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**ABSTRACT**

Of the dissertation for the degree of Philosophy Doctor

**ADVANCEMENT OF HYDROCARBON PRODUCTION,  
TRANSPORTATION, AND STORAGE EFFICIENCY  
THROUGH INNOVATIVE METHODS AND  
TECHNOLOGICAL MODELS**

Specialty: 3354.01 - Construction and operation  
of oil and gas pipelines, terminals, and  
storage facilities

Field of science: Technical sciences

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The work was performed at the Scientific-Research Institute of “Geotechnological Problems of Oil, Gas and Chemistry” under Azerbaijan State Oil and Industry University PLE.

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## GENERAL CHARACTERISTICS OF THE STUDY

### **Relevance and degree of development of the topic.**

The efficiency of oil and gas production, gathering, preparation, transportation, storage, and processing depends on the methods and technologies applied in design and operation.

Stable functioning of hydrocarbon gathering and transportation systems and prevention of technological complications are possible only through modern methods. Such complications disrupt pipelines and equipment, increase production costs, and cause delays and shutdowns.

One of the most frequent problems is the presence of asphaltene–resin–paraffin (ARP) compounds in well products from the bottom-hole zone. They form deposits on internal surfaces, reduce equipment efficiency, and may lead to accidents. Considering that the most resistant part of these deposits consists of asphaltene–resin complexes, developing new technologies for their decomposition and removal is of particular importance.

In some gas-condensate wells of the Azerbaijani sector of the Caspian Sea, pressure decline causes retrograde condensate and liquid blockages, which hinder hydrocarbon gathering. New technologies for cleaning the bottom-hole zone from such blockages have significant scientific and practical value.

The main complication in subsea gas pipelines is hydrate formation. Hydrates disrupt system operation, cause accidents, material losses, and environmental problems. Therefore, timely detection of hydrate onset and effective prevention methods are of great importance.

Compressor stations are among the key facilities of oil and gas production systems. In Azerbaijan, the operation of gas-turbine centrifugal compressors and underground gas storages under varying compression parameters necessitates new improvement methods. Evaluating the effect of compressor design on reciprocating compressor pulsations can be useful in pre-project studies. At the same time, utilizing supersonic gas flow to develop new technological processes can provide higher efficiency.

These issues are specific and relevant to the oil and gas industry. The scarcity of similar studies highlights the originality of the research conducted in this dissertation.

### **Object and Subject of the Research.**

1. Physical and chemical processes in the bottom-hole zone (BHZ) of oil and gas-condensate wells and production technology. The subjects of the research: cleaning the BHZ of oil wells from ARP (asphaltene–resin–paraffin) deposits and cleaning the BHZ of gas-condensate wells from liquid blockages.

2. Transportation of natural gas through subsea pipelines and hydrate prevention. The subjects of the research: development of an analytical method for determining the onset of hydrate formation and development of a method for preventing an already initiated hydrate formation process.

3. Compressor stations in natural gas gathering, transportation, and storage systems. The subjects of the research: development of an optimal technological model of gas-turbine compressor stations; improvement of compressor station operation under conditions of variable compression parameters and development of a method for modeling compressor stations of underground gas storage (UGS); development of a method for evaluating pulsations of reciprocating gas compressors; development of new technological processes based on the supersonic flow of natural gas.

### **Aim and Objectives of the Research.**

The aim of the research is the development of innovative methods to increase the efficiency of hydrocarbon production, transportation, and storage.

The main objectives of the research consist of solving the following complex tasks:

Improvement of oil and gas gathering and transportation processes through the development of technologies for cleaning the BHZ of oil wells from ARP deposits and the BHZ of gas-condensate wells from liquid blockages.

Development of analytical methods for determining the onset of hydrate formation in subsea gas pipelines and development of wave-

depression methods for prevention of already initiated hydrate formation.

Development of an optimal technological model of gas-turbine compressor stations, taking into account seasonal changes in ambient temperature.

Regulation of compressor productivity at low compression ratios, adjustment of productivity–power balance of compressors under high pressure conditions, and development of a technological transfer method for modeling compressor stations of UGS.

Development of a method for evaluating the effect of design features of reciprocating gas compressors on the amplitude of outlet pulsations.

Development of scientific recommendations for creation of new technological processes based on the supersonic movement of natural gas.

### **Research Methods.**

In the research process, theoretical and experimental methods were used in the development of technology for cleaning the BHZ of oil wells from ARP deposits and the BHZ of gas-condensate wells from liquid blockages; theoretical–empirical methods were used in the investigation of hydrate prevention in the transportation of natural gas through subsea pipelines; and statistical, observational, modeling, and comparative experimental methods were applied in solving the issues of regulation, improvement, and modeling of compressor station operation in natural gas gathering, transportation, and storage systems.

### **Main Provisions Submitted.**

- Technology for cleaning the filter zone of oil wells from asphaltene–resin–paraffin (ARP) deposits.

- Technology for restoring production in packerless gas-condensate wells at the final stage of operation by cleaning the bottom-hole zone (BHZ) from liquid blockages.

- Analytical method for determining the onset of hydrate formation in subsea gas pipelines.

- Wave-depression method for preventing an already initiated hydrate formation process.

- Optimal technological model of gas-turbine compressor stations considering seasonal changes of ambient temperature.

- Technological transfer methods for regulating compressor productivity at low compression ratios, balancing productivity and power under high-pressure conditions, and modeling compressor stations of underground gas storage (UGS).

- Method for evaluating the effect of design features of reciprocating gas compressors on the amplitude of outlet pulsations.

- Development of recommendations for applying new technological processes based on the supersonic movement of natural gas.

### **Scientific Novelty of the Research.**

- For the first time, a technology has been developed and field-tested for cleaning the BHZ of oil wells from ARP deposits by decomposing ARP compounds with naphthenic acids and dissolving the separated asphaltenes using pyrolysis light tar to lift them to the surface.

- For the first time, a technology has been developed for lifting condensed and blocked water in the flow channels of packerless gas-condensate wells at the final stage of operation by injecting methanol, thereby cleaning water plugs and enabling high-velocity gas flow to remove accumulated condensate. The application criteria of this technology were developed based on wells of the Gunashli field and Galmaz UGS, and field tests were conducted.

- For the first time, an analytical method was developed for determining the onset of hydrate formation in subsea gas pipelines with limited operating parameters.

- For the first time, the wave-depression method was developed to prevent an already initiated hydrate formation process, and a formula was proposed to determine the duration of valve closure at the end of the pipeline during operation.

- An efficient technological model of gas-turbine compressor stations was developed, considering seasonal changes in ambient temperature.

- Technological transfer methods were developed for regulating compressor productivity at low compression ratios, balancing

productivity–power under high-pressure conditions, and modeling compressor stations of UGS.

- For the first time, a universal method was developed to evaluate the effect of the structural features of reciprocating gas compressors on the amplitude of outlet pulsations.

- Recommendations were developed for creating new technological processes based on the supersonic movement of natural gas.

### **Theoretical and Practical Significance of the Research.**

The uniqueness of the technology for cleaning the filter zone of oil wells from ARP deposits lies in achieving a greater cleaning effect due to the deeper decomposition of resin–asphaltene compounds by naphthenic acid and the dissolution of separated asphaltenes by pyrolysis light tar. The application of this technology in heavy oil fields, where output has decreased due to ARP deposition and the number of such wells is increasing annually, may provide significant economic benefits.

