REPUBLIC OF AZERBAIJAN

On the rights of the Manuscript

ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT AND APPLICATION OF NEW METHODS FOR LIMITING THE IMPACT OF SAND RELATED PROBLEMS ON PRODUCION AND ITS GATHERING IN OFFSHORE OIL FIELDS

Speciality: 2526.01 – Technology for development of offshore fields

Field of sciences: Engineering

Applicant: **Elmira Sabir gizi Abdullayeva**

Baku - 2022

The dissertation work was performed at "OilGasScientificResearchProject" Institute of State Oil Company of the Republic of Azerbaijan

Academic supervisor: Corresponding Member of ANAS, technical sciences doctor, professor
Baghir Alekber oglu Suleymanov

Official opponents: Corresponding Member of ANAS, technical sciences doctor, professor
Garib Isak oglu Jalalov
Doctor of Philosophy in Technology, Associate Professor
Valeh Mammad oglu Shamilov
Doctor of Philosophy in Technology
Tural Khalig oglu Shafiev

One-time Dissertation Council BFD 2.03, created under the Dissertation Committee ED 2.03 of the High Attestation Commission under the President of the Republic of Azerbaijan, acting under the auspices of Azerbaijan State Oil and Industry University

Chairman of the Dissertation council: ____________ Doctor of Technical Sciences, Associate Professor
A.A.Suleymanov

Scientific secretary of the Dissertation council: ____________ Doctor of Philosophy in Technology, Associate Professor
Y.Y.Shmoncheva

Chairman of the scientific seminar: ____________ Corresponding Member of ANAS, technical sciences doctor, professor
Q. M. Efendiyev

I conform the signatures
Scientific Secretary of ASOIU,
Associate Professor **N.T.Aliyeva**

GENERAL OVERVIEW

Urgency of the research topic and the degree of development: Considerable petroleum reserves of Azerbaijan are confined to fields, the layers of which are mainly structured of incompetent rocks. Well operation is accompanied by the destruction of the bottom-hole formation zone, and, as a consequence, sand production, which leads to a drop in oil production. Sand production triggers challenges, from the bottom-hole formation zone to the point of gathering and treating the production.

In the course of movement, the sand-liquid slurry erodes all subsurface and surface equipment, infield communications and equipment of the production gathering and treating station. Part of the sand, for which there are no conditions available for carry-over up to and removal from the wellhead, settles at the bottomhole, thereby creating a sand plug and preventing the flow of fluid from the formation into the well.

In the meantime, it increases the costs of maintaining down-hole and infield equipment accordingly, which is accompanied by significant economic losses and an increase in the cost of oil.

In such challenging conditions of depletion in offshore oil fields, the development and application of new methods to restrict the influence of sand related problems on production and production gathering from producers is a critical task.

Purpose and objectives of research - development and application of new methods to restrict the influence of sand-related problems on recovery and well production gathering.

Main tasks of the research:

1. Working out a method for flushing a sand plug, which ensures the removal of sand and mechanical impurities from sand-producing wells.

2. Developing a unit for settling sand in order to protect the downhole equipment from the negative effects of sand and mechanical impurities.

3. Development of a downhole oscillation generator in order to improve the permeability of the bottomhole zone.

4. Industrial introduction of a sand settling unit and a borehole oscillator.

Research methods.

The tasks were solved by applying theoretical, experimental and field research.

The principal provisions submitted for defense.

1. A method for flushing a sand plug to carry over sand particles and mechanical impurities from wells complicated by sand production to the surface.

2. Sand settling unit designed to protect surface equipment and production gathering station from the effects of sand and mechanical impurities.

3. Making use of the energy of the fluid injected into the layer to create hydrodynamic pulses in the bottom-hole zone.

Scientific novelty of the research.

1. A method for flushing a sand plug using a foam composition has been set in place, which ensures the removal of sand and mechanical impurities from sand-producing wells.

2. A unit for sand settling has been developed to protect the field equipment from the effects of sand and mechanical impurities.

3. Taking into account the design features of the unit for settling sand, an empirical dependence is set forth, in order to increase its efficiency.

4. In order to restore the permeability of the bottom-hole zone of wells, a down-hole oscillator has been devised.

Practical significance of the research outcomes.

1. A unit for sand settling has been developed and fabricated in order to restrict the negative impact of sand and mechanical impurities on the operation of infield equipment and pipelines.

2. A down-hole generator has been developed and manufactured that converts the pressure energy of the injected process fluid into hydrodynamic pulses.

3. Industrial application of the developed devices.

The sand settling unit was installed on the onshore field pipeline of the DWFP (deep water fixed platform) No. 4 of the "Günəşli" field at the pump upstream in order to protect the field equipment from the effects of sand and mechanical impurities. Through only 7 (seven) days of operation, the sand settling unit is capable of capturing 450kg of sand and mechanical impurities. The relevant act on the results of application is presented in the appendix of the dissertation.

The borehole oscillator was applied at the production well №2041 of «Neft Daşları» OGPD and in the injector №374 of the «Qum adası» field. As a result of the use of the borehole oscillator at the producer №2041 of «Neft Daşları» OGPD, 150 tons of additional oil was recovered in 5 months of operation, and the economic efficiency from the application amounted to 7804.6 AZN. As a consequence of the use of the oscillator in the injection well №374 of the «Qum adası» field, the well water intake capacity increased by 10%, and the injection pressure decreased by 5%. The economic efficiency from the introduction was 1922.9 AZN. The relevant acts on the outcomes of application are provided in the appendices of the dissertation.

The following patent was obtained for the developed downhole oscillation generator: "Quyu dalğa generatoru", Patent № 991072, 1999, Azərbaycan.

The patent given below has been obtained for the developed sand settling device: «Способ улавливания механических примесей в потоке пластовых флюидов», Eurasian patent EA № 033309, 2019, Russia.

The following patent has been obtained for the developed method of washing out the sand plug: «Способ промывки песчаной пробки», Eurasian patent EA № 031680, 2019, Russia.

Approbation of work.

The main provisions of the dissertation were reported and addressed at:

- Second Azerbaijan International Caspian Oil and Gas Conference (Baku, September 17-20, 1996).

