.01m)

Considering that the basis of the transportation of multiphase systems is the interaction of phases and the driving force of this effect is the Bernoulli force, in order to evaluate the latter, it is sufficient to compare it with the force of gravity. For this purpose, it is sufficient to compare the acceleration (vdv/dr) included in the expression of the Bernoulli force with the acceleration of the force of gravity (g). The dependences reflecting the change in the ratio of momentum (a/g) along the cross-section of the pipeline at different speeds of movement are shown in Figure 5.



1÷7 – correspondingly when u=1; 1.5; 2; 3; 5; 10; 15 m/s

Figure 5. Dependence of a/g on the flow velocity (u) and distance from the center (α) (D=0.1m)

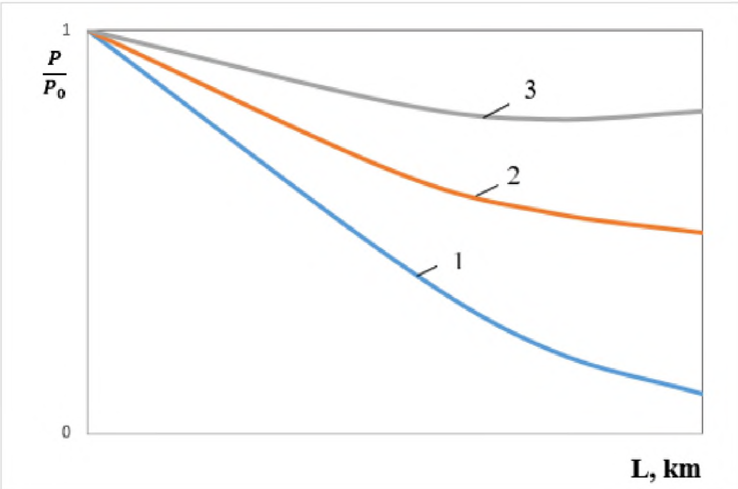
As can be seen from Figure 5, the maximum acceleration created by the Bernoulli force can be as much as 1400 and 600 times greater than the free fall velocity for the values of 15 m/s and 10 m/s, respectively. The analysis shows that the maximum value of the acceleration corresponds to the value α=0.577, corresponding to the variation of the Bernoulli force across the cross section.

This chapter examines the issues of pressure distribution and its effect on the throughput of a multiphase pipeline and itsThe following expression was obtained reflecting the distribution along the belt:

$$P = \frac{1}{\alpha_0}\left[(1 + \alpha_0 P_0)e^{-aNx} - 1\right]$$

Here, P_0-initial pressure (Pa), α_0 -compression coefficient of the mixture (Pa^{-1}), $\alpha_0 = 10^{-7}$; a and N-are constant quantities characterizing the flow regime.

As can be seen from the last expression, the pressure distribution for multiphase flows decreases exponentially along the belt, depending on the motion mode (Figure 6).



1÷3 for values of m=1, m=0.25, m=0.123

Figure 6. Variation of the relative pressure loss due to friction along the flow path in different motion modes

As can be seen from Figure 6, the greatest reduction in relative pressure loss due to friction occurs in the laminar regime of multiphase flow, i.e., when m=1.

The work examines the assessment of dynamic loads arising in multiphase flows. Gravity losses in railed pipelines are determined.

Dynamic loads, which are mainly characteristic of multiphase flows, occur at the turns of the pipeline route, in gravitational flow zones, and generally at the moment of change in the density of the transported medium. If the medium with a constant density moves in the pipeline, then dynamic loads do not arise.

To determine the maximum value of the dynamic pressure, it is necessary to determine the value of the critical flow velocity (the value corresponding to the change in structure).

In the dissertation work, the following expression was obtained to calculate the dynamic pressure for multiphase flows in which the leading phase (dispersed medium) is gas, taking into account the critical velocity of the mixture:

$$P_{din} = 1{,}59\, \rho_{mix} \cdot gD(\rho_l - \rho_g)/\rho_g$$

Considering that dynamic pressure can also be estimated as the difference between the dynamic pressures created by the liquid and gas phases, we get:

$$P_{din}^{ph} = 1{,}59\, (\rho_l - \rho_g)^2 gD/\rho_g$$

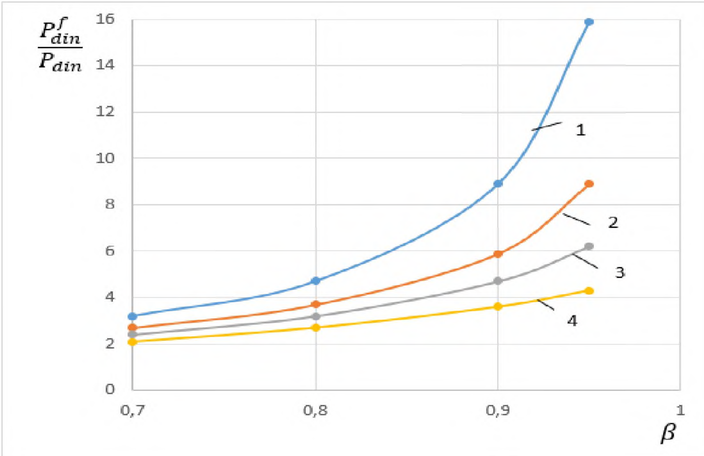
The analysis of the latter expressions once again proves that the formation of dynamic pressure, which is characteristic of multiphase pipelines, occurs not in dispersed (emulsion) flows in a gas, which is the leading medium (disperse medium) of the liquid (disperse phase), which is determined by the density ρ_{mix} parameter and can be considered as a homogeneous medium, but mainly in phase-separated, clogged movement structures.

The density of a multiphase mixture (oil+gas) is determined by $\rho_{mix} = \rho_l - \beta(\rho_l - \rho_g)$ considering the densities of the phases and the volume based on the gas capacity (β).

Considering this, we get the following expression:

$$\frac{P_{din}^{ph}}{P_{din}} = \frac{1 - \frac{\rho_g}{\rho_l}}{1 - \beta(1 - \frac{\rho_g}{\rho_l})}$$

Thus, the dynamic pressure generated in multiphase flows increases with increasing gas capacity and decreases with increasing density ratio of gas and liquid phases (Figure 7).



1÷4 – respectively = 1.3; 6.5; 10; $15 \cdot 10^{-2} \frac{\rho_g}{\rho_l}$.

Figure 7. Dependence of the ratio of dynamic pressures on $\boldsymbol{\beta}$ *and* $\frac{\rho_g}{\rho_l}$

This chapter also examines the issues of regulating the flow characteristics of mining pipelines for multiphase flows. One of the reasons for the high pressure losses in multiphase flows compared to single-phase flows is the presence of gravitational losses, in addition to the formation of waves and gas plugs, the breakdown of gas bubbles. A methodology for determining free-flow zones and estimating gravitational losses is proposed. The minimum pressure losses in the flow characteristics of multiphase mining pipelines are determined depending on the degree of hydration and degassing.

The fourth chapter of the dissertation work discusses the development of a new concept for the efficient collection and transportation of gas-condensate mixtures from offshore fields.

Taking into account the specific features of gas collection and pipeline design from offshore fields and in accordance with the dynamics of field development, efficient technologies for the collection and transportation of hydrocarbons have been developed.

Analysis shows that the vast majority of pipeline failures transporting multiphase gases are erosion or erosion-corrosion failures. Thus, the pipeline failure occurs mainly along its lower surface, and within a short time, erosion-corrosion processes destroy the pipe wall and even create cracks[4].

In general, according to the results of studies conducted to assess corrosion activity, if the gas does not contain hydrogen sulfide gas, it is considered an environment with low corrosion activity. Thus, in this case, the corrosion rate for steel pipes is not very high and is 0.1 mm/year. Formation waters with a high degree of mineralization have an average corrosion activity even in static conditions. Usually, the corrosion rate of steel structures in such an environment does not exceed 0.3 mm/year. A relatively high corrosion rate is observed in pipelines transporting condensable gases that have not fully passed the preparation stage. In this case, the corrosion rate reaches 3-5 mm/year and it is no coincidence that these pipelines can fail within a few years. This process is even faster if the gas contains mechanical impurities. Mining experience also confirms that pipelines operating at high speeds of multiphase flow are more durable. Analyses and facts show that the correlation between the rate of corrosion and the speed of movement of the multiphase oil-gas mixture is undeniable. The most frequent spills in pipelines occur at the beginning of the ascending sections of the pipeline profile. The greatest erosion exposure is mainly due to the accumulation of the liquid phase and solid mechanical particles in

[4] Ismayilov, GG Problems of hydrodynamic corrosion in multiphase pipelines, / GG Ismayilov, EK Iskandarov, FB Ismayilova // Protection of Metals and Physical Chemistry of Surfaces, - 2021. Vol. 57, No. 1, - p. 147–152.

these sections, as well as the periodic up-and-down movement of these particles along the flow.

Although other corrosion cases have been widely studied, corrosion problems, which are most commonly caused by erosion-corrosion and are related to the hydrodynamics of flow, have not been widely studied in practice.

The solution of the problem of preventing corrosion-erosion processes occurring in the lower part of pipelines requires extensive research. These processes, which occur primarily due to internal factors, require consideration of the structure and hydraulic properties of multiphase flows, including gas flows containing mechanical mixtures. First of all, at the stage of field development (as well as in the process of their exploitation), relatively reduced calculated values of the diameter of gas gathering and transportation lines should be taken into account in order to ensure the optimal level of movement speeds of multiphase mixtures in the pipes.

