ANNOTATION
dissertation work on the topic:
«Development of effective technology of deep water treatment from suspended solid particles for formation pressure maintenance at the oil fields»,
submitted for the degree of Doctor of Philosophy (PhD)
by specialty 6D070800 – « Oil and gas business »

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Rationale for the need for this research work:

Practice has shown that maintaining reservoir pressure allows not only to increase the recovery rate, but also allows you to achieve the maximum oil and gas recovery factor. A distinctive feature of the field operation at the middle and last stages of development is the annual increase in the water cut of the produced products, which can reach up to 80-90% or more, which in turn significantly complicates the operating conditions for oil, gas and water collection and treatment facilities. Purification of large volumes of produced formation water requires significant material, energy and labor costs.

For example, at the Ozen field, the total volume of formation water extracted from the subsoil exceeds 45 million cubic meters per year. Due to the increased load on the fluid supplied to the FWKO, there is a violation of the settling time of products in the technological apparatus, which leads to a deterioration in the parameters of the water prepared for the pressure maintenance and the mismatch of the quality of the water supplied for injection into the reservoirs with the requirements of the regulatory documentation of the Republic of Kazakhstan.

At the fields, due to the imperfection of the technology and technique of formation water treatment, the norms for the content of mechanical impurities not more than 50 mg/l are not observed in many cases. These regulations do not limit the size and quantity of suspended clay solids. Suspended clay particles do not settle at the bottom of the reservoirs during settling of formation water and, together with water, they enter through injection wells into the bottomhole zone of the oil reservoir, reducing the permeability of the reservoir rock. Therefore, the water treatment process requires improvement in terms of removing mechanical impurities and suspended clay particles.

Scientific research on the topic of the dissertation was carried out within the framework of the grant «AP05130484-OT-18» on this topic: « Scientific substantiation of the creation and effective integrated technology for maintaining reservoir pressure and increasing the production rate of oil wells», to 2018-2020 г.г.

The relevance of the dissertation topic:

The main methods of oilfield wastewater treatment in the industry are mechanical and physico-chemical. Preparation of water injected into the oil reservoir provides for: sedimentation of reservoir water, clarification of muddy waters by coagulation; decarbonization; iron removal; inhibition and final purification by filtration. However, with this method of final purification of field formation water, the pores of the filter (sand or crushed anthracite) are quickly filled with fine solid and suspended particles. Therefore, the preparation of formation water is mainly carried out by settling it in settling tanks, which do not provide full purification of formation water from suspended clay particles.

Sizes of solid suspended particles in water injected into oil reservoirs are commensurate with the pores of the rock - reservoir (0.8 ... 1.0 microns and above). Suspended clay particles gradually pollute the filtering surface of the bottomhole formation zone, reducing the injectivity of injection wells. There are many cases when injection wells do not accept injected water due to clogging of bottomhole zones of the oil reservoir with clay particles. Existing methods and technologies for formation water preparation are subject to further modernization on the basis of theoretical and experimental studies of processes for deep treatment of formation water from suspended clay solid particles. We have received a patent for a method of purifying formation water from suspended clay particles using granular filters with variable particle sizes and conducted research to establish its rational parameters and operating modes.

The purpose of the dissertation:

Development of a technology for deep formation water purification from suspended clay particles to maintain reservoir pressure, which ensures an increase in oil recovery of the deposit and an increase in well production.

Research objectives:

- Develop a method for deep treatment of reservoir water with suspended clay particles to maintain reservoir pressure in order to increase oil recovery from reservoirs.
- Establish rational parameters of a granular filter with variable pore sizes to treat formation water with suspended clay particles to maintain formation pressure.
- Development of scientific recommendations for the creation of a new technology for deep treatment of formation water from suspended clay particles to maintain reservoir pressure, which ensures an increase in oil recovery of the deposit and an increase in well flow rate.