The application of the technology for cleaning the BHZ of gas-condensate wells from liquid blockages can significantly increase gas intake in wells. Its implementation in previously high-rate wells such as Gunashli, 8 March, Absheron bankasi, and others, as well as in recently drilled wells of the Umid and Bulla-Deniz fields with sufficiently high reservoir pressure, can lead to both increased production and substantial economic dividends.

The methods for determining the onset of hydrate formation and wave-depression prevention in subsea gas pipelines ensure prevention and mitigation of blockages, thereby avoiding accidents, production and transportation losses, delivery issues for consumers, and eliminating potential large-scale economic damage.

The developed methods and models for regulating, improving, and modeling the operation of compressor stations in natural gas gathering, transportation, and storage systems can be applied to mitigate complications in operation.

The use of supersonic flow of natural gas can be applied in reconstruction projects of compressor stations at underground gas storage facilities.

## **Approval and Application of the Dissertation.**

The results of the dissertation were discussed at the following meetings and conferences:

1. Meetings of the Research Institute of “Geotechnological Problems of Oil and Gas and Chemistry” under Azerbaijan State Oil and Industry University.

2. Azerbaijan and Caspian Sea Oil & Gas Week. Baku, 2013.

3. Scientific Conference dedicated to the 20th anniversary of the “Contract of the Century.” Sumgayit, 23–24 September 2014.

4. Republican Scientific-Practical Conference dedicated to the 100th anniversary of Academician S.C. Mehdiyev. Baku, 2–3 December 2014.

5. XLV International Scientific-Practical Conference “Advances in Science and Technology.” Moscow, 15 June 2022.

6. International Scientific Conference “High Technologies and Innovations in Science.” Saint Petersburg, May 2022.

7. International Scientific-Practical Conference “Arctic: Modern Approaches to Industrial and Environmental Safety in the Oil and Gas Sector.” Tyumen, 28 November 2022.

8. International Scientific-Practical Conference “KhazarOilGasField”. Baku, Azerbaijan, 6–7 December 2022.

The results of the dissertation were also field-tested at “Bahar Energy” Operating Company and an act of implementation was obtained.

## **Publications.**

The main provisions of the dissertation are reflected in 23 scientific works, including 13 articles, 7 conference papers, and 3 patents.

## **Organization where the dissertation was carried out.**

Research Institute of “Geotechnological Problems of Oil and Gas and Chemistry” under Azerbaijan State Oil and Industry University.

## **Volume and Structure of the Dissertation.**

The dissertation consists of 202 pages, comprising 3 chapters, including 16 figures, 43 tables, 27 graphs, conclusions and recommendations, and a list of 145 references.

The total volume of the dissertation is 239,579 characters, including: Introduction – 12,454 characters, Chapter I – 46,521 characters, Chapter II – 152,102 characters, Chapter III – 24,935 characters, Conclusion – 3,567 characters.

## SUMMARY OF THE DISSERTATION

In the **introduction**, the relevance of the topic is substantiated, the aim and objectives of the research are defined, the problems to be solved are outlined, the scientific novelty, theoretical and practical significance, the main provisions submitted for defense, as well as the structure and volume of the dissertation are presented. The dissertation consists of three chapters.

**Chapter I** is a literature review. Here, technologies used in the collection, transportation, and storage of hydrocarbons are analyzed, and the main issues to be addressed are identified. Based on the review, the current scientific and practical level of processes, their advantages and shortcomings are evaluated, and research directions are determined. Since oil and gas gathering-transportation is part of a larger reservoir-consumer system, complications must be studied considering the entire system and interactions among its components.

Traditional studies have mainly been carried out on separate segments. This requires the use of different equipment, materials, and reagents in each segment, and sometimes actions in one segment negatively affect another, leading to reduced overall efficiency. Therefore, well operation regimes and processes occurring in the bottom-hole zone (BHZ) must also be considered. Reagents used for bottom-hole treatment may also positively influence subsequent transportation processes.

Although numerous studies have been conducted on the removal of asphalt-resin-paraffin (ARP) deposits in oil gathering and transportation, the decomposition of asphalt-resin compounds and the dissolution of the separated asphaltenes to bring them to the surface have not been studied. This issue has been included in the research.

To improve gas gathering and transportation, various technologies have been tested in gas-condensate wells to mitigate retrograde condensate effects, but results largely depend on reservoir and well properties. Therefore, additional research and field trials were planned in Azerbaijani gas-condensate fields to clarify the effectiveness of methanol treatment.

Despite numerous studies on hydrate formation, offshore trunk pipelines still lack effective methods to timely determine the onset of hydrate formation and to eliminate hydrates once formed. Addressing this problem was considered necessary.

In natural and associated gas storage, particularly in underground gas storage (UGS), discrepancies exist between technical requirements for compressor equipment and the parameters of compressors produced by global manufacturers. Therefore, considerable attention has been given to research aimed at reducing inevitable errors in design, assembly, and installation.

**Chapter II** develops new methods and technological models to enhance the efficiency of gathering-transportation systems. Initially, a technology for cleaning ARP deposits from the BHZ was developed: first, surface treatment with light pyrolysis tar; second, decomposition with naphthenic acids; and finally, dissolution of separated asphaltenes again with pyrolysis tar. This technology was tested in wells at Neft Daşları, A.C. Amirov and Absheronneft OGPDs, where significant production increases were recorded.

For deeper cleaning of BHZ flow channels, alongside pyrolysis tar, the use of naphthenic acids (as resin solvents) was investigated. Laboratory results showed that naphthenic acids decompose long-standing resin deposits, while asphaltenes can be dissolved by aromatic hydrocarbons and transported to the surface. Based on this, two new technologies were developed: one applying reagents sequentially, the other injecting them as a mixture.

In the sequential technology, components are introduced into the filter zone in the following order:

2.0 m<sup>3</sup> of light pyrolysis tar + 20 L of demulsifier (Alkan) for surface cleaning of asphaltenes.

0.1 m<sup>3</sup> of fresh water to prevent mixing of pyrolysis tar and naphthenic acid.

0.1–0.2 m<sup>3</sup> of naphthenic acid (3–6% of total composition, depending on resin mass fraction) to decompose asphalt-resin compounds and release asphaltenes.

0.1 m<sup>3</sup> of fresh water to separate pyrolysis tar from naphthenic acid.

1.0 m<sup>3</sup> of light pyrolysis tar + 10 L of demulsifier (Alkan) (≈30% of total composition) to dissolve asphaltenes released during decomposition, remove BHZ deposits to the surface, and neutralize residual naphthenic acid.

Displacement fluid – fresh water (depending on well design) to fully inject the composition into the BHZ and displace aggressive components from the wellbore and filter zone.

The holding time of the composition in the well is 1–3 hours.

As a result of well testing conducted at well No. 1862 in the Puta field of the OGPU named after A.C. Amirov, oil production increased from the previous 0.3 tons to 0.5 tons, i.e., by 67%, while water production rose to 4.0 tons (a twofold increase). During the 54-day monitoring period, production remained stable.

In the mixed technology, the components are injected into the BHZ simultaneously.