The issue of hydrodynamic regulation of the effect of mechanical particles in a multiphase gas pipeline was considered. It should be noted that multiphase flows can be water-oil, oil-gas, gas-condensate, and their mixtures with mechanical particles. The main issue in this case is the correct assessment of the leading (dispersed medium) and dispersed phase. Therefore, if we take the density of the leading dispersed medium as $\rho_{d.m.}$, and the density of the dispersed phase as $\rho_{d.p.}$, then the friction force on the inner surface for a mechanical particle during the movement of the mixture in the pipeline can be determined based on the following dependence known from mechanics:

$$F = (\rho_{d.p.} - \rho_{d.m.})\, g\varphi\pi d^3/6$$

Where: d is the diameter of the mechanical particle;

φ- is the coefficient of friction.

To determine the velocity of a particle in a multiphase flow, let us use the well-known law of velocity distribution across the cross section of a cylindrical flow:

$$\upsilon = 2u\left[1-\left(\frac{2r}{D}\right)^2\right] \quad (3)$$

Here: u - average flow velocity;

r- is the distance between the axis of the flow and the center of the mechanical particle.

Considering that r $=\frac{D-d}{2}$, then expression (3) can be written as follows:

$$\upsilon = 2u\frac{d}{D}\left(2-\frac{d}{D}\right) \quad (4)$$

Here, D and d are the diameter of the pipeline and the spherical mechanical particle, respectively.

Then, the following expression can be obtained to determine the strength of the friction force (N):

$$N = F\upsilon = 1.05\,(\rho_{d.p.} - \rho_{d.m.})\,\varphi u g\,(2- d/D)d^4/D \quad (5)$$

From the last expression it can be seen that the strength of the erosion effect on the pipeline depends more on the diameter of the mechanical particles.

Considering that the mechanical mixtures entering the well from the layers mainly consist of sands, and based on the average sizes of individual fractions and their relative distribution in terms of their impact on the pipes, the strength of the erosion effect can be calculated based on expression (5). The calculations were carried out based on the following initial data:

D = 0.2 m;

$\rho_{d.p.}$and $\rho_{d.m.}$– 1500 and 3 kg/m^3 were taken, respectively;

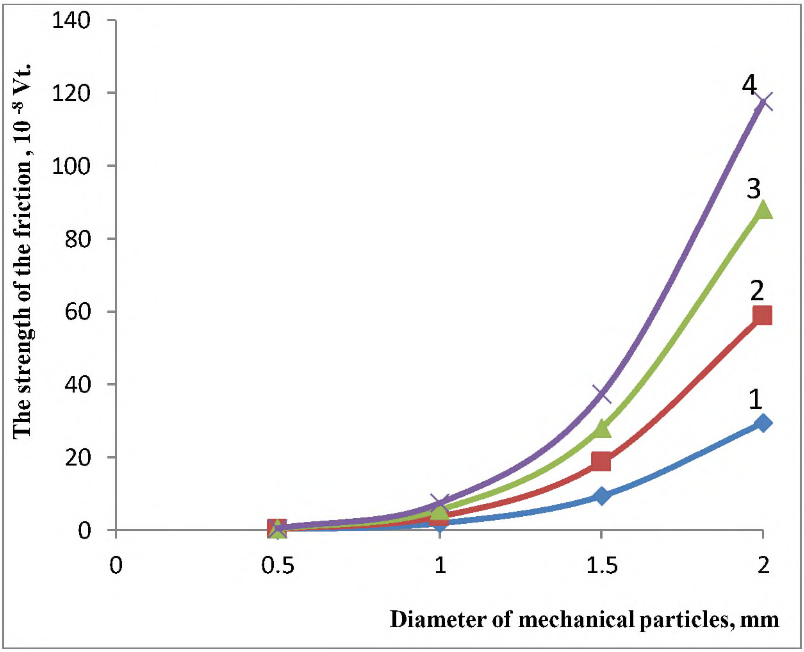
u= 5; 10; 15; 20 m/s (u is the flow velocity of the dispersed medium-gas).

Based on the results of the calculations, the dependence of the friction force generated by mechanical particles on the particle size at different velocities of multiphase flow is given in Figure 8.

Based on Figure 8, it can be said that the friction force is mainly due to the fractions with a size of d> 1 mm. The analysis shows that the erosion is mainly (more than 90%) caused by fractions with a diameter of 1-2 mm. The corrosion-erosion rate increases in proportion to the friction force of mechanical particles on the inner surface of the gas pipeline, and this increase depends not on the amount of mechanical particles, but on their size. Therefore, in order to protect the gas pipeline from the effects of solid mechanical particles, it is important that these particles fall from the bottom wall of the pipe into the flow core and are transported there.

For this, the static pressure gradient (dP/dr) across the cross section of the flow must be greater than the difference in the specific gravity of the mechanical particle and the gas.

$$dP/dr > (\rho_{d.p.} - \rho_{d.m.})\, g \quad (6)$$



1-4 when u=5, 10,15 and 20 m/s respectively

Figure 8. Variation of friction force depending on the size of mechanical particles

For the static pressure gradient across the cross section, the following expression can be written based on expression (1), taking into account the flow velocity, pipeline diameter, and solid particle diameter:

$$dP/dr = 16\rho_{d.m.}u^2 \frac{d}{D^2}\left(1-\frac{d}{D}\right)\left(2-\frac{d}{D}\right) \tag{7}$$

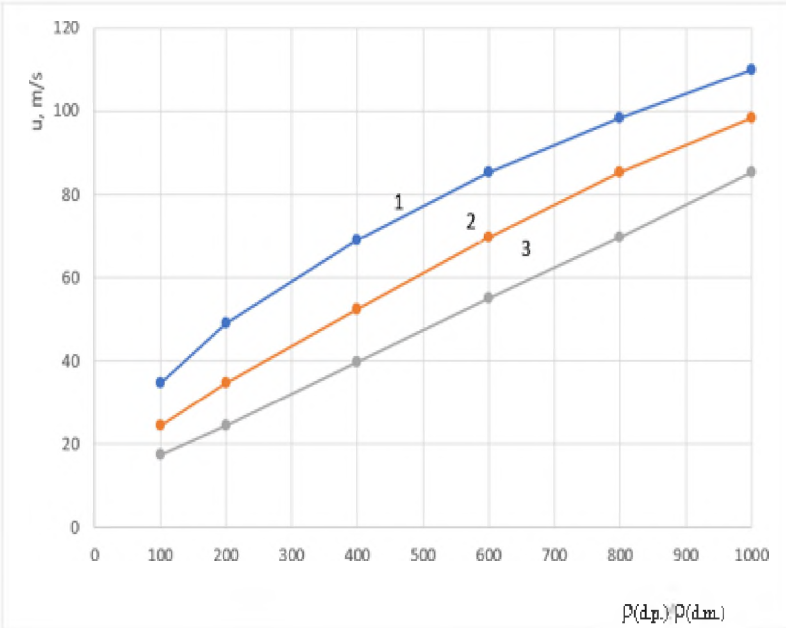
Then, in accordance with the equality condition of expressions (6) and (7), the following expression was obtained to calculate the flow velocity required for the transport of solid particles with a very small error:

$$u = A \cdot D\sqrt{\frac{\rho_{d.p.}}{2\,\rho_{d.m.}d}} \tag{8}$$

Here, A – is the coefficient (A=0.783), $\frac{m^{\frac{1}{2}}}{s}$

As can be seen from the last expression, the rate of transport (entrainment) of mechanical particles by the flow will vary depending on the densities of the phases, the diameter of the solid particles, and the pipeline.

Based on the last expression, the dependence of the transport velocity of mechanical particles of different sizes in the flow core in a gas pipeline with a diameter of D=0.2m on the parameter $\rho_{(d.p.)}/\rho_{(d.m.)}$ was investigated. It was determined that as the ratio of the densities of the phases increases, the transport speed increases, and as the size of the mechanical particles increases, it decreases. (Figure 9).



1÷3 at d=1 mm, 2 mm and 4 mm respectively

Figure 9. Dependence of transport velocity on the ratio of phase densities

Thus, one of the methods of protecting multiphase pipelines from erosion-corrosion is to select the correct flow rate, which will ensure the transport of dispersed phase particles into the flow core, preventing their accumulation on the inner surface of the pipe.

In this chapter, efficient methods based on multiphase technologies for the collection and transportation of hydrocarbons from offshore fields in accordance with the dynamics of gas resources have been developed.

The main condition when calculating multiphase gas pipelines is to take into account the interaction of the phases and correct the calculated diameter of the pipeline depending on the flow structure, depending on the ratio of the phases. The assumption of a large diameter will lead to additional costs and corrosion-erosion destruction of the gas pipeline. The assumption of an undersized diameter will not only limit the production of wells, but also increase pressure losses.

In multiphase flows, the selection of the optimal diameter of the gas pipeline and the specification of the structural forms of the flow, taking into account the interaction of the phases, were summarized and the sequence of calculations of multiphase pipelines was shown. It should be noted that these calculations were carried out for gas-condensate mixtures where the gas phase is the leading (carrying) phase. The calculations were carried out for both single-phase and multiphase flows. The selection of the gas pipeline calculation methodology and the determination of the structural forms of the flow are first determined by the gas capacity of the flow $\beta = Q_g/(Q_g + Q_l)$ The determination of the structural forms of the flow is specified according to the following conditions:

$(dP/dr)_{max} > g(\rho_c - \rho_g)$– emulsion (dispersed) flow;

$(dP/dr)_{max} < g(\rho_c - \rho_g)$ – stratified flow pattern.