Objects of study:

associated reservoir water coming from the preliminary water discharge units (FWKO-1, FWKO-2) and the central oil treatment facility (on the example of the Uzen field), as well as the process of deep purification of reservoir water in a granular filter with variable sizes and sequentially narrowing pores.

Subject of study:

associated field formation water pumped from a block-cluster pumping station (BCPS) into an injection well to maintain reservoir pressure and enhance oil recovery.

Research methods:

To solve the tasks set in the dissertation work, the following methods were used: analysis of domestic and foreign experience in the application of industrial wastewater treatment technologies at Kazakhstani deposits, such as Uzen, Kumkol, Aryskum, Alibekmola and Zhanatalap; summarizing the results of laboratory studies on water purification under various conditions in oil and gas fields; carrying out experiments with the use of formation water of the Uzen field and the use of suspended clay particles; statistical processing of the results of laboratory studies, and the construction of diagrams and graphs; processing and summarizing the results of laboratory studies obtained during the treatment of formation water; processing of the results of studies on the core of the permeability and porosity of the Uzen field using software using the ***STAR*** module from the ***CMG Computer Modeling*** software. In addition to theoretical and laboratory methods, they include the technologies of the ***Malvern Zetasizer Nano ZS*** particle analyzer characterizing the size of nanoparticles, the ***Binder FED53*** thermal cabinet, the ***Epsilon 3X Malvern Panalytical X-ray*** fluorescence spectrometer, the ***Hermle Z 206 A*** laboratory centrifuge, the microscope for analyzing and evaluating laboratory samples ***Motic Biological Microscope***, electronic laboratory ***Shimadzu*** scales, ***Eclipse Reservoir Simulator 2009*** software platform.

Basic provisions for defense:

- Produced water treatment technology, which provides for limiting the size and quantity of suspended clay solid microparticles, which, when settling, do not settle at the bottom of the reservoirs and, together with water, they flow through injection wells into the bottomhole zone of the oil reservoir, reducing the permeability of the reservoir rock significantly reduces well productivity.

- The method of treatment of water injected into the formation without suspended clay particles using granular filters with variable particle sizes and sequentially narrowing pores allows for deep purification of formation water from micro- and nano-sized clay particles, as a result of which the permeability of the bottomhole formation zone does not decrease and the injectivity of injection wells increases, as well as increased oil recovery.

Scientific novelty of the research:

− It was found that clayey solid suspended particles (on average 40-500 microns) present in the water injected into the reservoir are commensurate with the sizes of pores and cracks in the oil reservoir (0-2 mm and above), which clog the bottomhole formation of injection wells and significantly reduce oil recovery, lead to premature water breakthrough to production wells and water cut of produced oil.

− During deep purification of formation water through a granular filter with variable sizes and sequentially narrowing pores, clay particles suspended in the flow do not clog the filter pores and settle on the lower unit.

− It has been established that the recommended granular filter with a variable fraction of granular material, having a working granular layer thickness in the range of 400–500 mm and a particle size of 0.2–0.4 mm, completely purifies formation water from suspended clay particles.

Validity and reliability:

The validity and reliability of scientific provisions are the results and recommendations that are based on the use of standard proven research methods and the developed sand and gravel filter. High convergence of the results of theoretical and experimental data, the use of methods of statistical processing of experimental results with a high dependence index.

A significant difference between the developed formation water treatment technology and existing technologies is its profitability and cost-effective application in oil and gas fields.

Theoretical and practical significance of the work:

A new method for deep purification of formation water from suspended solid clay particles is proposed, which ensures a stable process of maintaining reservoir pressure and increasing oil recovery. The results of experiments on establishing the regularity of the process of formation water filtration with suspended clay particles through a porous medium with variable pore sizes and granular particles are presented. A scientific recommendation has been developed on the choice of rational parameters and operating modes of a new filter for formation water treatment.