A technology for restoring production by cleaning the BHZ of liquid blockages in gas-condensate wells at the final stage of operation has been developed. For this purpose, the three-year production data of 45 wells in the Gunashli and Absheron bankasi fields were analyzed, and the following primary criteria for selecting candidate gas-condensate wells for intervention were determined: high rate of gas production decline; lack of increase (or stabilization) in oil and water production; absence of formation water ingress at the well bottom. According to the technology, a solvent such as methanol is used to increase the flow rate of gas wells whose production has declined due to condensate or water blockage.

Additional criteria for implementing the technology are as follows:

- Reservoir pressure – below 25 MPa;

- Permeability – as low as possible ( $k < 0.05$ );
- Porosity – not of critical technological importance (10–15% preferred);
- Skin factor (if calculated) – positive and as high as possible;
- Formation water salinity – as low as possible (<200 mg/l).

The volume of methanol to be injected into the well was determined as 3.0–3.5 tons per meter of the filter zone thickness. Well testing was conducted at well No. 204 of the Qalmaz UGS as follows:

1. The geometric volumes of the well, including the central, annular, and bottom sections, were determined according to the well design, and the injection scheme was specified, taking into account the specific weights of methanol and water.

2. After establishing central-annular liquid circulation, 4.3 m<sup>3</sup> of methanol solution (equivalent to the volume of suspension pipes) was injected from the center, followed by closure of the annulus.

3. The remaining 0.7 m<sup>3</sup> of methanol solution was injected, followed by 4.5 m<sup>3</sup> of displacement fluid (water). Initial pressure  $P_b = 0$  MPa, final pressure  $P_e = 18.0$  MPa. Then, with the center closed, 0.3 m<sup>3</sup> of displacement fluid was injected through the annulus ( $P_b = 15.0$  MPa,  $P_e = 18.0$  MPa).

4. The well was sealed under pressure:  $P_{wh} = P_{ann} = 18.0$  MPa. After remaining closed for 24 hours, the well was connected to gas production.

As a result, the gas volume injected into well No. 204 increased from 17–23 thousand m<sup>3</sup>, with a share of 0.51–0.56% of total gas production, to 27–32 thousand m<sup>3</sup>, with a share of 0.84–1.72% after the intervention. Well performance remained stable.

The study yielded the following results:

1. As a result of methanol treatment of the BHZ, the share of well No. 204 in the total injected gas volume increased more than 2.05 times.

2. As envisaged by the proposed technology, under thermobaric conditions characteristic of wells in gas reservoirs over many years of operation (8.0–16.0 MPa pressure, 60–70°C temperature), condensate

water deposited and blocked the flow channels of the BHZ, which can be brought to the surface using methanol. The removal of water blockages ensured that high-speed gas flow in the channels also cleared condensate accumulations from the BHZ.

3. Application of the technology is recommended for other wells in the UGS, particularly for gas-condensate wells with decreased reservoir pressure, to clean the BHZ from liquids and increase well productivity.

The dissertation also addresses the development of an analytical method to determine the onset of hydrate formation in subsea gas pipelines. It is noted that under conditions of sharply reduced ambient temperature, hydrate formation occurs within a few hours. Without urgent and operative measures, pipeline blockage due to hydrate formation is inevitable<sup>1</sup>.

An analytical method to forecast the onset of hydrate formation is presented below.

The gas volume transported through the pipeline (without considering relief)  $Q$ , million m<sup>3</sup>/day, is calculated using the following formula<sup>2</sup>:

$$Q=3.32 \cdot 10^{-6} \cdot d^{2.5} \sqrt{\frac{P_b^2 - P_e^2}{\lambda \Delta T_{ave} Z_{ave} L}} \quad (1)$$

where:  $d$  – internal diameter of the pipe, mm;

$P_b$ ,  $P_e$  – absolute pressures at the beginning and end of the gas pipeline, respectively, MPa;

$\lambda$  – hydraulic resistance coefficient of the gas pipeline, dimensionless;

$\Delta$  – relative density of the gas compared to air, dimensionless;

$T_{ave}$  – average temperature of the gas transported through the pipeline, K;

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<sup>1</sup> Санжаров В.В. Проблема учета влияния состава газа на условия образования газовых гидратов при решении режимно-технологических задач автоматизированного диспетчерского управления. // "Автоматизация, телемеханизация и связь в нефтяной промышленности". 2014, №9, с.38-43

<sup>2</sup> Нормы технологического проектирования магистральных газопроводов, СТО ГАЗПРОМ 2-3.5-051-2006

$Z_{ave}$  – average compressibility factor along the pipeline, dimensionless;

$L$  – length of the pipeline, km.

By squaring both sides of equation (1) and grouping the parameters on the left-hand side  $Q$ ,  $P_b$  and  $P_e$ , the following equation is obtained:

$$\frac{Q^2}{P_b^2 - P_e^2} = \frac{11,0224}{\lambda \Delta T_{ave} Z_{ave} L} 10^{-12} d^5 \quad (2)$$

On the right side of the equation, the denominator contains the hydraulic resistance coefficient  $\lambda$ , relative density  $\Delta$ , average temperature  $T_{ave}$ , average compressibility coefficient  $Z_{ave}$  and the length of the pipeline  $L$ . The change in the indicated parameters during the joint movement of gas, condensate and formed hydrate inside the pipeline when the hydrate formation process begins was analyzed. It was found that a slight increase in pressure leads to a slight increase in  $\Delta$  and  $Z_{ave}$ , which depend on the thermobaric parameters ( $P$ ,  $T$ ) that do not change significantly. The temperature of the gas entering the pipeline depends mainly on the temperatures at the outlet of the compressor station and at the final separation point of the gas entering from the gas wells, which are constant, and is also related to the ambient temperature. The temperature regime of the subsea part of the pipeline is determined by the temperature of seawater, which is constant at certain depths. Hydrate crystals formed in the gas pipeline and rapidly increasing in number cause a rapid increase in the viscosity of the mixed flow and the hydraulic resistance coefficient. A faster increase in the hydraulic resistance coefficient  $\lambda$  also results in a faster decrease in the left side of the equation.

Thus, the expression  $K = \frac{Q^2}{P_b^2 - P_s^2}$  can be accepted as an analytical indicator of the hydrate formation process and can be used as a predictive indicator in offshore gas pipelines. A more intensive increase in the  $K$  coefficient is an indicator that the hydrate plug is formed closer to the beginning of the gas pipeline.

The results of calculations carried out specifically for the Neft Dashlari-Bahar subsea gas pipeline based on the developed analytical method are reflected in Figure 1.

Also, the wave-depression method of preventing the hydrate formation process that has begun in offshore gas pipelines was developed in the dissertation work. The essence of the wave-depression method is to increase the dynamics of the non-stationary regime by strengthening wave-like processes in the movement of gas in the pipeline by closing the linear valve at the end of the pipeline and opening it after a short time, taking advantage of the special change in thermobaric and gasdynamic conditions formed due to the compressibility of the gas.