- Scientific and technical conference dedicated to the 100th anniversary of Israfil Guliyev on the topic "Actual problems of the development of offshore oil and gas fields" (Baku, March 1, 2017)

- XX International Scientific and Practical Conference "Fundamental and Applied Research in Modern World". (Russia, St. Petersburg, December 4, 2017);

- XXII International Scientific and Practical Conference "Fundamental and Applied Research in Modern World". (Russia, St. Petersburg, May 29, 2018);

- II International Scientific and Practical Conference "Bulatov Readings" (Russia, Krasnodar, March 31, 2018);

- International conference dedicated to the 90th anniversary of Academician Azad Khalil oglu Mirzajanzadeh "Modern problems of cutting-edge technologies in oil&gas production in applied mathematics" (Azerbaijan, Baku, December 13-14, 2018);

- International Scientific and Practical Conference "Modern methods of developing fields with hard-to-recover reserves and unconventional reservoirs" (Kazakhstan, Atyrau, September 5-6, 2019);

- IY International Scientific and Practical Conference "Bulatov Readings" (Russia, Krasnodar, March 31, 2020);

- Off-site conferences organized by Azneft PA.

Contributions.

Based on the materials of the dissertation, 18 works were published, of which 7 articles, 8 theses, 3 patents (2 Eurasian, 1 Azerbaijani) for invention.

The name of the institution where the dissertation work was performed.

The work was carried out at "OilGasScientificResearchProject" Institute of the State Oil Company of Azerbaijan Republic.

Structure and scope of work.

The dissertation work consists of an introduction, 3 chapters; the first chapter consists of 46 pages, the second - 67 pages, the third - 18 pages; it includes - 202,695 characters, 14 figures, 10 graphs, 15 tables, a list of references, including 118 titles and an appendix.

SHORT SUMMARY OF WORK

The introduction presents an argument for the relevance of the dissertation work, formulates the goal, the main tasks of research, scientific novelty and indicates its practical value.

In the first chapter of the dissertation, a review of literature is provided, in particular, the driving forces behind the destruction of weakly cemented reservoirs and the ingress of sand into the well are given, as well as, an analysis of modern methods of sand control during the production and gathering of products of offshore oil fields is covered.

Many specialists of the oil and gas industry, both in Azerbaijan and abroad, dealt with the issues of the destruction of the bottomhole formation zone and the fight against sand ingress: A.X. Mirzajanzade, L.S. Melik-Aslanov, A.B. Suleimanov, B.A. Suleimanov, Sh.P. Kazymov, A.N. Adonin, D. Syumen, M. Masket, D.M. Mintz and others.

It is presented that in the course of the operation of wells, solid particles of sand and mechanical impurities are brought to the surface due to the destruction of natural cementing material.

The cause for such destruction can be: imbalance in the rock mass in the bottomhole formation zone under the effect of bottomhole and rock pressures, dissolution of the cementing material as a result of formation water inflow, the influence of variable mechanical loads on the formation, as well as the impact of loads during fluid filtration.

Especially, it is introduced that the destruction of weakly cemented reservoirs occurs due to the dissolution and removal of the cementing material and the development of capillary forces as a result of a significant influx of formation water.

Accordingly, it has been established that in the prevailing cases in unstable rocks, clay fractions act as a cementing material between the grains, which are easily destroyed when fluid inflow from the formation into the well occurs. It is common it is knowledge that, anthropogenic interference disrupts the physicochemical balance that exists between clay particles and their environment. As the formation is flooded, the composition of the fluid in the pores between the grains of sand changes, while the clay particles swell and, consequently, the strength of the clay cement decreases. It is obvious that the resistance of rocks to destruction is characterized by the presence of friction and adhesion forces between rock grains. As a rule, the adhesion force of weakly cemented rocks is small and the resistance of rocks to destruction is determined mainly by friction forces. It is also illustrated that during hydrocarbon filtration, a certain sand strength is observed, and during water filtration, the water saturation of the porous medium increases, the capillary cohesion forces between sand grains disappear and, as a result, sand is intensively carried out. The hydration of binder clays and the action of capillary forces are decisive in the destruction of productive reservoirs when water enters. It has also been established that the main reason for the destruction of the bottomhole formation zone is the high pressure gradient on the well walls and the fluid filtration rate. At high pressure gradients and insufficient strength of the cementing material, sandstone grains are separated from the main mass and carried into the well. In the process of well construction, the hydrostatic pressure of the drilling fluid column balances the stress in the bottomhole zone and helps to maintain the stability of the well walls. When the inflow occurs at the beginning of the well operation, the equilibrium state of the “well-formation” system is disturbed, destruction and plastic flow of loose rocks occur, which is enhanced by filtration processes when the formation fluid moves to the bottomhole. Furthermore, at high flow rates, tensile forces lead to the destruction of the bottomhole and the removal of rock particles from the well or their accumulation at the bottomhole. Accordingly, the higher the well flow rate, the greater the pressure drop at the bottom of the well and the radius of the disturbed zone, and the higher the stress in the oil-bearing horizons. Upon reaching critical tensile stresses exceeding the limits of elasticity of rocks, destruction of rocks is possible with subsequent removal of sand into the wellbore.

It is clear that with extended loading of rocks, a phenomenon called static fatigue is observed, which leads to the gradual destruction of the reservoir material. On account of dependence of strength on time under static load, many oil, gas, gas condensate and water wells are equipped with filters of various designs. This leads to a redistribution of stresses in the bottomhole zone, an increase in hydraulic resistance, an increase in the resistance of rocks in the bottomhole zone to fatigue damage, a decrease in sanding, and a reshaping of filtration channels.

Theoretical assumptions about the mechanism of destruction of a weakly cemented reservoir are based on the hypothesis that the stress state of the bottomhole zone is created by the weight of overlying rocks, fluid pressure and stress of the rock skeleton. It is demonstrated that the compressive strength of rocks decreases several times when the productive reservoir is exposed to non-mineralized leachate filtrate.

One of the reasons for sand manifestations and, accordingly, the formation of sand plugs is, meanwhile, the discrepancy between the choice of well bottom design and opening methods.

A scrutiny of the scientific and technical references showed that the methods of combating sand ingress are divided into: chemical, physico-chemical, technological and mechanical.

Chemical methods include fixing the bottomhole zone of wells with various compositions. Tars of various types may be contained in compositions for fixing. At the same time, cement-based compositions are also used, which form a permeable plugging stone.

However, in some cases, stabilizing of the bottomhole formation zone is accompanied by a decrease in the porosity and permeability properties of the reservoir and a deterioration in the permeability of the bottomhole formation zone.

The physico-chemical methods include consolidation of the bottom-hole formations of wells by viscous oil. This method is used mainly at the early stage of development of fields with shallow reservoir depths and high oil viscosity. However, the use of this method is accompanied by additional costs associated with the use of a heat generator to heat the injected air.