Compliance with the directions of scientific development or state programs:

The dissertation is devoted to the actual problem of enhanced oil recovery on the topic: «Development of effective technology of deep water treatment from suspended solid particles for formation pressure maintenance at the oil fields», corresponding to the priority direction 6D070800 – «Oil and gas business», approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan.

The dissertation work was carried out within the framework of the state grant funding project on the topic: «Scientific justification for the development of an effective integrated technology for maintaining reservoir pressure and increasing well production» (program IRN: AP05130484-OT-18) and received positive scientific and experimental results.

Author's personal contribution:

The results of the experimental data carried out in the laboratory, 3D modeling were obtained personally by the applicant. The problem statement, discussion of the results and calculations of economic efficiency were carried out jointly with the scientific consultant.

Reliability of results:

The reliability of the scientific conclusions of the work is confirmed by the reproducibility of the experimental results, the consistency of the results obtained with the theoretical premises and conclusions obtained by other authors in works similar in content, the use of proven methods of critical analysis.

Approbation of work

The materials of the dissertation work were reported and discussed in published scientific articles, at international scientific and practical conferences:

− Bulatov readings: materials of the III International scientific-practical conference "Development of oil and gas fields". (Krasnodar, 2019)

− International scientific and practical conference "Science of the new time: preserving the past - creating the future" (St. Petersburg, 2017)

− International scientific and practical conference "Genesis of scientific views in the context of the sustainable development paradigm" (St. Petersburg, 2018).

Contribution of the doctoral student to the preparation of each publication:

The results of the experimental data carried out in the laboratory, 3D modeling were obtained personally by the applicant. Statement of the problem, discussion of the results, calculations of economic efficiency were carried out jointly with a scientific consultant.

Based on the materials of the dissertation, 15 scientific papers were published, including: 1 - in an international peer-reviewed scientific journal included in the Scopus database, 6 - in publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 2 - in other foreign scientific journals and publications, 6 - in collections of international scientific and practical conferences.

1 «Treatment of formation water at oil fields using granular filters with varying particle sizes». Selection of materials for the review, writing a review and introduction, processing and description of the results of experiments, writing a conclusion.

2 «Оптимизация технологии подготовки воды для поддержания пластового давления на месторождении Узень». Selection of materials for the review and its writing, writing an introduction, methodology and conclusion, preparation of graphs and their description, article design.

3 «Качественная подготовка воды для поддержания пластового давления на месторождении Узень». Selection of materials for the review and its writing, writing an introduction, methodology and conclusion, preparation of graphs and their description, article design.

4 «Разработка эффективной технологии глубокой очистки воды от взвешенных твердых частиц для поддержания пластового давления на нефтяных месторождениях». Writing sections: introduction, methodology, experiments and their results, article design.

5 «Решение проблемы глубокой очистки воды от взвешенных твердых частиц для системы поддержания пластового давления на примере месторождения Узень». Writing sections: introduction, methodology, experiments and their results, article design.

6 «Мұнай кен орындарында қабат қысымын ұстап тұру жүйесіне арналған қалқымалы қатты бөлшектерден суды терең тазарту процесін зерттеу». Writing sections: introduction, methodology, experiments and their results, article design.

7 «Мұнай кен орындарында қабат қысымын ұстап тұруға арналған қалқымалы қатты бөлшектерден суды терең тазарту технологияларын жетілдіру». Writing sections: introduction, methodology, experiments and their results, article design.

8 «High performance water treatment technology for the reservoir pressure maintenance at oil fields». Search for publications for a review and its writing, writing sections: research methodology, research results, graphics design, responses to reviewers' comments.

9 «Development of effective technology of deep water treatment from suspended solid particles for formation pressure maintenance at the oil fields». Section writing: introduction, research methodology, mathematical processing and discussion of experimental results, article design.

10 «Проблемы водоподготовки в нефтедобыче». Writing sections: introduction, methodology, experiments and their results, article design.