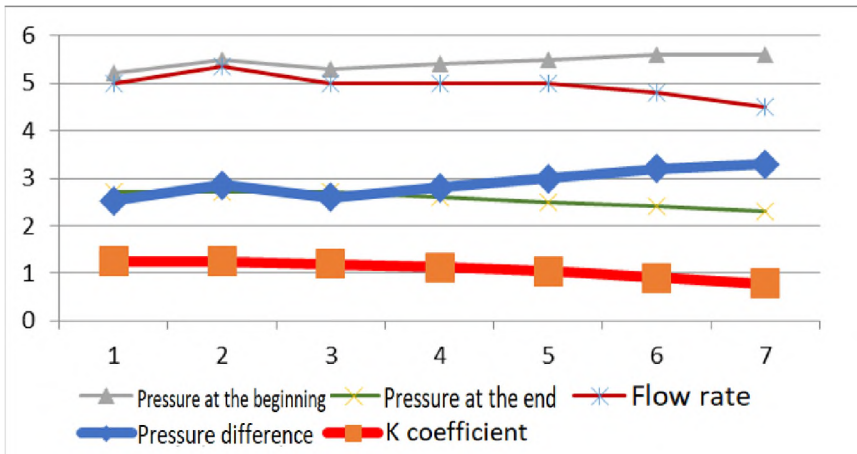


Figure 1. Changes in parameters of hydrate formation modes.

The process occurs in the following sequence:

1. As a result of closing the linear valve at the end of the pipeline, the pressure at the end of the pipeline begins to increase, gas continues to enter the pipeline (there may be a partial decrease), while the pressure increase is not accompanied by an increase in pressure at the beginning of the pipeline.

2. When an increase in pressure is observed at the beginning of the pipeline, as a result of opening the linear valve at the end of the pipeline, the gas velocity in the gas pipeline, especially in its sections near the end, increases sharply. The increase in the flow velocity forms depressions of varying degrees in different sections of the pipeline. Due to the greater depression in the sections where the cross-section

of the pipeline narrows, the liquid-hydrate compound, which is usually formed in the most depressed parts of the relief in the gas pipeline, is displaced and transported by the flow towards the end of the pipeline.

To determine the time the linear valve remains closed at the end of the pipeline, the difference in the gas volumes in the gas pipeline before and after the operation is determined.

The volume of gas in the gas pipeline is determined by the following formula:

$$V_p = V \cdot \frac{P_{ave}}{P_0} \cdot \frac{T}{T_{ave}} \cdot \frac{1}{Z_{ave}} \quad (3)$$

where:  $V = \frac{\pi D^2}{4} L$  – is the geometric volume of the pipeline<sup>3</sup>,

The average pressure in the pipeline is determined by the following formula:

$$P_{ave} = \frac{2}{3} (P_b + \frac{P_e^2}{P_b + P_e}) \quad (4)$$

where:  $P_b$  and  $P_e$  – are the pressure in the beginning and ending point in the pipeline, MPa.

Using the given expressions, the difference in gas volumes in the gas pipeline before and after the operation was determined.:

$$\Delta V = V_1 - V_2 = \frac{\pi D^2}{6} L \frac{1}{P_0} \cdot \frac{T}{T_{ave}} \cdot \frac{1}{Z_{ave}} (P'_b - P_b + \frac{P_e'^2}{P'_b + P'_e} - \frac{P_e^2}{P_b + P_e}) \quad (5)$$

where:  $P'_b$  and  $P'_e$  – are the pressures at the beginning and end of the pipeline, respectively, at the moment of opening the linear valve at the end of the pipeline, MPa;  $P_b$  and  $P_e$  are the pressures at the beginning and end of the pipeline, respectively, at the moment of closing the linear valve at the end of the pipeline, MPa.

For example, considering that the gas enters the pipeline at a rate of 4.3 million m<sup>3</sup>/day based on the change in parameters in the Neft Dashlari-Bahar subsea gas pipeline, the minute flow rate can be calculated as:

$$q = \frac{4,3 \cdot 10^6}{24 \cdot 60} = 2986 \text{ m}^3/\text{min} \quad (6)$$

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<sup>3</sup> Menon, E. Shashi. Gas pipeline hydraulics. // CRC Press Taylor & Francis Group. 2005, p.133

The valve closing time is taken as:  $t = \frac{\Delta V}{q} = \frac{102050}{2986} = 34 \text{ min.}$

Thus, using the above formulas, the following formula (7) is proposed to determine the valve closing time during operation:

$$t = 240\pi D^2 q L \frac{1}{P_0} \cdot \frac{T}{T_{ave}} \cdot \frac{1}{Z_{ave}} \left( P'_b - P_b + \frac{P_e'^2}{P'_b + P'_e} - \frac{P_e^2}{P_b + P_e} \right) \quad (7)$$

where:  $q$  - is the gas flow rate entering the pipeline, mln. m<sup>3</sup>/day.

Thus, formula (7) was obtained to determine the time the valve at the end of the pipeline is closed during operation when using the method, necessary calculations were made and recommendations were developed for the use of the wave-depression method by creating a critical flow.

One of the issues considered is the development of an efficient technological model of gas turbine compressor stations (CS) under seasonal changes in ambient temperature. The parameters of the CS at different temperatures were analyzed statistically and the best indicators were determined.

The nominal number of revolutions of gas turbines is 15,000 RPM. In summer, due to high pressure in the pipeline, overload occurs and the number of revolutions automatically decreases, as a result of which the turbine power decreases. 360 thousand m<sup>3</sup> of gas is taken daily from the 2nd stage compressors as fuel at the station. This gas, mixing with the flow directed to the pipeline, increases the collector resistance and reduces the turbine revolutions.

If the output of the 1st stage compressors is used as a fuel source, the collector load is reduced, the 1st stage productivity is increased, and only the 2nd stage compressors are used in the pipeline. This method provides an additional 0.2–0.25 million m<sup>3</sup>/day of gas transportation in the summer months and increases the overall productivity by 3–4%.

The development of UGS is of great economic and social importance. The active gas volume is possible by increasing the geometric dimensions of the reservoir or increasing the storage pressure. In the second, more efficient method, the buffer gas (up to 7.0 MPa) remains constant, only the active gas increases. In 2023, the

maximum injection pressure in UGS was 15–16 MPa. New technical solutions are required to increase it to 25–35 MPa.

The choice of compressor and technological scheme should correspond to the dynamics of gas injection: a small volume of gas is expected in April–November, and a high volume in May–September. At the same time, a low pressure at the beginning of the season and a high pressure at the end should be taken into account.

A method has been proposed that ensures the operation of UGS compressors at low compression ratios. Based on specific requirements, a model based on a G16CM34 gas engine driving a KBV/6 type compressor was selected. Studies have shown that the unit cannot operate at a pressure of 8–10 MPa, since the power consumed falls below 50% of the engine power. For this, a parallel connection scheme of 3 1st stage cylinders with 3 2nd stage cylinders was developed. In the range of 10–25 MPa, the unit operates in a conventional two-stage mode.

This scheme provides engine power regulation, low-pressure capability, and increases efficiency by 25–30%. The method is universal for all piston compressors, regardless of the type of transmission.

The work also considered the issue of regulating the efficiency-power balance of compressors under high pressures.

Calculations were carried out on the basis of Ajax 2804St type motor-compressors, capable of operating at pressures up to 37.9 MPa. In the design intended for the UGS, 3 compressor cylinders operate in parallel in a single-stage mode. As a result of the analysis of known methods of deactivating suction valves in order to regulate the efficiency-power balance in the operating experience of piston compressors, it was concluded that the deactivation of suction valves for the purpose of regulating the UGS in a wide range of outlet pressures is effective using a hydraulic control system.