Also, physical and chemical methods include a combination of physical and chemical methods to combat sand intrusion. Such methods include, for example, the creation of a proppant filter in the bottomhole zone of the well. While using this method, careful selection of activators is, however, necessary. In addition, the use of this method is accompanied by a rather large consumption of proppant, in some cases, the removal of proppant into the well.

Technological methods to prevent sand related problems include the regulation of fluid production from the well, depending on the stress state of the formations and the viscosity of the produced product. Thus, with increasing sand production, it is advisable to reduce drawdown on the reservoir (limitation of oil production). However, it is not always possible to reduce the flow rates of produced products.

Mechanical methods include the use of sand screens of various designs. Filters can be of wire, single-layer and multi-layer, ceramic-metal and mesh types. Filters are made from pipes of standard sizes with holes cut into them. Known filters with wire wrapping, packed downhole filters filled with sand or other materials. As sand filters, gravel packs made of sand are also used, which are formed by filling the annulus in the interval of the productive formation. Mechanical methods are widespread due to their simplicity and accessibility. However, the use of sand screens in sand control only helps to partially contain the flow of sand carried along with the production. At the same time, the installation of filters does not completely prevent the destruction of the bottomhole zone of the well.

A review of scientific and technical literature showed that the most common methods of sand control are chemical (fixing the bottomhole zone of wells with various compositions) and mechanical methods (installing sand screens of various designs). However, despite the widespread use of these methods, sand is nevertheless carried into the well in sufficient quantities, creating sand plugs there, both at the bottom and in any interval of the wellbore. Also being in the composition of the recovered product, sand is carried over to the surface, clogging up the infield communications and equipment, as well as the equipment of the product gathering and treating point. In addition, the measures taken at sand-producing wells with the aim of stabilizing the producing formation zone lead to failure in the formation permeability.

In this regard, an overview was performed on methods for removal the sand form the well, methods for preventing the effect of sand and mechanical impurities on infield communications and equipment, as well as equipment for gathering and treating products. In addition, methods were considered to improve the permeability of the bottomhole zone of wells.

The second chapter discusses the development of new methods to restrict the impact of sand-related problems on the production and its gathering from offshore oil fields.

As it is known, one of the most effective methods for cleaning a well from sand is to flush a sand plug. Recently, foam systems have been successfully used as a flushing liquid. This is due to the fact that, unlike other flushing liquids, foam systems have a lower density and high sand-holding capacity. Also, when flushing the sand plug with foam systems, the bottomhole pressure and the volume of fluid absorbed by the formation are reduced.

In addition, the use of foam compositions in the process of washing a sand plug creates favorable conditions for a gradual decrease in pressure at the bottom of the well and causes fluid inflow from the formation, and also helps to preserve the natural reservoir properties of the productive formation.

In this regard, a method has been developed for washing out the sand plug by forming a foam system (Eurasian patent № 031680, 28.02.2019, Russia) [17].

The method worked out for flushing a sand plug includes pumping a water solution of SNKX-04 reagent. Prior to pumping the water solution of SNKX-04, aluminum nanoparticles of 50-100 nm size are further introduced into it with the following ratio of components, wt. % [12,13]::

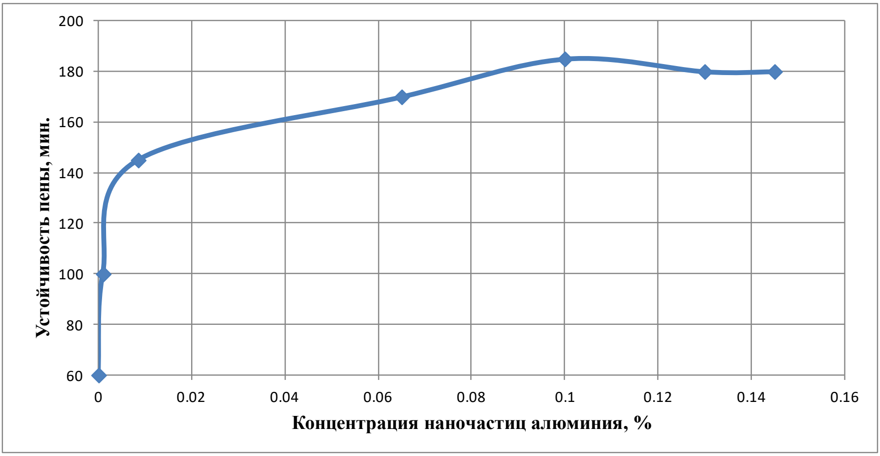
SNKX-04	0.2 - 0.4
Aluminum nanoparticles	0.001-0.1
Sea or industrial water	others

When aluminum nanoparticles are added to the water-based solution of SNKX-04 reagent, a stable, degradation-resistant, foam system is formed. Also, as a result of the implementation of the proposed method for a long period of time, the particles of sand and mechanical impurities are in suspension and do not precipitate.

To determine the resistance of the proposed foam system, experiments were carried out in laboratory conditions. As it is known, resistance is seen as the existing durability of the foam before syneresis (fluid outflow from the foam), as well as the ability of the foam system to maintain dispersion for a long time.

According to the results of experimental studies in an effort to determine the stability of the foam system created using a 0.25% water solution of the SNKX-04 reagent without the addition of aluminum nanoparticles and with the addition of aluminum nanoparticles in concentrations, respectively: 0; 0.001%; 0.0085%; 0.0650% and 0.1%, a relationship was secured between the resistance of the foam system and the concentration of aluminum nanoparticles (Graph 1).

The results provided indicate that the resistance of the foam system created by adding aluminum nanoparticles to the water-based solution of the SNKX-04 reagent is higher than the resistance of the foam system formed by the water-based solution of the SNKX-04 reagent without aluminum nanoparticles. It is known that aluminum nanoparticles have a high surface activity (area). In this regard, aluminum nanoparticles are also capable of possessing strong surface-active properties and increasing the resistance of the foam system, thereby reducing the surface tension at the interface between the two phases, by ensuring the resistance of the aggregate state of the system.



Graph 1. Dependence of the foam system resistance on aluminum nanoparticles' concentration.