11 «Существующие проблемы промысловой подготовки воды на нефтяных месторождениях». Drawing up an article plan, selecting materials for the review, writing an introduction, review and conclusion.

12 «Подготовка нефтепромысловых вод для использования в системе поддержания пластового давления на месторождении Узень». Drawing up an article plan, writing sections: discussion of research results and conclusions, article design.

13 «Промысловая подготовка воды на месторождении Узень». Drafting the plan of the report and its full preparation.

14 «Определение рациональных параметров технологии подготовки пластовой воды применением фильтров из зернистых материалов с переменной крупностью частиц». Development of a report plan, selection of materials, writing the main part with a discussion of research results.

15 «Advanced water treatment technologies to maintain reservoir pressure at the oil fields». Selection of material and its systematization, writing the main sections, presentation of the report.

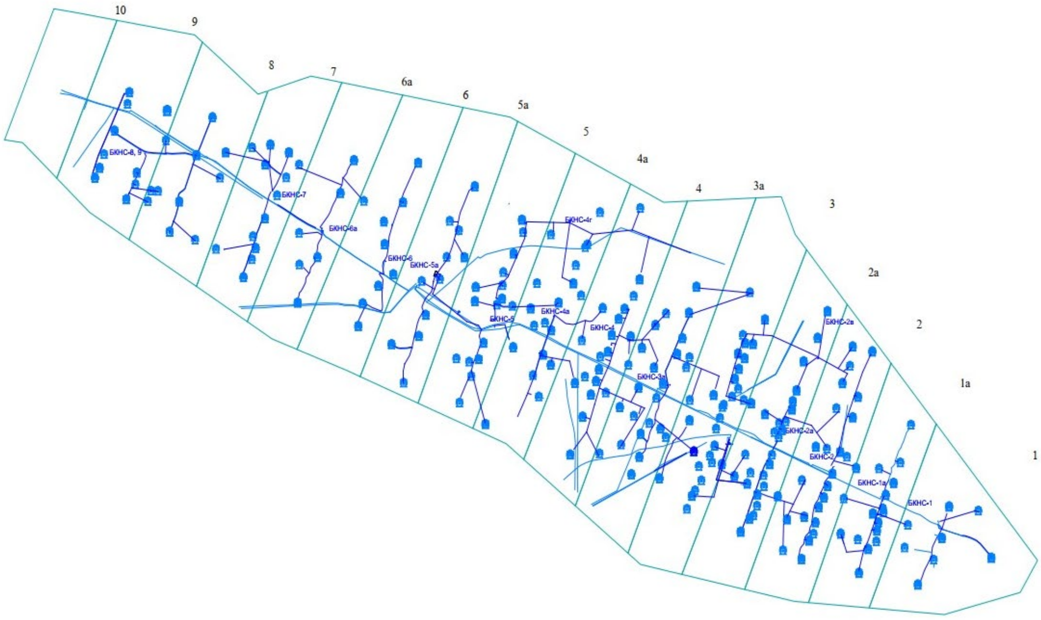
The main content of the work

It becomes obvious that for many fields that are at a late stage of development and are characterized by significant under-recovered oil reserves from interlayers with degraded reservoir properties, improving the quality of injected water is of great importance.

And technical solutions to improve the quality of wastewater injected into productive strata, both at the fields we have considered and at other fields of the Republic of Kazakhstan, will contribute to the implementation of the Government's requirement to increase the final oil recovery factor. The task of reducing the content of mechanical impurities in wastewater remains relevant, as it contributes to an increase in the oil recovery factor (ORF).

A good example of this is the Uzen field, where for more than 50 years of development, despite the implementation of such active methods of influencing productive formations as block, focal, areal, thermally staged, figure flooding, surfactant injection, downscaling of production facilities, sealing of wells, increasing pressure gradients, the current oil recovery factor did not exceed 0.4, and there is every reason to believe that at this operational facility, without the creation and implementation of original technical solutions, it will be necessary, at best, to achieve the design oil recovery factor of 0.45. Therefore, the use of new technologies that can significantly increase the oil recovery of already developed reservoirs is relevant.