Based on the initial data (volumetric flow rates, densities and viscosities of gas and condensate, geometric dimensions of the gas pipeline, initial and final pressure, etc.), the volumetric flow rate, movement modes and structural forms of the flow are determined according to the given or selected diameter.

Since phase shift is inevitable when the flow shape of the gas-condensate mixture is stratified (separated into phases), the diameter for the cross section of the gas flow is determined.

Based on the calculated values of $\rho_{mix}, and\ \vartheta_{mix}$ parameters for the gas-condensate mixture and the value of the static pressure gradient in the flow cross section is determined taking into account expression (1). As a result of the calculations, it was determined that while in the mono-phase case the gas transportation distance can be increased by increasing the diameter of the pipeline, the distance of multiphase (gas+condensate) gas transportation is limited.

Considering that the collection and transportation of condensed associated gases from offshore fields is significantly dependent on the dynamics of field development, hydraulic calculations were performed to determine the dependence of the transportation distance (L) on the diameter of the gas pipeline for multiphase flows at pressures of 0.6; 1; 1.5; 2.5; and 4.0 MPa and gas flow rates of 0.024; 0.048; 0.12; 0.24; 0.48; 1.2 and 2.4 million m^3/day.

Calculations were carried out taking into account the interaction of phases in multiphase flows, and the dependences L=f(D) were established for various pressures and gas flows. Based on these dependences, it was determined that in all cases considered, the transport distance of condensing gases is limited and characterized by a maximum transport distance. For example, The variation of the maximum gas transport distance at pressures P_i=1 MPa and P_e=0.25 MPa depending on the gas flow rate and pipeline diameter is given in Table 1. As can be seen from Table 1, the maximum gas collection-transportation distance at the initial transport pressure (P_i=1 MPa) varies from 45 km (Q_g=0.024 million m^3/day) to 85 km (Q_g=2.4 million m^3/day), depending on the gas volumetric flow rate.

The calculated values of the maximum transport distance depending on the initial transport pressure and gas flow rate are given in Table 2.

Table 1

Variation of the collection-transport distance of multiphase gas at pressures P_i=1 MPa and P_e=0.25 MPa for different diameters and flow rates

Conventional diameter, D, m	Qg, million m^3/day						
	0.024	0.048	0.12	0.24	0.48	1.2	2.4
0.1	22						
0.15	39	32					
0.20	44	42					
0.25	45	42					
0.30	44	50	50				
0.35	43	49.5	55				
0.40		49	57	54	45		
0.45			57	60	52		
0.50			56.5	62	57		
0.60			55	64	65		
0.70			54	63	70	60	
0.80					70	65	
0.90					69.5	70	
1.0					69	73.5	
1.1						75.5	70
1.2						78	74
1.3						79	77
1.4						80	78
1.5						79.5	79
1.8						76.5	82
2.0							85
2.2							85
2.4							84

Table 2

Values of maximum transport distance (in km) for condensable gases depending on gas flow rate and initial transport pressure (P_i)

Gas flow rate, million m^3/day	Transport pressure, MPa				
	0.6	1.0	1.5	2.5	4.0
0.024	22.5	45	75	126	200
0.048	25.0	50	80	140	225
0.12	29.0	57	92	160	260
0.24	33.0	64	110	180	285
0.48	35.6	70	123	198	320
1.2	40.0	80	139	225	365
2.4	43.0	85	150	245	400

As can be seen from Table 2, the maximum collection and transportation distance of gases condensed under pressures of 0.6, 1.0, 1.5, 2.5, 4.0 MPa increases depending on the gas flow rate and can vary in the range of 22.5-43; 45-85; 75-150; 126-245 and 200-400 km, respectively. The transportation distance for such flows depends more on the initial pressure in the gas pipeline than on the gas flow rate (Table 2). Thus, although the optimal diameter of the pipeline does not change with an increase in the initial pressure, it is possible to increase the transportation distance of the mixture several times. The analysis shows that, unlike the initial pressure, even a multiple increase in the gas and condensate flow rate allows increasing the transportation distance of the gas-condensate mixture only by a few kilometers.

Thus, based on the analysis of the results of the calculations, it was determined that in order to ensure the efficient operation of a multiphase gas pipeline, its diameter should be correctly selected in accordance with the dynamics of field development. Unlike mono-phase (gas), the transport distance of multiphase gas-condensate mixtures does not increase as much as desired with an increase in the diameter of the pipe and has a limited cost. If the transportation is carried out through a pipeline with a diameter larger than that, then technological difficulties in the multiphase gas pipeline will inevitably arise due to the stagnation zones (traffic jams) formed in places when the gas pipeline is filled with condensate. The efficiency of the collection and transportation of condensable gases or gas-condensate mixtures largely depends on taking into account gas resources and the correct selection of transportation technology.

The fifth chapter of the work discusses issues related to the development of new rheological and hydraulic criteria in order to increase the efficiency of multiphase well product collection, preparation and transportation processes.

The study of the sedimentation of ballasts in multiphase mixtures was carried out and diagnostics based on rheological modeling was shown. The formation of "undesirable" mixtures depending on their chemical composition during the mixing of various types of oils can also manifest itself in the intensive sedimentation of asphaltene -paraffin-resin (APR) and other ballasts and can cause technological difficulties and pollution. For the diagnostics of the sedimentation of ballasts such as APR, a graphoanalytical method based on the interpretation of rheological flow curves of multiphase oils was proposed.

Dispersed water, mineral salts and solid phase particles present in the oil, as well as high molecular weight chemical compounds such as APR dissolved in it ("black" emulsifiers) can significantly change the rheophysical properties and structure of oil emulsions. It should be noted that oil emulsions are considered polydisperse systems and in most cases are classified as non-Newtonian systems. The rheology of oil emulsions depends on many factors, including the degree of dispersion of water in the emulsion.

The results of rheological analysis of dispersed systems show that, despite the abundance and diversity of rheological models, the main research has been devoted to the construction of empirical models without taking into account the mechanism of phenomena that describe experimental data with a certain accuracy[5].

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[5] Kelbaliev, G.I. Rheology of non-newt oil. Monograph. / G.I. Kelbaliev, D.B. Tagiyev, S.R. Rasulov [and others]. // Moscow: - Mask, - 2022. - 601c.

The use of currently available empirical rheological models for determining the viscosity of various emulsions in oilfield practice is associated with considerable difficulties and in most cases is not suitable for solving engineering problems. This is primarily due to the determination of the size and volume fraction of water particles dispersed in oils. Mining practice shows that during the exploitation of deposits, due to the increasing percentage of water and changes in thermobaric conditions, the rheological and physicochemical properties of oil emulsions also change over a wide range. Since such changes probably affect the degree of water dispersion, any rheological test requires the determination of the size of these particles.

On the other hand, due to the presence of occluded gas in most cases in heavy and stable oil emulsions, oil emulsions should be considered partially degassed. Therefore, it is possible for bubbles to be present in such emulsions and to take on various shapes.

To determine how the viscosity of oil emulsions changes depending on the rheological properties of the oil and the degree of hydration, oil samples were selected and rheological tests were conducted. Rheological tests were conducted for both dehydrated and oils with different degrees of hydration. As a result of the rheological analyses, it was determined that the viscosity of the emulsions increases significantly as the degree of hydration of the oil increases. The results of rheological studies conducted at 20 0C on an oil sample taken from the Muradkhanli field are shown in Table 3 for degrees of hydration of 35, 40, 45, 50, 55, 60 and 65%. As can be seen from the table, the shear stress (viscosity) for oil emulsions increases significantly and with the same regularity with an increase in the degree of hydration.

As a result of research, it was determined that this pattern can be expressed by the following mathematical model:

$$\eta_{em} = \eta_o \left(\frac{\eta_{em}^*}{\eta_o}\right)^{\frac{\beta_W}{\beta_W^*}} \tag{9}$$

Here, β_W- current water-cut rate, %;η_o- viscosity of dehydrated oil, $Pa \cdot s$; β_W^*və η_{em}^*- the maximum degree of water-cut (%) and the maximum value of the viscosity of the emulsion corresponding to that hydration $(Pa \cdot s)$.

As can be seen from the last expression, when $\beta_w = \beta_w^*$, then $\eta_{em} = \eta_{em}^*$, and when there is no water-cut $(\beta_w = 0)$, then $\eta_{em} = \eta_o$.

The tests were continued on a dehydrated oil sample with a viscosity of $\eta_o = 0.1\ Pa \cdot s$, up to the maximum viscosity of the oil emulsions (η_{em}^*) until the water content was reached.

The value of the water content corresponding to the maximum viscosity of the emulsion $(\beta_w^* = 65\%)$ was determined based on the flow curves $\tau = f(\dot{\gamma})$. The values of $\eta_{em}^*\ and\ \beta_w^*$ parameters for different values of the velocity gradients are given in Table 3.

The calculated viscosities for the tested oil emulsions (η_{em}) based on the obtained mathematical model and the data in Table 3 are also given in that table.

The calculated viscosity (η_{em}^{mod}) values for oil emulsions at different dilution rates and velocity gradients were compared with the experimentally obtained (η_{em}^{eks}) values of the emulsions, and the corresponding errors were calculated. As can be seen from Table 3, the values determined values of viscosity based on both the experiment and expression (9) do not differ much from each other (average error 4-5%), so they can be accepted for engineering calculations.