Calculations have shown that 12–25% more efficiency is achieved with hydraulic regulation in CS compared to other methods. The change in efficiency depending on the discharge pressure is reflected in Figure 2.

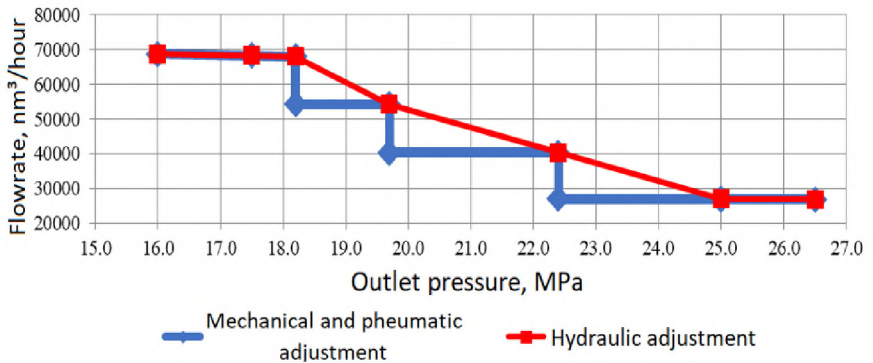


Figure 2. Variation of productivity depending on the pressure.

The development of a technological transfer method for modeling the CS of UGSs is one of the next issues considered in the dissertation work. The essence of the method is to operate the same equipment with different technological parameters at different times. To implement this method, it is enough to change only the working position of certain cranes or valves and adjust the safety valves.

The most obvious and highly economically significant example of the application of the technology transfer method is the reconstruction of the CS of the Galmaz UGS. 11 of the 16 existing 10GKNAM1/55-125 type gas motor compressors (GMCs) in the CS were retained as before. In each of the other five and two additional compressors, 4 150 mm diameter compressor cylinders (one cylinder space is empty) capable of operating up to an outlet pressure of only 12.5 MPa were replaced with 5 140 mm diameter compressor cylinders capable of operating up to an outlet pressure of 15.0 MPa, and 7 10GKNAM1/(50-53)-(70-125)/90-(125-150) type GMCs were installed.

While before the reconstruction, it was possible to operate the 10GKNAM1/55-125 type GMCs only up to a pressure of 12.0 MPa, in the new situation it was possible to inject gas into the Galmaz UGS up to a pressure of 15.0 MPa. At the beginning of the gas injection season, all GMCs operate in parallel, and when the pressure reaches a certain level, the station switches to a two-stage mode.

Based on the developed technological transfer method, a report on the thermobaric parameters of the transition to a two-stage regime at the Galmaz UGS (changes in pressure at different temperatures/pressures of the suction gas) was conducted and the dependence is reflected in Figure 3.

According to the dynamics of gas injection into the reservoir up to a pressure of 25.0 MPa at the Garadagh UGS and the productivity of motor-compressors at different suction pressures, the report requires 12 working and 4 backup compressor units. Using the technological transfer method, it is planned to use motor-compressors in two modes during the gas injection season. From the beginning of the season, that is, starting in April, when the pressure varies between 7.0-14.5 MPa, 16 motor-compressors will operate in parallel with the existing 10GKNAM and MKS12 compressors at CS No. 1 and 2. In the middle of the season, after the pressure exceeds 14.5 MPa, the gas entering from the existing compressor stations will be compressed to a pressure of 14.5-25.0 MPa using motor-compressors..

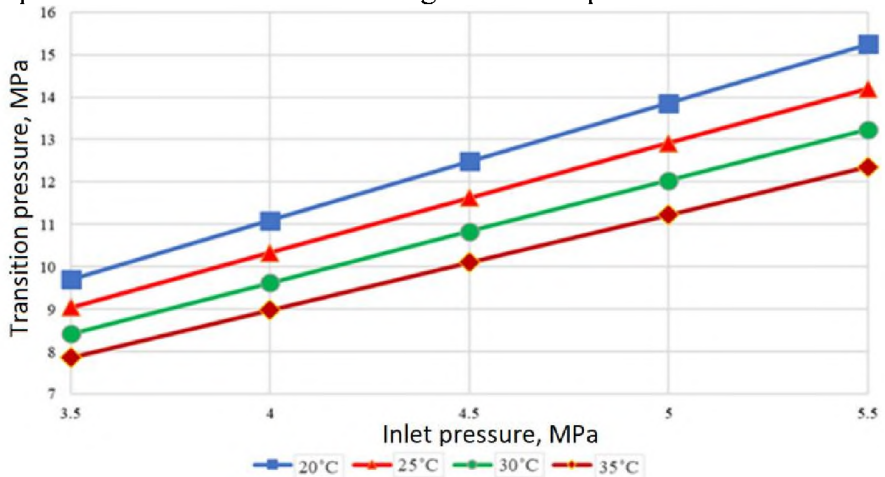


Figure 3. Graph of the transition to a two-stage mode.

Thus, based on the technological transfer method and using the features of the dynamics of gas injection into the gas storage facility, a model was created that will ensure technological and economic efficiency.

The following operational model was created for the operation of the same compressors in three different pressure-productivity modes during the season, if gas is injected into the Garadagh UGS at a pressure of up to 35.0 MPa.

24 Ajax 2804 compressors, consisting of 3 114.3 mm compressor cylinders, are operated in a 3-stage mode.

1. When the outlet pressure is 7.0-14.3 MPa, all compressors in the new CS-3 operate in parallel with the existing CS-1 and CS-2.

2. When the outlet pressure is 14.3-25.0 MPa, CS-1 and CS-2 operate at the intake of 24 Ajax 2804 (CS-3).

3. Depending on the demand, from 1 to 8 compressors (0.9-7.2 million m<sup>3</sup>/day) are switched to the operating mode at the 3<sup>rd</sup> stage in the outlet pressure range of 25.0-35.0 MPa.

The inlet pressure of the existing compressors and the new compressor-3 at the Garadagh UGS is 4 MPa, the outlet pressure is 25 MPa. and the joint operation model in the 35 MPa mode is shown in Figure 4 below.

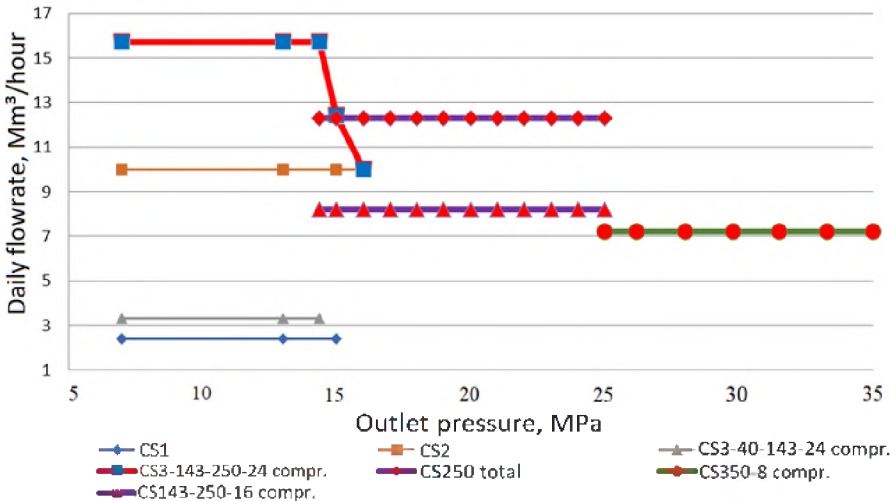


Figure 4. Work schedule of CS in the three-mode technology transfer model.