At the same time, with an improvement in the concentration of aluminum nanoparticles, the resistance of the created foam system increases. The optimum concentration of aluminum nanoparticles added to an water-based solution of the SNKX-04 reagent, at which the developed foam system acquires the greatest stability, is 0.001% -0.1%. A further increase in the concentration of aluminum nanoparticles does not lead to an improvement in the resistance of the foam system. This is because the resistance of the foam system (foam frame structure) is not determined solely by mechanical strength. Maximum resistance is observed only when the density of the adsorption layer is up to its saturation, when the ability of the adsorption layer to restore in case of imbalance has not yet been lost and the molecules retain mobility, which is lost in the saturated adsorption layer. Thus, the optimal concentration of aluminum nanoparticles in the water-based solution of SNKX-04 corresponds to an under-saturated adsorption layer, and consequently a high resistance of the developed foam system is achieved (flexible structure of the foam frame).

In these ways, when aluminum nanoparticles with a concentration of less than 0.001% are added to a water-based solution of the SNKX-04 reagent, a foam system is developed, which has insufficient resistance for the particles of sand and mechanical impurities to be suspended in solution. Consequently, the developed foam system does not provide conditions for the most complete removal of clogging particles to the surface. In turn, when aluminum nanoparticles with a concentration above 0.1% are added to a water-based solution of the SNKX-04 reagent, no improvement in the resistance of the developed foam system is observed. The method, which is worked out, is most optimal when the concentration of aluminum nanoparticles is 0.001-0.1%.

The proposed foam system, formed by adding aluminum nanoparticles to the water-based solution of the SNKX-04 reagent, can also be used for continuous influx of liquid into the annulus of sand-producing wells in order to ensure the removal of sand and mechanical impurities to the surface. However, in a number of cases, the developed foam systems do not have sufficient stability to maintain sand particles and mechanical impurities in suspension for a long time, as well as to ensure complete removal of sand to the surface in deep directed and vertical wells. In connection therewith the possibility of increasing the resistance of the foam system by selecting a high-molecular weight polymer - polyacrylamide (surfactant), was also investigated, due to which the optimal consumption of surfactants and nanoparticles was ensured [18]. For the complete removal of sand to the surface from deep wells, a composition for washing a sand plug has been developed, including injection of a composition consisting of a polymer, an anionic surfactant, aluminum nanoparticles with a size of 50-70 nm and water.

The research results showed that a high resistance of the foam system is achieved when polyacrylamide (surfactant) with a concentration of 0.25-0.5% is used as a foam system stabilizer. This can be made clear by the fact that the aqueous solution of polyacrylamide has a significant viscosity. Combining with the foam generating agent – the agent SNKX-04, it creates a gel-like strong structure, due to which the stability of the system is increased thanks to aluminum nanoparticles, which also have surface activity. It was also revealed that if the optimal concentration of the SNKX-04 reagent in the range of 0.2-0.4% is required to obtain a stable foam without a stabilizer (PAA), then with the addition of PAA, it is sufficient that the content of the specified reagent is 0.03-0, 05%, that is, the specified concentration allows to increase the stability of the foam system created without polymer. Studies have also confirmed that the addition of aluminum nanoparticles with a concentration of 0.001-0.1% helps to increase the stability of the created composition by ensuring the stability of the aggregate state of the system.

From this perspective, to ensure the complete removal of sand to the surface from inclined and vertical wells, a foam-polymer composition has been developed, consisting of polyacrylamide (PAA) with a concentration of 0.25-0.5%, and SNKX-04 as a surfactant reagent with a concentration of 0.03- 0.05% aluminum nanoparticles and water.

The developed composition was tested in laboratory conditions and is currently recommended for serial use in wells with potential risks of sanding.

Further, the work presents the development of a unit for settling sand in order to protect the field equipment from the effects of sand and mechanical impurities.

Field observations have shown that most of the sand and mechanical impurities settle in the in-field pipeline before the point of gathering and treatment of production, which leads to early failure of field equipment and breaching.

In this regard, a unit for sand settling has been developed, which is installed directly on the in-field pipeline, before the point of gathering and production treatment, both on the line of one well, and at the junctions of several wells [6, 8, 9, 10, 15, 16].

Figure 1 shows an image of a sand settling unit.

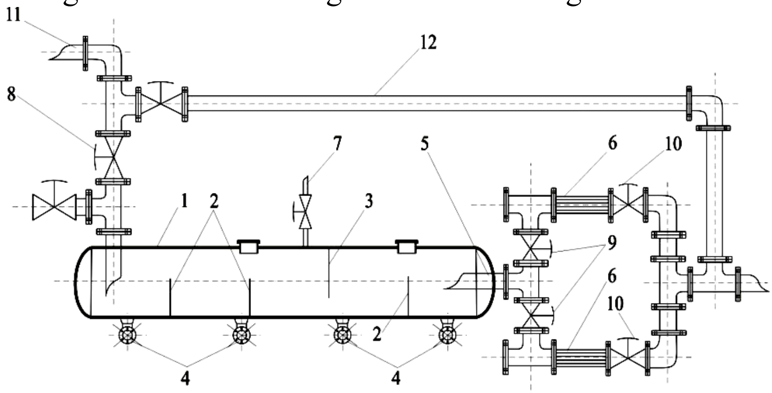


Figure 1. Sand settling unit

1-body; 2-lower limiting plates; 3- upper limiting plate; 4- pipe junctions for sand removal; 5-downstream line; 6- slotted wire-gage screens installed in a quill cylinder; 7-line for gas removal; 8-gate valve installed at the upstream of the body; 9-gate valve installed at the downstream of the body; 10-valve installed after the filter; 11-pipe for borehole fluid supply; 12-auxiliary line

The unit for settling sand includes: a body (1), transverse partitions made in the form of limiting plates - lower (2) and upper (3), pipe junctions (4) for removing sand and mechanical impurities accumulated at the bottom of the unit, located downstream of facilities (5) two slotted wire-gage screens (6), coaxially installed inside the spools (quill cylinder), a gas line (7) for removing the gas accumulated in the upper part of the body; a pipe for supplying well fluid (11), an auxiliary line (12) installed to transport well products during workover, valves (8, 9, 10) located at the inlet (8) and outlet of the body (9) and after the filters of the unit (10) installed to shut off the fluid flow during the repair of the unit.

Thus, the sand settling unit consists mainly of two parts: the unit body and the slotted wire-gage screen.

The operation of the body of the unit for settling sand is based on the complex use of the effects of hydro-aerodynamics (the Borda and Coanda effect), as well as on various principles of settling suspended solids on obstacles. At the same time, the structural form of the unit for sand settling ensures the maximum effects show of hydro-aerodynamics and the principles of settling of suspended particles on obstacles in the removal zone. The removal of sand and mechanical impurities contained in the liquid entering the device is carried out mechanically, that is, when a fluid flow with sand particles and mechanical impurities enters the device according to the Borda effect, a sudden local expansion of the flow occurs, and therefore the pressure drops sharply, i.e. there is a loss of energy or fluid pressure.