Thus, for any oil sample (whether taken from a well, a tank, or a pipeline), it is possible to predict how the viscosity of oil emulsions will change based on the change in hydration using the proposed mathematical model. For this, it is sufficient to conduct rheological testing of that oil sample at different hydration levels in laboratory conditions, establish dependencies $\tau = f(\dot{\gamma})$, and$\eta_{em} = f(\beta_{w.})$ and determine the parameters $\beta_w^*\ and\ \eta_o$from these dependencies, so that it is possible to predict how the viscosity will change for oil emulsions in the future.

Table 3

Calculated values of viscosity for oil emulsions based on experience and the proposed mathematical model
(t=20 ^{0}C, $\eta_o = 0.1\ Pa \cdot s$)

$\dot{\gamma}$, c-1	τ, Pa	$\beta_w, \%$	$\eta_{em}^{mod}, Pa \cdot s$	$\eta_{em}^{eks}, Pa \cdot s$	Error, %
0.3333	2.00	35	5.71	6.00	4.8
	3.37	40	10.18	10.11	0.6
	5.9	45	18.14	17.7	2.5
	10.74	50	32.33	32.22	0.3
	19.70	55	57.61	59.11	2.5
	33.66	60	102.68	101.08	1.6
	61.12	65	183	183.38	0.2
1.0	3.87	35	3.83	3.87	1
	6.43	40	6.44	6.43	0.2
	11.17	45	10.85	11.17	2.9
	17.86	50	18.26	17.86	2.3
	31.04	55	30.74	31.04	3.8
	56.37	60	51.74	50.37	2.7
	87.1	65	87.1	87.1	0
3.0	7.84	35	2.71	2.64	2.7
	13.0	40	4.34	4.32	0.5
	21.00	45	6.96	7.00	0.6
	31.81	50	11.14	10.84	2.8
	55.7	55	17.86	18.23	2.0
	69.97	60	28.61	26.62	7.5
	137.52	65	45.84	45.84	0
9.0	13.91	35	1.90	1.99	4.5
	25.76	40	2.89	2.86	1.0
	41.84	45	4.41	4.64	4.5
	57.84	50	6.72	6.42	4.7
	91.75	55	10.24	10.18	0.6
	113.97	60	15.60	14.88	4.8
	213.92	65	23.76	23.77	0.04
48.6	43.84	35	0.92	0.90	2.2
	59.01	40	1.27	1.21	4.9
	89.32	45	1.76	1.84	4.3
	108.00	50	2.41	2.23	3.6
	170.72	55	3.32	3.52	5.7
	204.37	60	4.57	4.31	6.0
	305.6	65	6.29	6.28	0.1
145.8	84.04	35	0.54	0.57	5.2
	104.6	40	0.69	0.72	4.2
	155.72	45	0.88	1.09	19.2
	190.5	50	1.22	1.30	6.1
	230.4	55	1.42	1.51	5.9
	269.54	60	1.81	1.84	1.6
	336.16	65	2.30	2.31	0.4

The effect of the hydration, mixing and cooling rate of oils on their freezing point was also studied based on laboratory tests. It was found that during transportation of high-viscosity oils mixed with each other, light oil and condensate, the freezing point may change anomalous depending on the mixing ratio, and with an increase in the hydration degree and cooling rate of oil emulsions, the freezing point may increase by 5-10 ^{0}C.

The role of "black" emulsifiers and the Bernoulli force in increasing the efficiency of the decomposition (phase separation) of multiphase mixtures was studied in the dissertation work.

It is known that the efficiency of oil preparation technology largely depends on obtaining the maximum volume of dehydrated oil with minimal demulsifier consumption. At the same time, the oil preparation process must be carried out at such a speed that fuel consumption does not increase and the loss of light hydrocarbon fractions is minimal.

The experience of oil field development shows that the composition, physicochemical and rheological properties of oils constantly change during the exploitation process depending on the dynamics of development. This process is mainly observed during the mixing of oils, the formation of oil emulsions with their hydration and the increase in the amount of APR contained in them, which are called natural emulsifiers ("black" emulsifiers).

It has been found that as the amount of "black" emulsifiers increases, the efficiency of emulsion breakdown - the percentage of dehydration - decreases.

In oil and gas field practice, the processes of purification (separation) of hydrocarbons from produced water and mechanical particles are based on multiphase technologies. In practice, it was possible to reveal the reason for the low efficiency of hydrocyclone technology in many cases based on the mechanism of interaction of phases. Thus, the negative effect of the Bernoulli force on the operation of the hydrocyclone was revealed, and the possibility of preventing the negative effect of this force, which is formed along the cross section in a cylindrical flow, on the operation of the unit was shown by correctly selecting technological parameters based on multiphase technology.

The work considers the issue of diagnostics of stable flow characteristics during the flow of multiphase systems based on rheological modeling. In many cases, increasing the efficiency of technological processes formed in a multiphase manner requires correct rheological modeling of multiphase flows and stability of hydraulic (flow) characteristics. Rheological tests of multiphase systems show that in many cases their flow curves $(\tau = f(\dot{\gamma}))$ are characterized by non-monotonic dependencies. The following rheological model has been proposed for the mathematical description of the flow curves of such systems[6].

$$\tau = \tau_0 + \mu_0(\dot{\gamma} + \varkappa_1\dot{\gamma}^2 + \varkappa_2\dot{\gamma}^3) \qquad (10)$$

As can be seen from the last rheological equation, since the dependence between $\tau\, and\, \dot{\gamma}$ is of the 3rd degree (cubic), the existence of the above-mentioned unstable states is inevitable. By adopting the proposed rheological model, it is shown that it is possible to transfer the rotoviscosimetric results to pipe hydraulics (transport) and determine the flow characteristics of multiphase systems.

The parameters $\tau_{0,}\, \mu_0, \varkappa_1, \varkappa_2$, included in the last expression (11) were determined based on the interpretation of the rheological flow curve.

Based on the elements of pipe hydraulics, the following identification model has been constructed according to the rheological model for the flow characteristics of multiphase flows:

$$\Delta P = a_1Q^3 + a_2Q^2 + a_3Q + a_4 \qquad (11)$$

Here, $a_1 = 2l\mu_0\varkappa_2/(\pi^2R^{10})$

$a_2 = 2l\mu_0\varkappa_1/(\pi^2R^7)$;

$a_3 = 2l\mu_0/(\pi \quad R^4)$;

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[6] Sattarov, R.M. Nanomodeling of technological processes of development and exploitation of oil and gas deposits / R.M.Sattarov, I.R. Sattarzadeh, A.G. Gusmanov // Azerbaijan Oil and Gas Industry, Baku: -2010. No. 1, - p. 42-51.

$a_4 = 2l\tau_0/R$.

For the flow characteristic, $\Delta P = f(Q)$, to be stable, it is important that equation (11) has 1 real and 2 complex roots. As can be seen from the expression, the pressure loss (:ΔP) can be the same even at three different flow rates (Q). The flow rates corresponding to the extreme values are found based on the following expression

$$3a_1Q^2 + 2a_2Q + a_3 = 0 \qquad (12)$$

Considering that expression (12) has no real roots ($a_2^2 < 3a_1a_3$) and the above expressions for a_1, a_2, and a_3, we can write the condition for the existence of a stable consumption characteristic as follows:

$$\varkappa_2 = \varkappa_1{}^2/3$$

Thus, it has been shown that the rheological parameters calculated based on the proposed rheological model and experimentally are almost the same for multiphase systems, and that it is possible to describe the rheological properties of these systems with the mentioned mathematical model and to verify whether the flow characteristics are stable for the systems tested based on rheological modeling.

The sixth chapter of the dissertation work is devoted to the issues of diagnostics of technological problems and operational difficulties occurring in multiphase flows. Graphoanalytical analysis of oil spills with pressureless (free) flow was carried out. The influence of the water-cut factor on the well's fountaining was analytically evaluated.The role of phase interaction in the formation of structural regimes in vertical flows has been evaluated. The effect of phase shift on the density of the mixture in risers and vertical pipes has been evaluated. Ways of transporting gas while maintaining its dispersed state have been shown.

In general, the currently available mathematical models for calculating the amount of oil and gas spilled as a result of accidents are based on the hydraulics of single-phase flow of liquids and gases through holes and pipes. In regulatory documents and literature sources, there are almost no appropriate evaluation and calculation methods for multiphase flows.

The possibility of complete discharge of a pipeline section depending on the terrain was investigated when the valves at the beginning and end were closed.

A grapho-analytical method has been proposed for the assessment of accidental oil spills in pipelines with free flow. It has been established that even in the worst case, complete discharge of the oil pipeline is not possible. During accidental spills, complete discharge of the pipeline in free flow mode is possible only if holes are formed at all extreme points of the pipeline (at the maximum and minimum points of the profile) during the accident.

The work examined the issue of determining the minimum value of the bottomhole pressure for diagnosing the possibility of a well blowing, investigated the effect of the product's water content on the operation of a multiphase lift, and solved the issue of diagnosing blowing against the background of an increasing water percentage.

The following mine data were used to determine the limit value of the gush injection condition based on multiphase technologies:

- The depth of the productive layer is 1700 m;
- Formation pressure – 14 MPa;
- Density of degassed oil – 860 kg/m^3;
- Density of produced oil – 760 kg/m^3;
- Density of water – 1180 kg/m^3;
- Saturation pressure – 8.92 MPa;
- Gas factor – 47 m^3/m^3;
- Gas density – 1.38 kg/m^3;
- Minimum pressure at the wellhead – 0.3 MPa;

Let's assume that the field is operated with the reservoir pressure maintained at 14 MPa. The dependence of the productivity coefficient on water-cut is shown in Fig. 10. The diameter of the riser in the well is 62 mm.