The dissertation work reflects the development of a method for assessing the impact of the design features of piston gas compressors on the amplitude of the pulsations of the outlet node. The MKS12/(75-

85)-(85-180) type gas compressors at the Garadagh UGS and the 10GKNAM1/(50-53)-(70-125)/90-(125-150) type gas compressors at the Galmaz UGS were selected as the object of research.

For comparison, a diagram of gas pressures was constructed for a period of 0.2 seconds. The diagram of gas entering the buffer capacity during this period is shown in Figure 5 for MKS12s and in Figure 6 for 10GKNAMs. With this method, it is also possible to correlate the gas volume with the angle of rotation of the crankshaft in the same time interval. On the other hand, this method allows comparing compressors according to the nature of their designs' tendency to create pulsations.

In MKS12s (Fig. 5), gas enters the buffer tank every 0.05 seconds for 0.02 seconds, that is, at a shaft rotation angle of  $48^\circ$ . Then, for 0.03 seconds ( $72^\circ$  rotation angle), gas is not supplied for more than 1.5 times the output of the compressor cylinders. Considering that a relatively large volume ( $0.406 \text{ nm}^3$ ) of high-pressure gas from the three cylinders of the compressor sequentially and intermittently enters the buffer tank at different points, it becomes clear that the dynamics of gas movement in the buffer tank is unbalanced..

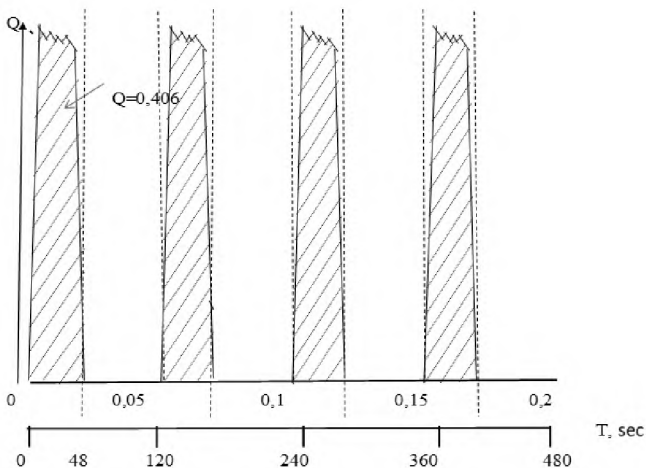


Figure 5. Diagram of gas entering the buffer tank in MKS12.

In 10QKNAMs (Fig. 6), gas enters the exhaust manifold every 0.015 seconds, which corresponds to a  $36^\circ$  rotation of the crankshaft. The process is repeated every 0.02 seconds, which corresponds to a

48° rotation of the crankshaft. After the crankshaft has rotated 36°, i.e. 0.015 seconds, gas enters from the next cylinder. Thus, during a 12° rotation of the crankshaft (0.005 seconds), gas is directed into the exhaust manifold from two cylinders in the same time interval.

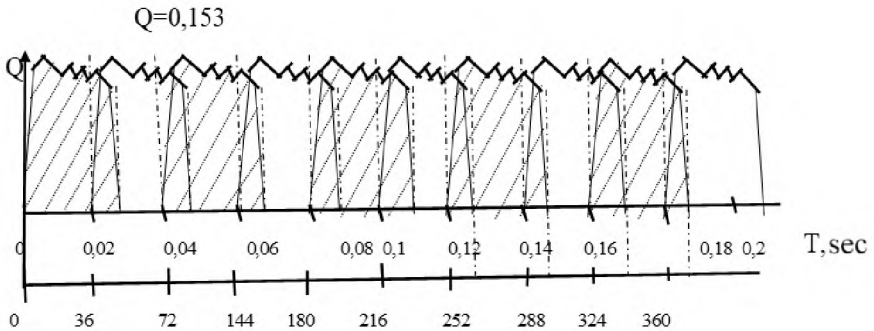


Figure 6. Diagram of gas entering the buffer capacity at 10GKNAM.

Thus, in 10GKNAMs, not only are there no intervals when gas does not enter the buffer capacity, but even during the period of 0.005 seconds, which is 25% of the entry, two cylinders work simultaneously at the outlet. The presence of 2.65 times less ( $0.153 \text{ nm}^3$ ) volume of high-pressure gas in each portion compared to MKS12 makes the gas movement much smoother and self-extinguishing.

As a result of the conducted analyses, it was concluded that it is appropriate to design the outlet manifolds of the compressors in a conical manner and has already been applied in the design of the buffer capacity of 10GKNAM GMCs. The developed method can be used in the pre-project assessment of piston compressors of any design.

The last issue studied in the dissertation is related to the development of scientific recommendations for the creation of new technological processes based on the supersonic movement of natural gas.

The thermodynamic environment arising in the supersonic movement of natural gas makes it possible to solve the following technical and technological problems:

- Cleaning of high-pressure gas produced in offshore gas-condensate fields from heavy hydrocarbons before transportation by

subsea pipelines and transportation to shore without allowing hydrate formation;

- Cooling of gas heated to high temperatures (100-120°C) as a result of multi-stage compression processes at compressor stations and rejection of numerous energy-intensive air cooling devices;

- Deep drying of gas due to deep cooling of gas in underground gas storages before sending it to consumers and rejection of less efficient throttle effect;

- Separation of propane-butane fraction from gas entering the gas processing plant at high pressure;

- Separation of heavy fractions from gas entering the gas distribution points at high pressure before supplying natural gas to the consumer system.

For comparison of the effects of gas cooling with different structural structures, the temperature changes at the outlet section depending on the outlet pressure are given in Figure 7.

In the third chapter, an assessment of the technical, technological and innovative features of the application of the developed methods and models in oil and gas industry facilities, as well as an analysis of economic advantages, was carried out.

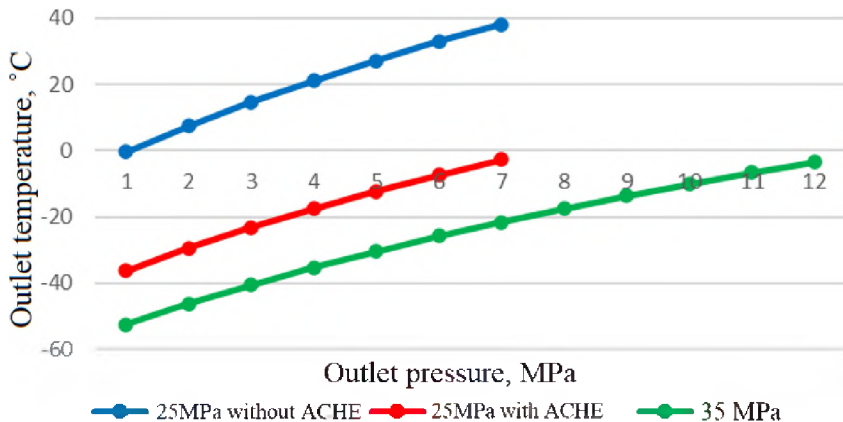


Figure 7. Temperature variation at the outlet section depending on the outlet pressure in different structural configurations.