In this case, the liquid head loss coefficient is to the maximum, i.e. is equal to one. Accordingly, the fluid flow rate after local expansion is much lower than before local expansion of the flow. The Borda effect is enhanced by the Coanda effect, which consists in the fact that when the flow of fluid moves out in the inner lower wall of the pipe, a decrease in pressure occurs. This prevents the flow from flowing freely, causing a decrease in pressure in the flow area and causing the flow to deviate. As a result of the combined action of these hydrodynamic effects, the pressure of the fluid flow decreases sharply, as a result of which the fluid flow rate also sharply decreases, and the particles of sand and mechanical impurities contained in the fluid settle to the bottom of the unit body.

The body is also equipped with three stop plates, which are tightly fitted at the bottom of the body. With the help of these plates, gravity settling chambers are formed. In these chambers, the settling of relatively coarser sand particles contained in the production takes place. Particles of sand, colliding with the stop plates, lose speed and settle to the bottom of the unit. Moreover, as a liquid jet with sand particles hits the lower plates, the direction of the flow changes, that is, the liquid jet deviates upward, which also contributes to the sedimentation of particles to the bottom of the device housing. Another restriction plate is installed in the upper part of the body. The upper restraining plate facilitates the settling of relatively medium-sized sand particles contained in the liquid in suspension. Particles of sand, in contact with the plate, adhere to it and for some time slide down the plate down to the bottom of the unit body. The height of the restraining plates is selected depending on the particle size distribution of the sand particles and on the concentration of sand in the produced fluid. Thus, the main part of the sand and mechanical impurities contained in the liquid entering the unit settles in the first part of the unit - a horizontal cylindrical body.

On the downstream line of the unit, two quill cylinders (spools) are coaxially installed. They house two slotted wire-gage filters, one of which is active, one in reserve. The filters are designed for a more complete and thorough cleaning of the liquid from relatively small particles of sand and mechanical impurities still remaining in the recovered product. In a slotted wire filter, sand particles and mechanical impurities are trapped by mechanical cleaning. The dimensions of the screen slots and the distance between the wires are selected in accordance with the particle size distribution of the sand particles, and the work of the slotted wire-gage filter is based on the principle of filtration of a heterogeneous liquid through narrowing slots.

As can be seen, the sand settling unit has a simple structure. In addition, the unit can be easily cleaned when it is filled with particles of sand and mechanical impurities. The process of cleaning the device from sand particles and mechanical impurities is carried out as follows.

The valves at the inlet (8) and outlet from the housing (9) and after the filters (10) are closed, the fluid flow is directed to the auxiliary line (12), thereby transporting the produced products using the auxiliary line. Sediments consisting of sand particles and mechanical impurities accumulated in the body are eliminated with the help of nozzles for removing mechanical impurities, and particles of sand and mechanical impurities adhering to the unit body are removed by flushing. A slotted wire-gage filter, filled with particles of sand and mechanical impurities, is removed from the quill cylinder (spool), cleaned and reinstalled in the inner surface of the cylinder.

After cleaning is completed, the valves at the beginning and at the end of the auxiliary line are closed, and the valves at the housing upstream and downstream and after the unit filters are opened, and the flow of liquid through the unit is resumed again. If, during the transportation of the produced liquid, the filter (6) of the unit located at the outlet of the housing is filled earlier than the housing, the transportation process continues, and the liquid is purified by another filter, prudently left in reserve. The filter, filled with particles of sand and mechanical impurities, is removed from the cylinder, cleaned and reinstalled in the inner surface of the cylinder.

Unlike devices installed at the point of gathering and treatment of production, units for settling sand, which are located directly on the in-field pipeline, must meet certain requirements:

- the unit must be compact enough;
- the unit must ensure a continuous process of transportation of liquid pumped through the field pipeline in the required daily volume;
- the unit must ensure the removal of most of the sand and mechanical impurities contained in the recovered production, pumped over a certain period of time, during which the liquid with sand particles and mechanical impurities flows through the unit;

Thus, the design parameters of the unit must meet these requirements. In this regard, the following functional connection is proposed (Eurasian patent № 033309, 2019), [16]:
:

$$L_r = \frac{D 18 \mu_g 4Q}{g d^2 (\rho_t - \rho_g) \pi D^2}$$

Where D-pipeline diameter, м,

d – particle size, м,

ρ_g, ρ_t - density of liquid and solid particles, respectively, kg/m^3

μ_g - dynamic viscosity of liquid, Pa·s

g - free-falling acceleration, m/s^2.

Q_g - flow rate of liquid entering the pipeline, m^3/s

With the help of this functional connection, it is possible to determine at what distance and after what time a particle of a certain diameter, moving in the flow of the produced fluid, will settle in a production pipeline of a certain length.

In this case, the diameter of the solid particle d is set in accordance with the analysis of the granulometric composition of the rocks, and the design parameters of the unit are determined taking into account the daily volume of liquid passing through the unit by comparing such parameters as the settling time of a solid particle in the unit and the time of passage of a solid particle through the unit. Knowing the granulometric composition of sand particles and the concentration of sand particles and mechanical impurities in the produced fluid, it is possible to determine the distance at which, starting from the wellhead, it is advisable to install a unit, one or more, located independently of each other.

The thesis covers the main indicators that were used to determine the parameters of the process of settling a solid particle of a certain size in a fluid flow moving through an in-field pipeline. Also given are indicators that were used to determine the main parameters of the process of sedimentation of a solid particle of a certain diameter in the unit.

Further, the paper presents a unit for generating a wave action on the bottomhole zone of wells, designed to improve the permeability of the formation.

The practice of oil field development shows that during the entire period of well operation, the permeability of the bottomhole formation zone is steadily deteriorating. The bottomhole zone of the well is clogged with particles of mechanical impurities, mineral salts, etc. Also, particles of high molecular weight hydrocarbon compounds settle on the surface of rocks and in the pore channels of the formation, tightly adhering to them and thereby creating a skin factor.