Based on the initial data, characteristic hydraulic curves for the lift in various cases of oil hydration were constructed (Figure 11). The figure also reflects the indicator curves at β_{water} = 0%, K = 100 t/day * MPa) and P_r =14 MPa.

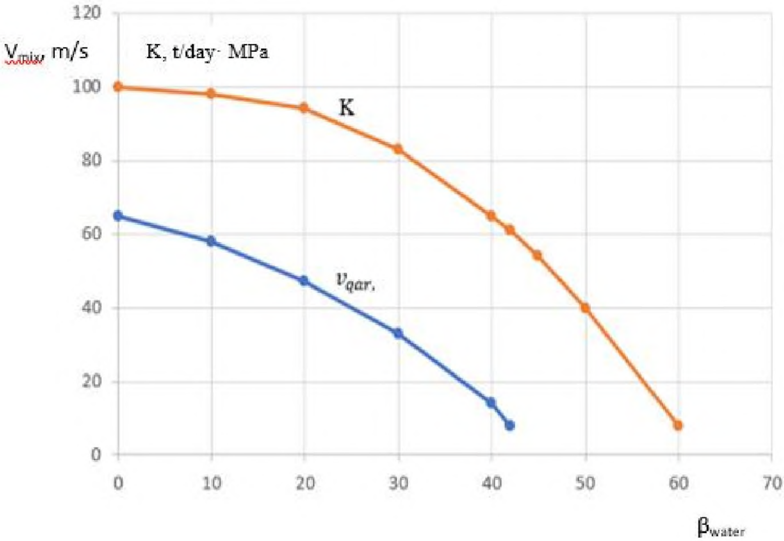

Figure 10. Dependence of productivity coefficient (K) and velocity (v_{mix}) on the percentage of water-cut

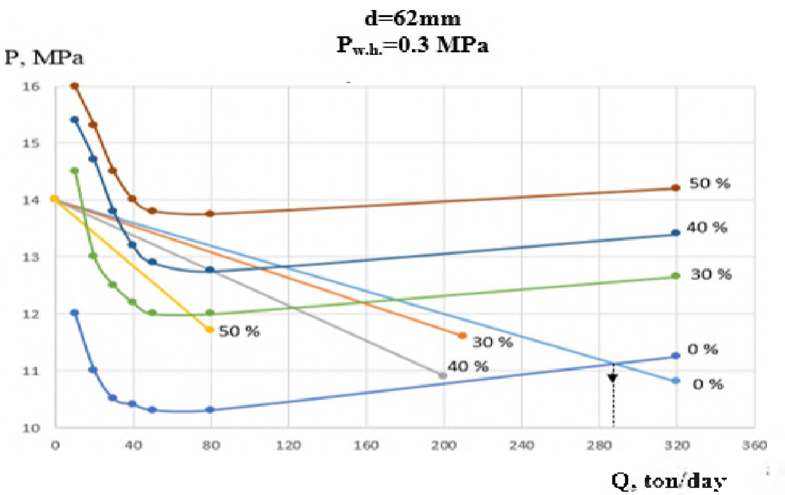

Figure 11. Determination of the limit value of the fountain condition (in different water-cut, %)

According to the established graphs, the intersection point of the indicator line with the characteristic curve of the riser in the case of waterlessness (β_{water}=0%) allows determining the well's gush mode without water-cut: P_{wb} = 11.2 MPa and Q=288 t/day. Then, using the dependence K=f(β_{water}) (Fig. 10) for different water-cut in the graph, indicator curves for different water-cut cases were also constructed. Thus, the mode characteristic of the well's operation at different water-cut degree was determined, and the values of Q_m , and $\Delta P = P_l - P_{wb}$ parameters are given in Table 4.

As can be seen from Figure 11, at 50% water-cut, the indicator line does not intersect the characteristic curve of the riser. That is, the well cannot produce a fountain at this water-cut. However, the well produces a fountain when β_{water} = 40% water-cut. It is likely that the limit value of the water-cut for a fountain well is between 40 and 50%. By interpolation, it can be determined that the fountain stops when β_{water} = 42.0%. As can be seen from Figure 10, at this water-cut limit, the productivity coefficient is K=60 t/(day·MPa).

Under the given conditions, the minimum bottomhole pressure for fountain at 42% water content was $P_{wb.min}$=12.88 MPa.

The flow regime of a liquid-gas mixture in a riser pipe was also investigated based on multiphase technologies. The following two cases were considered:

1. The well fluid is not watered. That is, under the given conditions, a homogeneous flow of oil, a dispersed form of movement, exists in the riser. Since the volumetric gas capacity has a large value, the gas phase is considered as the leading-dispersed medium, and the oil is considered as the dispersed phase. Therefore, the maximum value of the pressure gradient along the cross section can be calculated by the following formula:

$$(dP/dr)_m = 6{,}16 \cdot \bar{\rho}_{mix} v_{mix}^2 / d \quad ;$$

$$v_{mix} = \frac{4\, Q_{mix}}{\pi d^2}$$

Here $\bar{\rho}_{mix}$ – the average density of the mixture, kg/m^3; d – diameter of the riser, d=0.062 m; Q_{mix} and v_{mix} are the mixture flow rate $(\frac{m^3}{s})$ and velocity $(\frac{m}{s})$, respectively.The calculated values of $\bar{\rho}_{mix}, Q_{mix}, v_{mix}$ and $(dP/dr)_m$ for oil-gas mixtures at different water-cut percentages are given in Table 4.

The variation of the multiphase mixture velocity (v_{mix}) and the pressure gradient $(\frac{dP}{dr})$ across the riser cross section as a function of the percentage of water-cut of the well product is shown in Figures 8 and 10, respectively. The variation of the well operating mode depending on the water-cut is given in Table 4.

Table 4

Well operating parameters at different water-cut (β=0.979)

β_{water},%	K $\frac{t}{day \cdot MPa}$	P_{wb}, MPa	Q_m, $\frac{t}{gün}$	ΔP, MPa	$\bar{\rho}_{mix}$, $\frac{kq}{m^3}$	Q_l, $\frac{m^3}{s}$	Q_g, $\frac{m^3}{s}$	Q_{mix}, $\frac{m^3}{s}$	v_{mix}, $\frac{m}{s}$	$(\frac{dP}{dr})$ $\frac{MPa}{m}$
0	100	11,12	288	2.88	810	0.0041	0.1927	0.1968	65	340
20	95	11.65	220	2.35	884	0.0029	0.1363	0.1392	46	170
30	83	12.22	148	1.78	921	0.0019	0.0893	0.0912	30	72
40	65	12.82	77	1.18	956	0.0009	0.0423	0.0432	14	15
42*	60	13.25	45	0.75	964	0.0005	0.0235	0.024	8	5
50	36	-	-	-	995	-	-	-	-	*

*- After this water-cut degree, the fountaining stops.

2. Various cases of product hydration (20, 30, 40, 42 and 50%) were considered. In this case, it was also investigated at what percentage of hydration the fountain ends and at what minimum bottomhole pressure it occurs at this time. Considering that $P_{wb} > P_p$ according to the condition of the case, the existence of a multiphase dispersed motion regime was checked. For this purpose, the calculated values of the pressure gradient formed along the cross section of the riser were compared with the difference in the specific gravity of the phases $(\bar{\rho}_l - \bar{\rho}_g)$ g. It should be noted that in this case - was taken as the average density of the oil-water mixture. The gas density was calculated taking into account the minimum wellhead pressure and the minimum bottomhole pressure.Considering that

these densities are 4.2 and 15.1 kg/m^3, respectively, $\bar{\rho}_g$=15.1 kg/m^3 was adopted for the calculation. Thus,

$$g(\bar{\rho}_{mix} - \bar{\rho}_g) = 9{,}81(964\text{-}15{,}1) = 9310\,\frac{Pa}{m} = 0{,}01\frac{MPa}{m}$$

As can be seen, the gradient dP/dr is 500 times greater than the difference in the specific gravity of the phases (in the considered case dP/dr=5MPa/m). That is, in all considered cases of hydration, a dispersed form of the flow will exist. Against the background of the latter calculation, it is also possible to calculate the value of the critical velocity corresponding to the transition of the flow from a dispersed form to a stratified (in the form of separate phases) regime of motion.

$$v_{cr} = \sqrt{\frac{\frac{dP}{dr} \cdot d}{6{,}16 \cdot \bar{\rho}_{mix}}} = \sqrt{\frac{10^5 \cdot 0{,}062}{6{,}16 \cdot 946}} = 1{,}03\ \frac{m}{s}$$

As can be seen, for a gas-liquid mixture with a volume gas capacity β=0.997, this is a very small velocity, and the mentioned regime will not be possible to realize during the gush period.

As one of the important results, it should be noted that, as can be seen from Figure 12, it is possible to diagnose the end of the well's gush cycle based on the change in the pressure gradient along the cross section of the riser depending on the percentage of product hydration. Thus, approximately 40-41% product hydration, which corresponds to the minimum value of the parameter $(\frac{dP}{dr})$, This is an indirect sign that the fountain is about to end.

Thus, the effect of well product liquefaction on blowout was studied based on multiphase technologies. A diagnostic method was developed to determine at what percentage of liquefaction the blowout is completed and at what value of bottomhole pressure it occurs.