The number of wells whose production has decreased due to ARP reaches several hundred (Sangachal-Khara-Zira-Bulla adasi,

Alat, Buzovna, Muradkhanli, etc. fields) indicates that the technology of cleaning the filter zone of wells can provide high economic efficiency.

The production of many gas-condensate wells of the Gunashli, 8 March, Absheron bankasi, Bulla-Deniz, etc. fields, which once had high debits (except for those with high marginal formation water occurrence and formation water flatness), can be restored using the technology of cleaning the well bottom zone from liquid plugs. There is no doubt that the new wells of the Umid and Bulla-Deniz fields, which currently have sufficiently high formation pressure, will also need the same intervention when the time comes.

The analytical method and the wave-depression method for determining the onset of hydrate formation in submarine gas pipelines have both technological, commercial and social significance.

The optimal technological model of gas turbine power plants in relation to seasonal changes in ambient temperature was developed using mathematical statistical methods based on multifactor analysis, ensuring the additional transportation of 150-200 thousand m<sup>3</sup> of natural gas per day, preventing the release of the same volume of associated gas into the atmosphere and environmental pollution.

The method of regulating the efficiency of compressors at low compression ratios ensures the ability to operate in a wide outlet pressure range at Garadagh and Galmaz UGSs operating in Azerbaijan.

The dissertation compares two models for the UGS reconstruction project (G16CM34 engine + KBV/6 compressor tandem consisting of 6 units and 24 DPC Ajax 2804St compressors) and explains the technological advantages of the second option.

As for economic parameters, only a comparison of the cost of equipment is sufficient to make a decision. Thus, while the total cost of the G16CM34 engine + KBV/6 compressor tandem consisting of 6 units is not less than 50 million US dollars, the cost of 24 DPC Ajax 2804St compressors is at the level of  $0.6 \times 24 = 12$  million US dollars. Thus, the method of selecting equipment for UGS compressor stations developed in the dissertation allows to ensure economic efficiency along with technical and technological advantages.

The developed technological transfer method for modeling of gas turbine compressors has already been applied at the Galmaz gas turbine compressor plant, and the volume of active gas stored in the gas turbine compressor has been increased by 330 mln. m<sup>3</sup>. Technological transfer models developed at the Garadagh gas turbine compressor plant for pressures of 25.0 and 35.0 MPa can be used in future projects for the reconstruction of compressors.

Since the method for assessing the impact of the structural features of piston gas compressors on the amplitude of the pulsations of the outlet node is universal, it allows for pre-design diagnostics of piston compressors of any design and can be successfully and usefully used at numerous production facilities.

The report on thermobaric parameters conducted for cooling gas formed due to supersonic motion in various structural structures has proven that there are wide opportunities for creating new technological processes.

The effectiveness of some of the developed methods (technologies for restoring production by cleaning oil wells from ARP deposits of the gas-condensate wells and gas-condensate wells from liquid plugs of the gas-condensate wells) is determined directly by the results of field tests, while others (technology transfer, optimal technological model of gas turbine compressor stations) are used at production facilities, while other methods (analytical and wave-depression methods against hydrate formation, modeling of compressor stations, etc.) are published in scientific publications and brought to the attention of production specialists.

## KEY CONCLUSIONS

1. For the first time, to increase the efficiency of the oil gathering and transportation system, based on the concept that the most difficultly soluble part of the oilfield waste of the well BHZ consists of compounds formed by asphaltenes and resins, a technology was developed to initially decompose the resin using naphthenic acid and dissolve the separated asphaltenes using pyrolysis light resin consisting of 50-70% aromatic hydrocarbons (benzene compounds), and the oil production of the well, where field tests were conducted, steadily increased by 67% [8, 19, 22].

2. In order to increase the efficiency of the natural gas gathering and transportation system, a technology has been developed to clean the liquid plugs of the BHZ of the packerless gas-condensate wells in the final stage of operation, which involves raising the condensate water deposited and clogged in the flow channels of the well bottom zone to the surface using methanol, and cleaning the BHZ from condensate accumulations thanks to the high-speed gas flow formed due to the cleaning of water plugs. As a result of field tests conducted at the Galmaz UGS, the share of the test well in the total volume of gas injected into the reservoir has steadily increased by more than 2 times [3, 4, 5].

3. For the first time, since the formation of hydrate in gas pipelines and the occurrence of irreversible blockages occur in a short period of time, an analytical method has been developed that provides for the prompt determination of the onset of hydrate formation in order to take operational measures in submarine gas pipelines, where the number of known technological parameters is quite limited, in order to correctly assess the onset of the hydrate formation process [16, 23].

4. For the first time, a wave-depression method has been developed to eliminate hydrate formation that has formed in submarine gas pipelines and is no longer possible to eliminate by inhibitors. The physical meaning of the method is the formation of a wave with an increased amplitude and depression along the entire pipeline due to the high gas flow rate that occurs when the tap is opened due to the high pressure formed in the pipeline as a result of

closing the tap at the end of the pipeline for a certain period of time [21].

5. The displacement of the fluid accumulated in the depressions of the pipeline under changing dynamic and inertial conditions ensures both the decomposition and movement of the formed hydrate compounds, which, together with the expansion of the cross-sections of the pipeline narrowed by hydrate, ensures the protection of the pipeline from complete blockage. A formula has been obtained for determining the time the crane at the end of the pipeline remains closed during the operation process.

6. An efficient technological model of gas turbine compressor stations has been developed based on the study of pressure, temperature and productivity parameters under conditions of changing ambient air temperature using mathematical statistical methods.

7. A method for regulating the efficiency of compressors in the conditions typical for UGS at the beginning of the gas injection season, when the compression ratio is low, has been developed [17]. Methods for regulating the efficiency-power balance of compressors under conditions of high intake pressure have been developed [14]. In order to ensure the efficiency of UGS compressor stations during the gas injection season, when the pressure of the compressor stations varies over a wide range, a technological transfer method has been developed for modeling compressor stations. The essence of the method is that at the beginning of the gas injection season (April-August), when the gas volumes intended for injection into the reservoir are large, all compressors operate in parallel in a single-stage mode, and in the subsequent period (September-November), when the gas volumes decrease and the pressure increases, a two-stage mode is ensured by transferring some of the compressors to the second stage [11].

8. For the first time, a method for assessing the influence of the design features of piston gas compressors on the amplitude of the pulsations of the outlet node has been developed [1, 18].

9. The scientific basis for the creation of new technological processes such as deep cooling, separation and drying of natural gas based on supersonic motion has been studied and recommendations have been made [12].

**The main content of the dissertation has been published in the following scientific works:**

1. Багиров, А.Н., Багиров, Ш.А. Сравнительный анализ влияния конструкции газовых коммуникаций газомотокомпрессоров на амплитуду пульсаций. // «Нефтепромысловое дело», РФ, 2012, №6, с.40-44.

2. Hacıyev, H.Q., Əliyev, Y.M., Bağırov, Ş.Ə. Kapilyar viskozimetr. // “Neftin, qazın geotexnoloji problemləri və kimya” Elmi-Tədqiqat İnstitutunun Elmi əsərləri, XIV cild. Bakı. -2013, -s.187-193.