With any water treatment system, a certain amount of suspended solids always remains in the water, which gradually pollutes the filtering surface of the bottomhole formation zone. The intensity of filtration attenuation depends on the nature of the suspension and the size of the pore channels of the flooded reservoir. Reservoir permeability in the bottomhole zone decreases tenfold due to severe contamination of the filtration surface, and industrial water injection becomes impossible. Therefore, systematic progressive contamination of the filter surfaces of injection wells should not be allowed. Despite the importance of the issue and a fairly large number of publications devoted to the study of deep purification of formation water from suspended solids and its uniform injection into the oil reservoir, the above problem remains relevant today.



Drawing 1 – Reservoir pressure maintenance system at the Uzen field

Productive formations of the Uzen field are represented by relatively densely cemented terrigenous rocks. Therefore, from the very beginning of the field development, a slight presence of mechanical impurities was noted in the well production. Perhaps the reason was the operation of wells at bottomhole pressures below saturation pressure, at which filtration rates increase, contributing to the breakdown and removal of mechanical impurities from the reservoirs of the bottomhole formation zone. The need to improve the quality of water used in the reservoir pressure maintenance system, due to the reservoir properties of reservoirs, requires an innovative plant for water treatment in the fields. Invention that can be used in the oil fields.

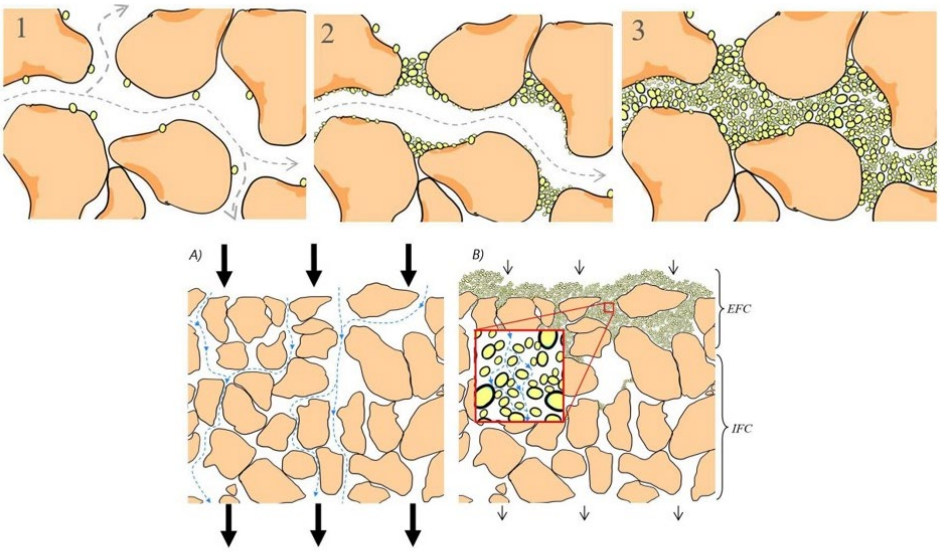
Due to the high content of mechanical impurities in the injected water, the injectivity of injection wells decreases, the processes of oil displacement from low-permeability formation intervals worsen, which leads to a decrease in recovery factor. The capacitive properties of the reservoir of the productive formation are high, and the injection well is able to accumulate large volumes of mechanical impurities without a noticeable decrease in injectivity.

The bottomhole formation zone (BFZ) of injection wells is subject to the negative influence of mechanical impurities, which reduce the injectivity of wells.