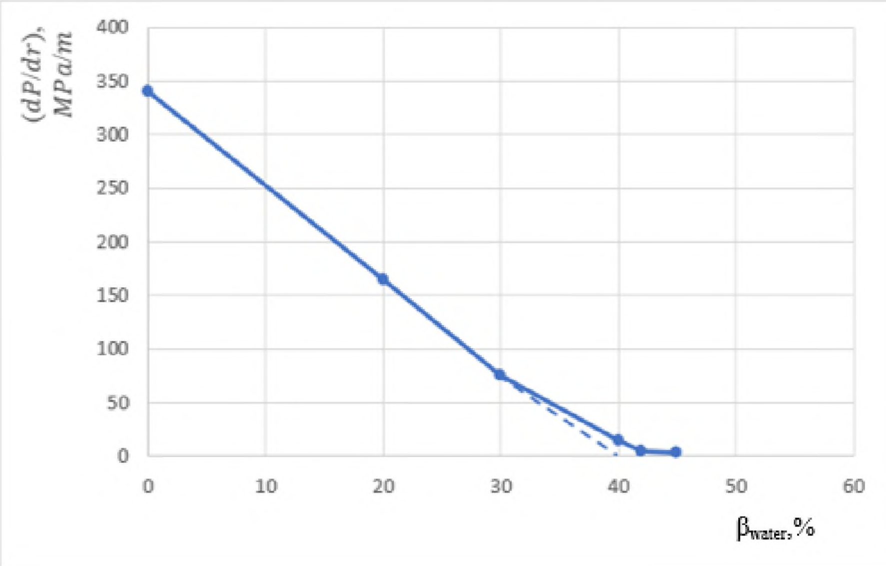

Figure 12. Dependence of pressure gradient on water-cut percentage

The work shows the possibility of diagnosing the technological condition of a gas pipeline during multiphase flows. If the ranks calculated according to the gas composition change without obeying the additivity rule, then a structural change (phase transformation) occurs in the pipeline. If the rank values change despite the additivity rule being satisfied, this indicates the separation of the liquid phase (hydrocarbons and water) in the pipeline.

Methodological guidance for diagnosing the technological condition of multiphase gas pipelines has been developed and approved by SOCAR.

This chapter of the dissertation examines the issues of diagnosing the structural forms and actual characteristics of multiphase flows in a fountain (gas lift) riser and in vertical pipes.

Structural analysis of gas-liquid flows in the risers of fountain and gas lift wells, as well as in the vertical pipes of submarine pipelines, shows that in the form of a bubble (emulsion) structure, the dispersion of the system is usually high, since the size of the gas bubbles is very small, and their sliding in the liquid due to the Archimede force (sliding speed) is very weak, so the mixture is considered a homogeneous system. As the pressure decreases as they rise in the risers, these gas bubbles increase their volume and, merging with each other, become even larger. Thus, the sliding of the bubbles relative to the liquid phase begins to manifest itself and gradually various structural modes begin to form.

In general, although there is no clear transition boundary between individual structures, it is currently accepted that three main structural forms for bottom-up flows exist and are more widespread: dispersed (emulsion), plug and annular structures.

In multiphase flows, the transfer of matter and energy across a cross-section does not occur solely by turbulent diffusion. This process is also caused by the directed motion of the medium. The driving force for such transfer is the pressure gradient that develops across the cross-section.

In a multiphase gas-liquid flow in a vertical pipe with a diameter D, the interaction of a gas particle (bubble) with a diameter d with the leading phase occurs as follows: During the movement from bottom to top, due to the influence of dynamic pressure, the gas bubbles close to the walls of the pipe move as quickly as other bubbles. In this case, phase shift can also occur. Depending on the intensity of the formed gradient-velocity field, the following situations can exist:

- $dP/dr<(\rho_l - \rho_g)$. The (gas bubbles) close to the pipe surface continue to move along the cross section without changing their positions with the flow velocity (ρ_g-gas density).

- $dP/dr>(\rho_l - \rho_g)g$. In this case, the bubbles located close to the pipe wall will be under the influence of the Bernoulli force directed towards the center of the flow.

Due to the effect of the force F, which is the substitute for the Bernoulli (F_B) and dynamic pressure (F_d) forces, the gas bubbles near the pipe wall increase their speed and move towards the center of the flow. For cylindrical flows, based on the above-mentioned equilibrium condition, the following expression can be written, taking into account expression (2), to evaluate the Bernoulli force:

$$F_B = 0{,}167\pi d^3(\rho_l - \rho_g)g \qquad (13)$$

As can be seen from the last expression, this force directed from the pipe wall towards the flow axis increases more intensively as the diameter of the gas bubbles increases.

For example, for the case of d = 10 mm, ρ_g= 10 kg/m^3 and ρ_l = 800 kg/m^3, the dependences of the Bernoulli force on the diameter of the gas bubble and the ratio of the densities of the phases are shown in Figure 13 for diameter values of 2.5 and 10·10^{-3} m.

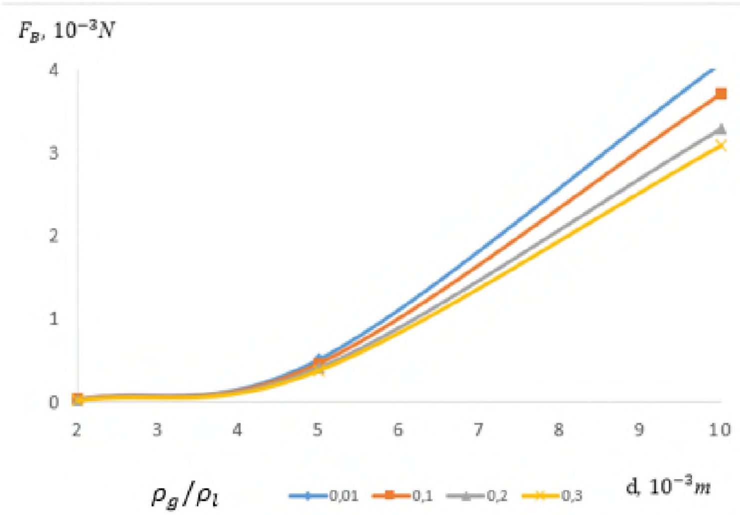

Figure 13. Dependence of Bernoulli force on the diameter of gas bubbles

Based on the known diameter of the gas bubbles (d) and the pipe diameter (D), it is also possible to calculate the speed at which the bubbles are transported to the flow core. In order to calculate the value of the transport speed in accordance with the above-mentioned equilibrium condition, the following expression was obtained after simple transformations:

$$u = \frac{1}{4}\sqrt{\left(1-\frac{\rho_q}{\rho_m}\right)\frac{g\cdot D}{\frac{d}{D}\left(1-\frac{d}{D}\right)\left(2-\frac{d}{D}\right)}}$$

Based on the last expression, calculations were made for the values of ρ_l= 800 kg/m^3 and D = 0.12 m and the dependences of the transport rate on the ratio of the densities of the phases ρ_g/ρ_l and the diameter of the bubbles (d) were established (Figures 14 and 15). As can be seen from Figures 14 and 15, with an increase in the diameter of the bubbles and the ratio of the densities of the phases, a significant decrease in the transport rate of gas bubbles (dispersed phase) to the center of the flow occurs most often with an increase in the diameter of the bubbles.

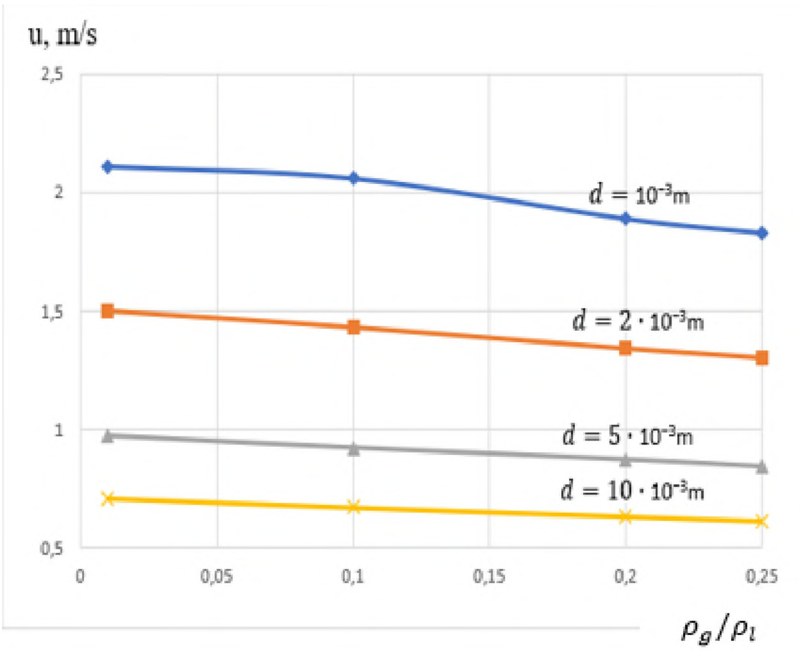

Figure 14. Dependence of transport velocity on the ratio of phase densities

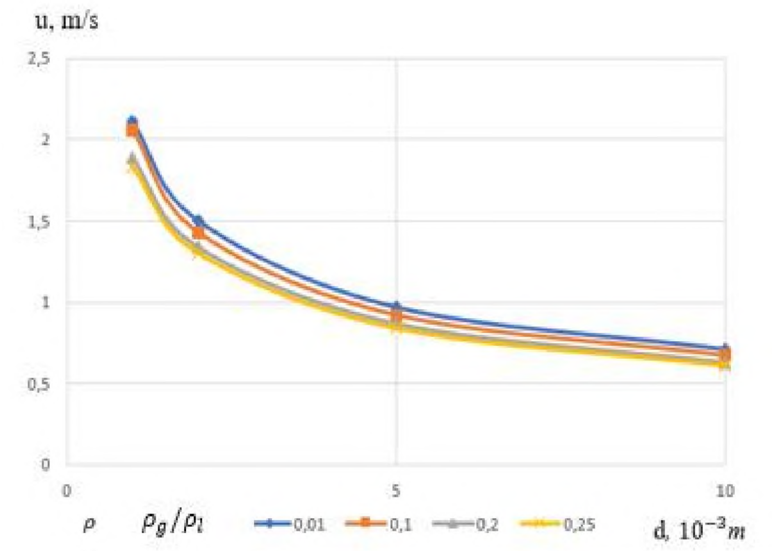

Figure 15. Dependence of transport velocity on the diameter of gas bubbles

The formation of structural regimes of vertical multiphase flows occurs not only due to the pressure drop along the length (height) of the risers and the separation of gas, but also due to the migration of gas bubbles into the flow core due to the Bernoulli force created by the pressure gradient changing along the cross section of the riser. Therefore, as in horizontal flows, it is important to take into account the interaction of phases during hydrodynamic calculations for vertical flows.