It is known that wave action methods are one of the most effective ways to clean the bottomhole zone of wells from bridging agents (colmatant) of various origins. The use of wave action promotes the detachment of solid particles of high-molecular hydrocarbon compounds adhered to the surface of the rocks that make up the reservoir. This is due to the fact that as a result of wave advance in the reservoir, high pressure gradients are formed in short time intervals, that is, the "compression-tension" phenomenon occurs. The energy or magnitude of the resulting high pressure gradients, as a rule, is sufficient to destroy solid particles and abnormally viscous structures in the pore channels. As a consequence, hard particles break away from the walls of the channels and pass into a suspended extremely fine dispersed state.

Among the wave methods, a method has become widespread, in which the energy of the hydrodynamic head of the fluid injected into the well is used to create pulses. For this, special devices (oscillation generators, vibrators) are used, which are run into the hole on the tubing and installed at the bottom of the well. During pumping through the oscillator of the process fluid (water, solvents, surfactant solutions, oil, acids, etc.), a uniform fluid flow is converted into a pulsating one, as a result of which a number of hydraulic pulses (hydroshocks) are spread in the formation, leading to the creation of pressure drops affecting the bottomhole zone of wells. As a result, the permeability of the bottomhole zone of the well is improved, the productivity and injection capacity of wells increases. In this regard, a borehole oscillator has been developed, which is distinguished by its simplicity of design and high efficiency (Patent No. 991072, Azerbaijan, 1999), [3].

Figure 2 illustrates downhole oscillation generator [1, 2, 7, 11, 14].

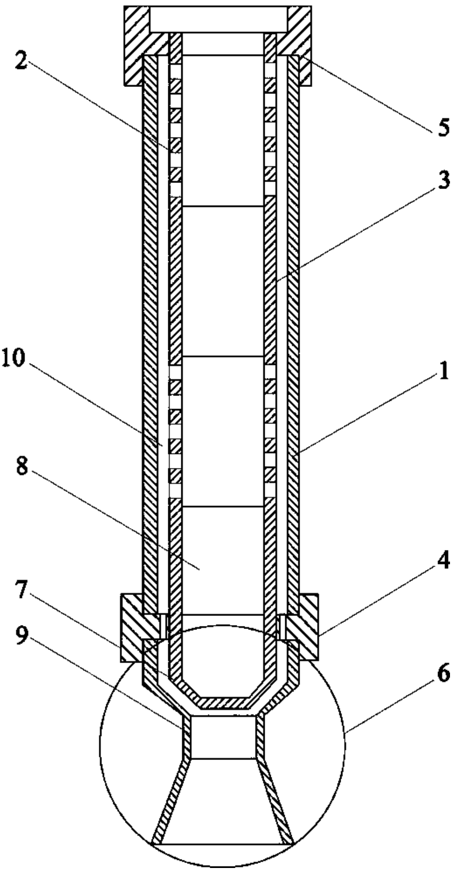


Figure 2. Downhole oscillation generator

The oscillator consists of a body 1 installed concentrically in the housing of the inner cylinder, composed of alternating perforated 2 and solid 3 parts, lower 4 and upper 5 clamping sleeves, an ejector assembly 6, the fitting pipe 7 of which is communicated with the cavity 8 of the inner cylinder, and the receiving chamber 9 with ring channel 10.

As one can see, the generator is equipped with an ejector device. The operation of the ejector device is based on Bernoulli's law, that is, on the interdependence of pressure and fluid flow rate. With an increase in the flow rate, a decrease in pressure is observed, and vice versa, with an increase in pressure, the flow rate decreases. Also, the operation of the ejector is based on the Venturi effect, which is a direct consequence of Bernoulli's law. The Venturi effect consists in the fact that when the flow of liquid through the intended part of the pipe, the pressure decreases, and the flow rate increases. The device is designed in such a way that the ejector fitting pipe is connected to the cavity of the inner cylinder, and the receiving chamber is connected to an annular channel. This design ensures the creation of an unstable flow mode from the device. The unstable mode is caused by the fact that when the liquid passes through the ejector fitting pipe, the flow pressure decreases. Some liquid is sucked out through the perforated (permeable) walls of the inner cylinder and the annular channel. In this case, the flow rate from the fitting pipe increases. This leads to an increase in the flow rate of the aspirated liquid, which is accompanied by a decrease in the flow rate from the fitting pipe. Thus, the constancy of the unstable mode of the outflow from the device is ensured, that is, the ejector prevents the formation of a uniform flow of the liquid.

An alternating change in fluid flow rates in the channels of the device leads to the formation of pressure pulses in it, which is accompanied by the appearance of hydrodynamic waves in the bottomhole formation zone. By adjusting the flow rate, you can create pulses of varying intensity.

Basic parameters and dimensions of the borehole oscillator.

Length - 850mm.

Width - 132.1mm.

Material - steel grade 45 GOST 633-80.

The frequency of the generated vibration, kHz - 0.1 - 20.

Amplitude - 0.5-2 MPa.

The ability to control the parameters of hydrodynamic pulses makes it possible to successfully use the device in wells that have different geological and physical properties (depth, reservoir thickness, reservoir pressure, clay content). At the same time, it is recommended to use a downhole oscillator depending on the structure of the formation and the properties of the formation fluid, the parameters of which are individual for each field. The downhole oscillator can be used both in production wells to increase productivity, and in injection wells to improve the injection capacity of the formation.

The third chapter presents the results of industrial implementations of a sand settling unit and a borehole oscillator.

Sand settling units have been designed and manufactured, depending on the productivity of the wells, in two versions, with a throughput of up to 1000 m^3/day, and above 1000 m^3/day of recovery.

To conduct field tests of the unit for settling the sand, the deep-sea fixed platform (DSFP) № 4 of the "Günəşli" field was selected, since on this platform there were facts of frequent failure of field communications and equipment due to strong sand production. Pumps that pump recovered production also belong to the category of equipment that most often fail due to the negative effects of sand. In this regard, it was decided to install a unit for settling sand at the pump upstream.

In order to assess the efficiency of the sand settling unit, an analysis of the granulometric composition of the formation sand contained in the produced fluid was carried out. For this, before the implementation of the device, samples of formation sand were taken, contained in the recovered production, pumped through the transport line of the 4th platform. The research results are presented in graph 2.