Table 1 - The results of the control of mechanical impurities and oil products (monthly averages) in the injected water of the Uzen field

Index		**Name of company**		
		LLC RN-UfaNIPIneft	**KazNIPIneft**	**LLP "ITC"**
pH		≥7	5,7 - 6,8	6 - 6,5
Density, g/l		1,036 - 1,048	1,027 - 1,055	1,035 - 1,090
General mineralization, g/l		42,54 - 45,03	26 - 75	32,68 - 103,28
Type of water according to Sulin		calcium chloride	calcium chloride	calcium chloride
Hydrogen sulfide, mg/l		17	2 - 510	7,4 - 37
Sulfate-reducing bacteria, cells/ml		10-10^2	10-10^5	no data
Oil content at outlet c (mg/l):	CPF	8-780	87-530	21-270
	FWKO-1	19,8-87	51-702	32-150
	FWKO -2	38,4-71,8	110-803	32-180
The content of mechanical impurities at the outlet from (mg / l):	CPF	160-760	2,5-470	22-52
	FWKO -1	310-350	54-237	27-42
	FWKO -2	320-360	50-163	26-59
The content of mechanical impurities at the inlet of the MGPS		300-1030	40-176	no data

According to the data obtained, it can be seen that the content of mechanical impurities in the injected water at the inlet of the MGPS (modular group pumping station) is found to exceed the standard concentrations. Therefore, the water treatment process requires improvement in terms of removal of mechanical impurities.



Drawing 2 – I. Schematic representation (1, 2, 3) of formation of IFC (internal filter cake) and EFC (external filter cake) in a thin disk with subsequent formation damage.

II. Schematic drawing of a thin disk before (A) and after (B) fluid injection testing. The black arrow indicates the flow rate.

When water is injected into a reservoir composed of mixed reservoirs, its movement mainly occurs along a system of fractures, from where it is filtered into the intergranular porous medium of the reservoir or vice versa. These are the most common collectors. According to some data, it has been established that, regardless of the reservoir type, maintaining a high injection pressure allows maintaining a high injectivity of wells for a number of years. Obviously, in this case, the well injectivity is determined by the number of fractures in the reservoirs and their opening. For such reservoirs, according to experts, the requirements for the quality of injected oilfield wastewater can be significantly reduced.

To justify the need to create a new formation water treatment technology that provides deep treatment of formation water without suspended clay particles, we will compose the equations for the costs of radial filtration of formation water according to the Darcy law. The flow rate of production wells does not decrease if the initial flow rate (injectivity) of the radial filtration of oil-displacing water Q_1 does not change during the entire period of operation of the wells.

However, due to the presence of a large amount of suspended solid clay particles in the composition of the injected water, which clog the pores of the rock, the permeability of the oil reservoir is significantly reduced. In this case, the initial flow rate (injectivity) of the radial filtration of water displacing oil is reduced to the value Q_2. According to Darcy's law, these parameters can be defined as

$$Q_1 = \frac{A\, k_1\, dp}{\mu_1\, dR} \;\geq\; Q_2 = \frac{A\, k_2\, dp}{\mu_2\, dR},$$

where A is the filtration area of the bottomhole formation zone, k_1 and k_2 – reservoir permeability during injection of formation water, respectively, without and with suspended clay particles, dp – downhole pressure change p_0 till formation pressure p, μ_1 and μ_2 - viscosity of the injected water, respectively, without and with suspended clay particles, dR – changing the contour of the well drainage area (well feeding contour) from 0 to R.

After integrating the variable parameters, we obtain

$$Q_1 \int_0^R dL = \frac{A\, k_1\, dp}{\mu_1} \int_{p_0}^{p} dp \;\geq\; Q_2 \int_0^R dL = \frac{A\, k_2\, dp}{\mu_2} \int_{p_0}^{p} dp$$