The effect of phase shift on the actual parameters of a multiphase mixture in a fountain (gas lift) lift was studied and ways to reduce the effect of the shift effect were shown.

The work examines the issues of diagnosing the stationary characteristics of multiphase viscous-plastic systems (water emulsions, drilling mud, partially degassed rheological complex oils).

During the transportation of products extracted from offshore fields, despite the preparation of the gas in accordance with the design requirements, phase transformations (condensation or re-separation) occur. Depending on the phase state of the natural gas and the relief (gravity forces) of the transportation pipeline, it is very important to maintain or ensure its single-phase dispersed state along the flow. This chapter also discusses a method for ensuring stable operation of the gas pipeline by maintaining the dispersed state of the natural gas.

The chapter 7 of the dissertation is dedicated to the modeling of reservoir - well system, the determination of optimal operating modes of wells based on the establishment of their joint characteristics, and the development of scientifically sound methods for periodic monitoring of well operation based on operational data.

The experience of developing oil and gas fields, both in Azerbaijan and in other countries of the world, shows that the development of innovative and intellectual methods aimed at solving the issues of increasing production from fields while saving energy and resources is of great relevance. Such solutions are becoming more relevant at the final stage of oil field development, or rather, during the decline in production. One of such solutions is the creation of intelligent information systems, the development of innovative methods that allow optimizing oil production based on joint modeling of reservoir-well systems, organizing the efficient operation of gathering-transportation systems, and solving other issues, allowing for increasing the efficiency of technological processes[7]. Thus, using “intelligent reservoir” and “smart well” models, it is possible to promptly collect and process data on exploitation facilities, as well as conduct an analysis of the reservoir-well-gathering system based on retrospective analysis and make operational decisions to optimize technological processes.

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[7] Bobb, I.F. International experience of the creation of oil and gas IT-technologies for the modeling of deposits // Georesursy. -2018. - T.20, №3. - p. 193-196.

Such modeling not only allows for modeling of individual wells, but also allows for making adjustments necessary to optimize oil and gas production during well operation[8].

In general, the production rate is determined by the difference between the average formation pressure and the bottomhole pressure in the well. In practice, the following two methods are most commonly used:

- Constant productivity coefficient (K_p) method;
- Fogel method.

The constant productivity coefficient (Km) method or linear productivity coefficient method is the production that assumes that the productivity of the well remains constant and corresponds to a unit of energy consumption.

$$K_p = \frac{Q_p}{P_{lay} - P_{q.d.}}$$

Here, Q_l- total liquid production of the well $(Q_o + Q_w)$;

P_{res}- average value of static reservoir pressure;

$P_{w.b..}$ - is the pressure at the bottom of the well during operation.

The second method, called the Fogel method, allows programming the maximum production of a well. It should be noted that this method can be applied to any reservoir, taking into account the water-pressured reservoir regime. This method can also be applied to wells with free gas in their product. The equation proposed by Fogel is as follows:

$$\frac{Q_p}{Q_{max}} = 1.0 - 0.2\left(\frac{P_{w.b.}}{P_{res}}\right) - 0.8\left(\frac{P_{w.b.}}{P_{res}}\right)^2 \qquad (13)$$

Q_{max}- is the maximum fluid output.

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[8] Перциянцев, М.Н. Oil production in complicated conditions. / M.N. Percyantsev. Moscow: OOO Nedra-Business-center, - 2010. - 653 p.

As can be seen, the dimensionless production ratio $\frac{Q_m}{Q_{max}}$ can be determined based on the pressure ratio. In this case, the maximum production (Q_{max}) is considered to be achieved when the depression is 100%. At any given production of fluid, the flow characteristic to the well at a given bottom pressure can be determined based on expression (13).

The hydraulic characteristic for a risers in accordance with multiphase technologies allows, in addition to take into account friction and gravity losses, to determine the mode of movement of the multiphase flow (Fig. 16).

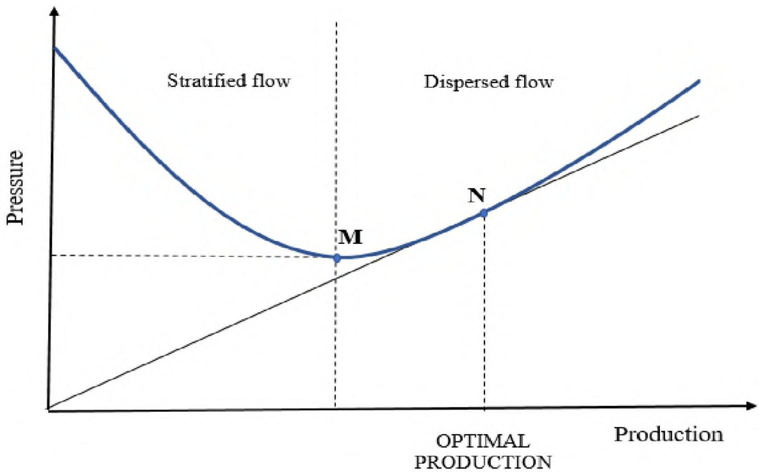

Figure 16. Structural regime change during multiphase flow

As can be seen from Figure 16, a stratified flow pattern exists to the left of point M, and a dispersed (bubbly) flow pattern exists to the right. In this case, the point corresponding to the optimal operating mode is point N, and this point is determined by the tangent drawn from the coordinate origin.

The operating characteristic curves of the riser pipes andIt is possible to evaluate and optimize the operating modes of wells based on the construction of the reservoir characteristic curves and the determination of their intersection point. Since the intersection point of these characteristics will determine the production value at a given total pressure level for the modeled well. The intersections of the hydraulic characteristics with the reservoir characteristic for various multiphase flows (risers) are shown in Figure 17.

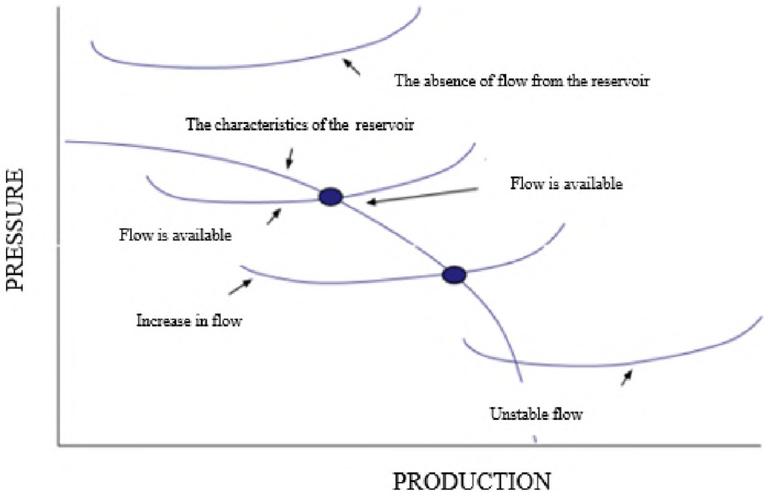

Figure 17. Variants of the joint characteristics of the riser and the reservoir

As can be seen from Figure 17, it is also possible that these characteristics do not intersect. This case would correspond to the absence of flow from the reservoir. As can be seen, for the lift to operate efficiently, it must intersect the reservoir characteristic curve not at the minimum value of its characteristic, but at a point to the right of it. Otherwise, that is, if it intersects to the left of the minimum point, then the operating mode will be unstable, and the flow will be separated into layers (phases).

Based on the modeling of the reservoir-well system, the combined characteristics of the wellbore and the flow from the reservoir to the wellbore were established in accordance with the above-mentioned multiphase technologies (Figure 18). In the figure, the characteristics of the wellbore were established for different diameters of pipes, and the intersections of these characteristics with the reservoir characteristics were analyzed.