3. Ramazanova, E.E. Reservoir water isolation technology / E.E. Ramazanova, T.Ş. Salavatov, H.G. Hacıyev, Y.M. Aliyev, Sh. A. Baghirov [etc.] // Azerbaijan and Caspian Sea Oil & Gas Week. – Baku. -2013. -pp.101-108.

4. Hacıyev, H.Q., Əliyev, Y.M., Bağırov, Ş.Ə. Hasilatın sulaşmasının quyu profilindən asılılığı // Əsrin müqaviləsinin 20 illiyinə həsr edilmiş elmi konfransın materialları. -Sumqayıt. -2014. 23-24 sentyabr. -s. 198-200.

5. Гаджиев, Г.К., Алиев, Е.М., Багиров, Ш.А. Влияние профиля наклонно-направленных скважин на обводненность их продукции // Нефтепромысловое дело. -2014. -№9. -с. 51-54.

6. Hacıyev, H.Q., Əliyev, Y.M., Bağırov, Ş.Ə. Lay sularının təcrid edilməsi üçün nanotərkibli suspenziyanın işlənməsi // Akademik S.C. Mehdiyevin 100 illik yubileyinə həsr olunmuş respublika elmi-praktiki konfransının məruzələrinin tezisləri. I cild. - Bakı. -2014, 2-3 dekabr. -s. 199-200.

7. Hacıyev, H.Q., Əliyev, Y.M., Bağırov, Ş.Ə. İşlənmənin son mərhələsində yatağın texnoloji göstəricilərinin təhlili. // “Neftin, qazın geotexnoloji problemləri və kimya” Elmi-Tədqiqat İnstitutunun elmi əsərləri, XVI cild, Bakı. 2015. s.231-244.

8. Зейналов, А.Н., Бабаев, Р.Т., Рамазанова, Э.Э., Багиров, Ш.А. Высокоэффективные реагенты для борьбы с отложениями парафина // “Azərbaycan neft təsərrüfatı”. -2016, -№7-8, -s.26-31.

9. Əliyev, Y.M., Hacıyev, H.Q., Bağırov, Ş.Ə. Kapilyar viskozimetr. İxtira İ 2017 0063, Azərbaycan Respublikası / Y.M.

Əliyev, H.Q. Hacıyev, Ş.Ə. Bağırov. - Dövlət reyestrində qeydə alınıb: 05.12.2017.

10. Məmmədov, E.A., - Dayanıqlı neft emulsiyalarının əmələ gəlməsinin qarşısının alınması üsulu, İxtira İ 2020 0012, Azərbaycan Respublikası. / E.A. Məmmədov, M.F. Əsədov, Ş.Ə. Bağırov [və b.] - Dövlət reyestrində qeydə alınıb: 24.02.2020.

11. Bağırov, Ə.N., Bağırov, Ş.Ə. Yeraltı qaz anbarların kompressor stansiyalarının modelləşdirilməsində texnoloji transfer üsulunun tətbiqi. // “Azərbaycan neft təsərrüfatı”, №4, 2020, s.29-32.

12. Искендеров, Э.Х., Багиров, А.Н., Багиров, Ш.А., Исмаилова П.Ш. Разработка новых технологических процессов на основе сверхзвукового течения природного газа. // “SOCAR Proceedings”, 2020, №4, с.117-123.

13. Məmmədov, E.A., - Anion səthi-aktiv maddələrin alınması üsulu, İxtira İ 2020 0079, Azərbaycan Respublikası. / Məmmədov, E.A., Əsədov, M.F., Bağırov, Ş.Ə. [və b.] - Dövlət reyestrində qeydə alınıb: 15.10.2020.

14. Ələsgərov, G.Ə, Bağırov, Ə.N., Bağırov, Ş.Ə. Texnoloji proseslərin təhlili əsasında qazturbini kompressor stansiyalarının optimal iş rejimlərinin diaqnostikası. // Azərbaycan ali texniki məktəblərinin xəbərləri. 2022, Cild 12, Buraxılış 01, s. 14-29.

15. Bağırov, Ş.Ə. Qaz-kondensat quyularının hasilatının bərpası texnologiyasının işlənməsi. // “Azərbaycan Mühəndislik Akademiyasının XƏBƏRLƏRİ”, 2022, Cild 14, №4, s.62-68.

16. İskəndərov, E.X., Bağırov, Ş.Ə. Sualtı dəniz magistral kəmərlərində hidratyaranmanın başlanmasının müəyyən edilməsi üsulu. // Azərbaycan neft təsərrüfatı/ 2022, № 5, s.31-36.

17. Искандеров, Е.Х., Багиров, А.Н., Багиров, Ш.А. / Метод регулирования мощности и производительности компрессоров ПХГ при низкой степени сжатия. // Материалы Международной научной конференции «Высокие технологии и инновации в науке», май 2022 г., // Санкт-Петербург, с. 114-117.

18. Baghirov, Sh. A. Evaluation method of impact of gas-motor compressor designs on the amplitude of gas pulsations in discharge lines. // “Proceedings of Azerbaijan high technical educational institutions”. 2022, Volume 17, Issue 06, p.180-187.

19. Багиров, А.Н., Багиров, Ш.А. Очистка призабойной зоны нефтяных скважин от смол и асфальтенов. // Сборник статей XLV Международной научно-практической конференции «Advances in Science and Technology» 15 июня 2022 г. // Научно-издательский центр «Актуальность.РФ» Москва, с. 125-126.

20. Искендеров, Э.Х., Багиров, А.Н., Багиров, Ш.А. / Оценка условий гидратообразования при смешении потоков природного газа различной кондиции.// Материалы Международной научно-практической конференции «Арктика: современные подходы к производственной и экологической безопасности в нефтегазовом секторе», 28 ноября 2022 г., Том II, Тюмень, стр.312-316.

21. Iskandarov, E. Kh., Baghirov, Sh.A. / Analytical and wave-depression methods of elimination of the onset of hydration in subsea gas pipelines. // NEWS of the National Academy of Sciences of the Republic of Kazakhstan/ Series of geology and technical sciences. 2022, Volume 4, Number 454, p.96-108.

22. Iskandarov, E.Kh., Baghirov, A.N., Baghirov, Sh.A., Farzalizade Z.İ. /Technology of cleaning the bottomhole zone of oil wells from ARP deposits. // Proceedings of Azerbaijan high technical educational institutions.2022,Volume 24, Issue 04(138), p.6-9.

23. Iskandarov, E.Kh., Baghirov, A.N., Baghirov, Sh.A. / Determining of primary hydrate formation in subsea gas pipelines. // International Scientific-Praktical Conference, KhazarOilGasField (ISPC-KOGF-2022). Proceedings of Scientific Papers. 6-7 December 2022, Baku, Azerbaijan. // Scientific Research Institute “Geotechnological Problems of Oil, Gas and Chemistry”, p.22-27.

**The applicant's personal contribution to the published works:**

[15], [18] – performed independently.

[1], [12] [14], [16], [17], [23] - formulation of the problem, research work and analysis of the results.

[11], [19] - conducting research and applying the results in production.

[2], [3], [4], [5], [6], [7], [8], [9], [10], [13], [20], [21], [22] - the authors' share of participation is equal.



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