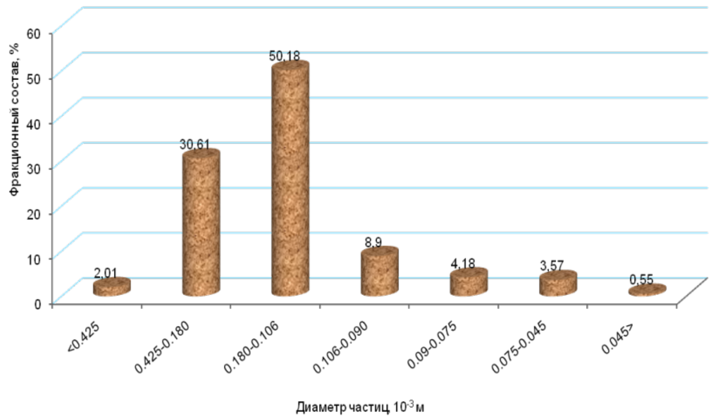


Diagram 2. Distribution of the fractional composition of sand samples taken from the transport line of the DWFP No. 4 of the "Günəşli" field

The research results showed that the fractional composition of 80% of the sand contained in the transported production is 0.425-0.106mm.

Also, in the process of introducing the device, samples of formation sand were taken from the fitting pipes for utilization of the body and an analysis of the granulometric composition of sand particles was carried out. The research outcomes are provided in diagram 3.

As one can see, the bulk of the sand settles and mechanical impurities in the gravity chambers of the unit body.

Also, samples of sand were taken from the filter part of the device and an analysis of the granulometric composition of the sand particles was carried out. The analysis showed that the slotted wire-gage filter allows the removal of silica sand particles with a size of bigger than 0.2 mm and a diameter of less than 0.1 mm (Diagram 4).

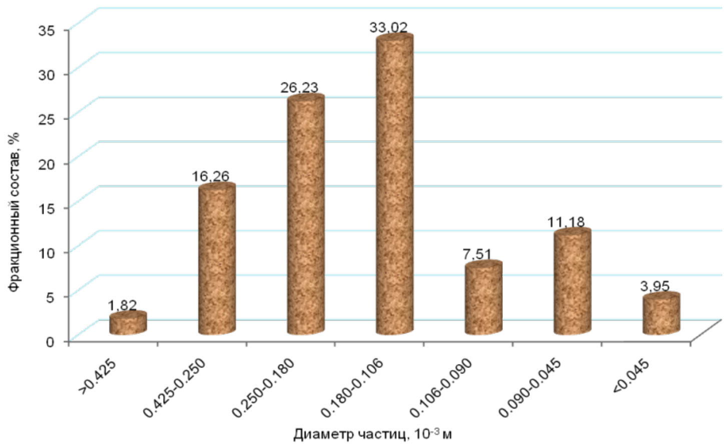


Diagram 3. Granulometric composition of sand samples taken from the body of the unit for settling sand

In the process of field testing of the device, it was found that during only 7 (seven) days of operation, the unit for settling sand is capable of removing 450kg of sand and mechanical impurities. Thus, the results of field tests of the sand settling unit have confirmed its high efficiency.

Further in the work, the results of field tests of the borehole oscillator are presented.

The field tests of the developed borehole hydrodynamic oscillator were carried out in well No. 2041 of OGPD at «Neft Daşları». The results of field tests of the downhole oscillation generator of hydrodynamic vibrations are shown in Table 1.

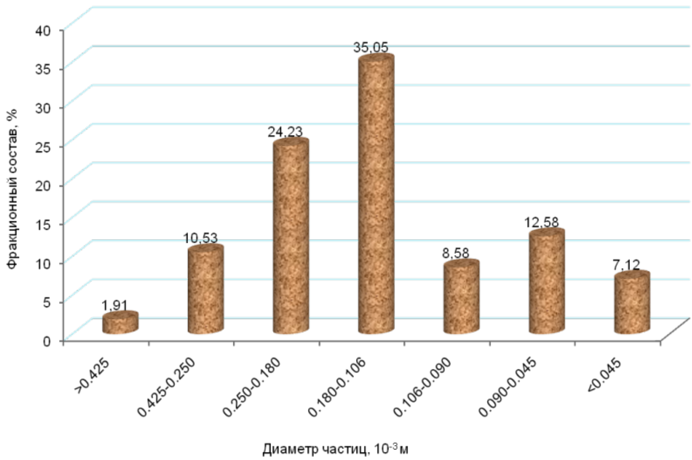


Diagram 4. Granulometric composition of sand samples taken from the filter section of the sand settling unit.

Table 1

Results of field tests of the borehole oscillator

Before application		After application		Well operation days	EOR, т	Gas saving, m^3
Oil production, t/day	Gas flowrate, m^3	Oil production, t/day	Gas flowrate, m^3			
9,0	990,0	10,0	790	150	150	30000

As a result of the tests carried out in well №2041, 150 tons of additional oil were obtained for 5 months of work, gas savings amounted to 30,000 m3, and the economic efficiency from the implementation was 7804.6 AZN (the corresponding implementation act is presented in the appendix).

Thus, the results of field tests confirmed the high efficiency of the downhole oscillator and the possibility of further wider application of the device in production wells.

The downhole oscillator was also installed in the injection well in order to increase its injection capacity. For implementation, the injection well №374 of the «Qum adası» field was chosen, which is characterized by low injection capacity, with the help of which water was injected into the УП horizon for a long time.

Before the implementation of the event, studies were carried out and the injection capacity profile of the injection well was determined (recorded). The data on the injection capacity of the injection well №374 for 3 (three) months before and after implementation are presented in Table 2.

Table 2

Results of field tests of the borehole oscillator

Process performance	Before application			After application		
	April	May	June	July	August	September
Volume of injected water, m^3/day	270	271	269	297	299	298
Wellhead pressure, MPa	7,5	7,6	7,4	7,1	7,0	6,9

Specific-injectivity index, characterized by the ratio of the amount of injected fluid per unit of pressure, before the implementation of the measure, averaged 36 m^3/day/MPa.

Analysis of the results of field studies already in the first three months of the device implementation in the injection well showed that the specific-injectivity index increased sharply and averaged 42.5 m^3/day/MPa, which is approximately 18% higher than its initial value.

Repeated recording of the injectivity profile showed that as a result of the impact on the bottomhole formation zone using a borehole oscillator, the coverage of the formation by the action also increases. Comparative data presented in the table show that after running the proposed device into the well, the well injectivity increased by an average of 10%, with an average decrease in injection pressure by 5%, while the economic efficiency from implementation was 1922.9 AZN. The relevant act of application is presented in the appendix of the dissertation.