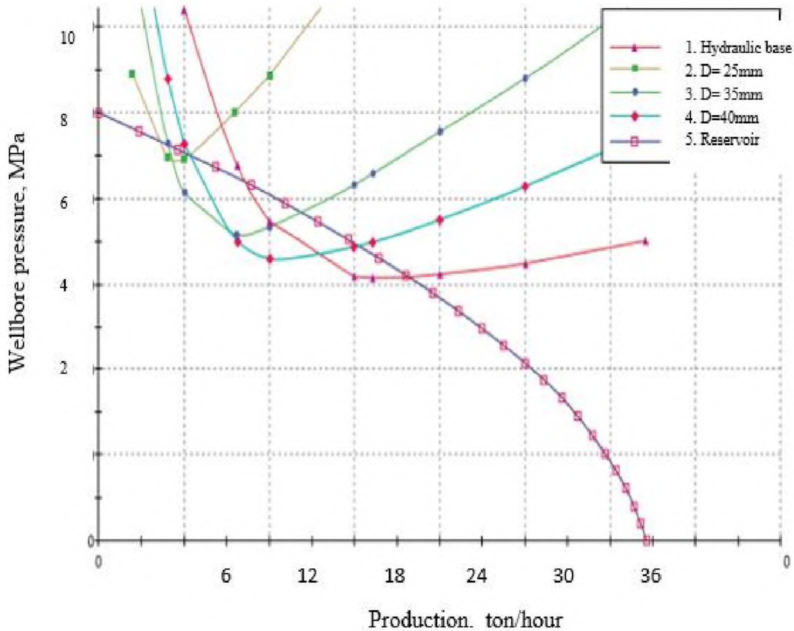

Figure 18. Joint characteristics of the reservoir -well system (simulation for risers of different diameters)

As can be seen from Figure 18, the established joint characteristic can be considered as a calculation diagram for pump-compressor pipes. Thus, as can be seen from the figure, for the base variant, that is, when a riser with a diameter of 50/75 mm is used in the well, the well production will be 20 tons/hour in accordance with the intersection of the well-reservoir characteristics. If small diameter pump-compressor pipes are used in the well, then the well's production will decrease. For example, at diameters of 40; 35 and 25 mm, the well's production will decrease accordingly and will be 15, 12, 4 tons/hour. Thus, as can be seen from the figure, it will not be possible to achieve maximum production (35 tons) at any diameter of the riser. Therefore, in such cases, it would be more expedient to choose a way to reduce the wellhead pressure in the pump-compressor pipes in order to increase the well's production.

Thus, the study of the issues of establishing optimal operating modes in fountain (gas lift) wells based on the joint characteristics of the well-reservoir system shows that modeling the flow from the formation using the Fogel method, and building the hydraulic characteristics of risers where multiphase flows exist in accordance with the new theory of the velocity-gradient field and based on a new physical model of flow, allows for a more accurate determination of the operating characteristics of the risers. On the other hand, such an approach also allows for the determination of the formation of stratified or dispersed flow, which is one of the main structural forms in riser pipes.

MAIN RESULTS

1. The necessity of creating multiphase technologies in oil and gas production and hydrocarbon transportation is shown, and its scientific and experimental aspects are substantiated. Based on the theory of the gradient-velocity field and a new physical model of flow, the possibility of constructing simple mathematical models that allow solving engineering problems without making large errors and applying them to analyze and increase the efficiency of technological processes formed in a multiphase manner is shown.
2. It was determined that the main problem of efficient utilization of associated petroleum gases is related to their multiphase nature. Thus, during the transportation of these gases, the condensation of propane-butane fractions and their deposition in the pipeline significantly increase pressure losses and significantly reduce the transportation distance, which does not allow for their efficient utilization. The feasibility of taking into account gas

resources when selecting technological equipment for the purpose of efficient utilization of gases has been shown.

3. The Bernoulli force, which is the driving force of the interaction of phases in multiphase flows, has been evaluated for oil and gas pipelines depending on the flow velocity. It has been established that the maximum acceleration created by this force, directed from the edges of the flow towards the center, can be even 1400 and 600 times greater than the free fall acceleration for the flow velocity of the dispersed medium of 15 and 10 m/s, respectively. It has been found that the maximum value of the Bernoulli force along the cross section corresponds to the radius of the pipe 0.577R.

4. Unlike single-phase flows, the pressure distribution along the flow path in multiphase flows decreases exponentially depending on the degree of compression of the mixture and the mode of movement. The greatest decrease occurs in the laminar mode and when the degree of compression is high.

5. It has been determined that the pressure level in multiphase pipelines has a significant effect on the pipeline's throughput (mixture flow). It has been shown that in real pipelines, depending on the average pressure, the mixture flow rate can increase by up to 60% with increasing pressure.

6. During the assessment of dynamic loads (pressures) typical of multiphase flows and occurring in the turns of pipeline routes, in gravitational flow zones, in places where the density of the transported medium changes, etc., the dependence of the dynamic pressure arising on the volume gas content of the mixture and the density of the phases was determined. It was found that this pressure increases with increasing gas content, and decreases with increasing the ratio of the densities of the phases.

7. A methodology for determining multiphase flow zones and gravity losses with a rail is proposed. The minimum pressure losses in the flow characteristics of multiphase mining pipelines, depending on the degree of hydration and degassing, are determined.

8. A concept has been developed based on multiphase technologies for the efficient collection and transportation of gas-condensate mixtures from offshore fields:

- The importance of choosing the correct hydrodynamic regime for protecting multiphase subsea gas pipelines from the mechanical effects of mechanical particles (dispersed phase) that cause erosion-corrosion wear has been shown. Thus, if the speed of movement of the gas (dispersed medium) ensures the transportation of these particles with the gas flow, their accumulation and oscillation on the pipe surface will not occur;
- It has been established that for the efficient operation of a multiphase gas pipeline transporting gas-condensate mixtures, it is very important to correctly select its diameter in accordance with the dynamics of field development. Unlike single-phase (gas), the transportation distance of a multiphase gas-condensate mixture is limited depending on the diameter. The efficiency of collecting and transporting condensable gases or gas-condensate mixtures largely depends on the consideration of gas resources and the correct selection of transportation technology.

9. Based on numerous laboratory studies, it has been established that "undesirability" when mixing different oils can also be manifested by intensive sedimentation of various ballasts. When mixing Karachukhur and Bulla oils in a ratio of (42:58%), the sedimentation of ballasts is completed within 10 hours. Based on rheological studies of the mixed oils, a method has been proposed to determine the probable value of the transition temperature (sedimentation) to structural formation during their extraction from the well and movement in intra-field gathering and transportation lines.

10. A mathematical model has been proposed to predict how the viscosity of stable oil emulsions changes depending on the degree of dilution.

11. Based on the results of laboratory tests, it has been determined that increasing the degree of hydration and cooling rate of oils can significantly increase their freezing point.

12. The reason for the low efficiency of centrifugal separation of multiphase mixtures into phases is explained, and the possibility of preventing the negative impact of the Bernoulli force generated across the cross section in cylindrical flows on the operation of the device is shown, based on the correct selection of technological parameters.
13. A grapho-analytical method has been proposed for the assessment of free-flow oil spills in multiphase pipelines. It has been established that even in the worst case, complete discharge of the oil pipeline is not possible. During accidental spills, complete discharge of the pipeline in free-flow mode is possible only if holes are formed at the extreme points of the pipeline (at the maximum and minimum points of the profile) during the accident.
14. The effect of well product liquefaction on jetting was studied based on multiphase technologies, and a diagnostic method was developed to determine at what percentage of liquefaction the jetting ends and at what value of bottomhole pressure it occurs.
15. The possibility of diagnosing the technological condition of a multiphase gas pipeline based on the composition of the transported gas (gas mixtures) has been demonstrated. It has been substantiated that the change in the ranks calculated according to the dynamics of changes in the components of the gas mixture, not obeying the additivity rule, is a structural change (phase transformation) in the pipeline, and the change in the rank value, while obeying the additivity rule, is an indirect indication of the separation and precipitation of the liquid phase, i.e. hydrocarbons and water.
16. For the first time, it has been substantiated that the formation of structural regimes in fountain (gas lift) risers and risers occurs due to the migration of gas bubbles into the flow core due to the influence of the Bernoulli force created by the pressure gradient changing along the flow cross-section.
17. The effect of phase shift on the density of a multiphase mixture in vertical pipes and fountain (gas lift) risers was investigated, and the effect of volume flow on the density of the mixture at different gas capacities was investigated. It was

determined that the density of the mixture increases monotonically with increasing gas relative velocity. In order to reduce the slip effect, it was proposed to switch to a smaller diameter riser pipe and increase the fluid flow rate.

18. A methodology has been developed for determining the time to reach a stationary operating mode for multiphase visco-plastic laminar flows, taking into account inertial forces. The dependence of this time on the parameter 8ν/R2 as well as on the formation of the flow core (r0/R), which is determined by the initial shear stress (τ0), has been determined.

19. The importance and significance of using transportation technology that allows maintaining the dispersed state of multiphase gas in order to ensure stable operation of the gas pipeline has been theoretically and experimentally substantiated. The feasibility of using mechanisms for obtaining dispersed systems, including a "drill" device that creates a vortex motion, to ensure its single-phase nature during natural gas transportation has been shown. During laboratory tests, it was also determined that such a design also reduces harmful pressure pulsations many times over.

20. Based on the modeling of the reservoir-well system, the possibility of establishing and optimizing the technological operating mode in production wells in accordance with the combined hydraulic characteristics of the flow into the well and the movement in the riser in accordance with the new physical model of multiphase flow has been shown.

The main results of the dissertation are reflected in the following scientific works:

1. İskəndərov, E.X., İsmayılova, F.B. Dəniz qaz-kondensat yataqlarından karbohidrogenlərin yığılmasının səmərəliliyi haqqında // İsrafil Quliyevin anadan olmasının 100 illik yubileyinə həsr olunmuş "Dəniz neft və qaz yataqlarının işlənilməsinin aktual problemləri" mövzusunda konfransın materialları, - Bakı: - 2017, - s. 6-12.

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Claimant's personal contribution in published works and dissertation.

[23], [29], [31], [39], [46], [47], [50] – It was carried out independently (without co-authorship).

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