Thus, it can be concluded that the use of a borehole oscillator in injection wells improves injection capacity. The conducted studies show the need to optimize the operating and technological parameters of the impact on the bottomhole zone of wells, depending on the depth of the well and the geological and physical characteristics of the target objects, which is quite successfully implemented by the design features of the developed oscillator. The results of field tests of the downhole oscillator in production and injection wells confirmed that the use of the developed wave device is accompanied by both an increase in injection capacity in injection wells and an increase in recovery in production wells.

SUMMARY

1. Developed a new foam composition for washing the sand plug. The addition of aluminum nanoparticles with a concentration of 0.001% -0.1% contributes to the most complete removal of sand and mechanical impurities from the well.

2. A unit for removing sand and mechanical impurities in a fluid flow is proposed, which is installed before the point of gathering and treatment of products, directly on the in-field pipeline, both on the line of one well, and at the junction points of several wells.

3. An empirical dependence is proposed for determining the distance of the device for settling sand and its optimal design parameters are determined.

4. A downhole oscillator has been developed to improve the permeability of the bottomhole zone of wells.

5. The unit for sand settling was introduced at the DWFP №4 of "Günəşli" field. During only 7 (seven) days of operation, the sand settling unit is capable of removing 450 kg of sand and mechanical impurities.

6. As a result of use of a downhole oscillator in the production well №2041, «Neft Daşları» OGPD received 150 tons of additional oil, and the economic efficiency from the implementation amounted to 7804.6 AZN. As a result of the use of an oscillator in the injection well №374 of the «Qum adası» field, the injection capacity of the well increased by 10%, and the injection pressure decreased by 5%, while the economic efficiency from implementation was 1922.9 AZN.

The main outcomes of the dissertation have been published in the following proceedings and academic periodicals:

1. Aliyev, Y.M., Nagiyev, A. G., Abdullayeva, E.S. Impact on the bottomhole zone of an injection well in offshore conditions. Abstracts of the Second Azerbaijan Caspian Conference on oil and gas // Baku: 1996, - September 17-20 - pp. 33-35.

2. Aliyev, Y.M., Nagiyev, A. G., Abdullayeva, E.S. Impact on the bottomhole zone of an injection well in offshore conditions // Baku: Azerbaijan Oil Industry, - 1997, - №1, pp. 42-44.

3. Xasayev, A.M., Əliyev, Y.M., Abdullayeva, E.S., Nağıyev, A.G. and oth. Bownhole oscillation generator, Patent № 991072, Azərbaycan, - 1999.

4. Ahmed, F.F., Abdullayeva, E.S., Gafarova, G.M., Gasanova, E.G. and oth. Experience in the use of a new composition for lifting mechanical impurities to the surface. // Baku: Azerbaijan Oil Industry, - 2014, - №5, - pp. 30-33.

5. Kazimov, Sh.P., Abdullayeva, E.S., Rajabov, N.M. Structure of swelling packers and their applicability in the fields of Azerbaijan // Baku: - SOCAR Proceedingsб - 2015, - №3, - pp. 43-51.

6. Gasanov, F.G., Rajabov, N.M., Abdullayeva, E.S. Sand settling device to protect infield equipment from sand exposure // - “Ministry of Education of the Republic of Azerbaijan, Azerbaijan State University of Oil and Industry, Israfil Guliyev's 100th anniversary Materials of the conference on "Actual problems of development",- Baku-2017, - pp. 121-128.

7. Abdullayeva, E.S., On the possibility of wave action application in combination with methods improving bottomhole formation zone permeability // Baku: Azerbaijan Oil Industry, - 2017, - № 9, - pp. 27-31.

8. Abdullayeva, E.S. Mitigation of Environmental Complikations in the Operation of the infield transport systems. Oilfield Engineering, - 2017, - pp. 50-54.

9. Hasanov, F.G., Abdullayeva, E.S. A new way of mechanikal impurities trapping in the system of flowstream preparations. Fundamental and applied researches in the modern world. Materials XX of the international scientific and praktikal conference 4 december, 2017, Volume 1, Russia, Sankt-Peterburg, pp. 47-52.

10. Hasanov, F.G., Kazimov, Sh.P.,Abdullayeva, E.S. A new approach to the mechanical impurities utilization in the flowstream preparation system. Baku, SOCAR Proceedings, - 2017, - № 4, - pp.57-65.

11. Abdullayeva, E.S. Enhanced oil recovery through restoration of the bottomhole zone permeability. Readings of A. L. Bulatov. Materials of II International scientific and praktikal conference, March 31, 2018, Krasnodar, pp. 32-34.

12. Abdullayeva, E.S. The development of foam system for withdrawal of sand. Materials XXII of the international scientific and praktikal conference 29 may, 2018, Russia, Sankt-Peterburg, pp. 47-52.

13. Abdullayeva, E.S. A New Solids Washover Method for Sand-Producing Wells. International Conference dedicated to the 90th anniversary of Academician Azad Khalil oglu Mirzajanzade. Azerbaijan National Academy of Sciences. Azerbaijan State Oil and Industry University. Baku. December 13-14, 2018. P. 368-370.

14. Abdullayeva, E.S. Improving the permeability of the bottomhole zone of wells by applying wave action. Materials International scientific and praktikal conference, Kazahstan, Atirau, 5-6 September, 2019, Volume 1, pp. 19-22.

15. Abdullayeva, E.S. Protection of overland lines of communication and equipment against harmful sand effects. // - Baku: SOCAR Proceedings. - 2019, № 4, - pp. 39-45.

16. Gasanov, F. G. Kazimov, Sh.P., Abdullayeva, E.S., Rajabov, N.M. Method for capturing mechanical impurities in the flow of formation fluids. Eurasian patent № 033309, - 2019

17. Ismayilov, F.S., Abdullayeva, E.S. Sand plug washing method. Eurasian patent № 031680, - 2019.

18. Abdullayeva, E.S., Kazimov, E.A. Development and study of a foam composition for sand control in Production Wells. Bulatovskie chtenie, Development of oil and gas fields, - Krasnodar - 2020, -Volume 2, -pp. 30-33.

The defense will be held 21 October 2022 at 11^{00} at the meeting of the Dissertation council BFD 2.03 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating Azerbaijan State Oil and Industry University

Address: Baku, D. Aliyeva str., 227

Dissertation is accessible at the Azerbaijan State Oil and Industry University Library

Electronic versions of dissertation and its abstract are available on the official website of the Azerbaijan State Oil and Industry University

Abstract was sent to the required addresses on

20 (day) september (month) 2022 (year)

Signed to print: 16 September 2022

Paper format: A5

Volume: 36008 characters

Number of hard copies: 20 copies