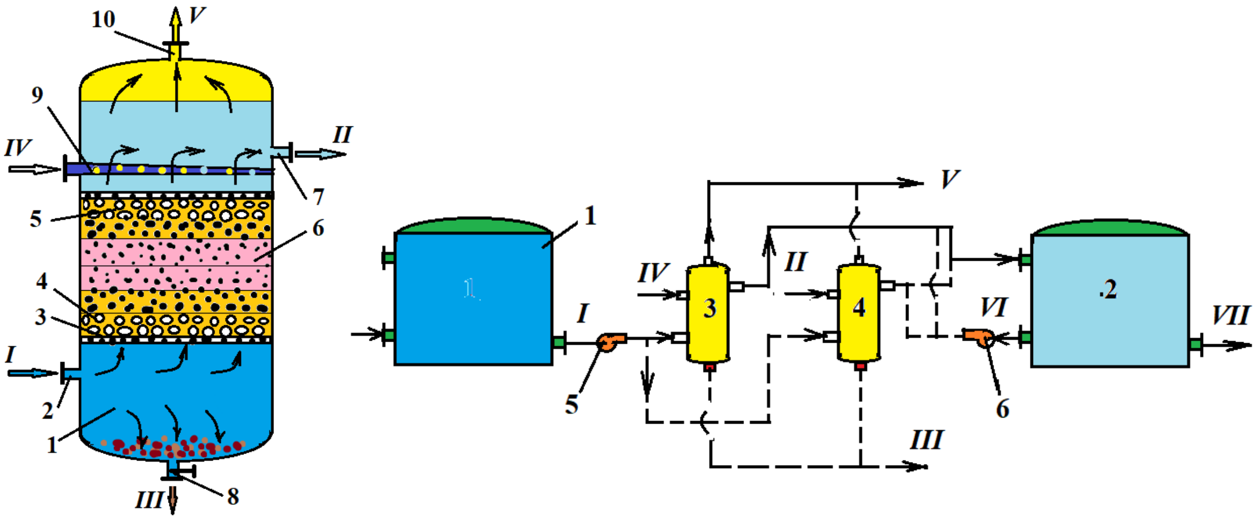
$$Q_1 = \frac{A\, k_1\,(p - p_0)}{\mu_1\, R} \;\geq\; Q_2 = \frac{A\, k_2\,(p - p_0)}{\mu_2\, R}, \qquad (1)$$

After reducing the parameters of the same name, we obtain

$$\frac{k_1}{\mu_1} \geq \frac{k_2}{\mu_2} \qquad \text{or} \qquad k_1 \geq \frac{k_2}{\mu_2}\mu_1$$

The obtained dependencies show that a decrease in the injectivity of injection wells occurs with an increase in the permeability of the bottomhole zone of the oil reservoir and the viscosity of the injected water due to suspended clay particles. Of course, this increases the resistance to the movement of water, which displaces oil from the reservoir and an increase in the power consumption of pumping stations. The flow rate of producing wells is significantly reduced, as the volume of water injected into oil reservoirs per unit of time decreases. This suggests that it is necessary to create a new technology for the treatment of formation water, which provides deep treatment of formation water without suspended clay particles.

We received a patent for a method for deep treatment of formation and waste water with suspended solids. This method is carried out by supplying purified water *I* (Figure 3a) from the lower compartment 1 of the installation with an inlet pipe 2 vertically from bottom to top sequentially through a perforated partition 3 and several layers of granular material with variable particle sizes in the vertical direction. The lower 4 and upper 5 layers of the granular material have the maximum overall dimensions of the particles, and the middle layer 6 has the minimum overall dimensions of the particles. Due to this, suspended solids do not clog in the pores of the filter and sink down and accumulate in the lower wedge-shaped part of the installation. Water moves from bottom to top freely passes through the pores of the filter. The purified formation water *II* is discharged through the outlet pipe 7. Through the lower pipe 8, the accumulated clay particles *III* are periodically discharged by the pressure of the purified water after they have been coagulated with reagents. If necessary, in the upper compartment of the unit, water purified from suspended solids with sulfide-reducing bacteria can be uniformly exposed to oxidizing gas *IV* (for example, ozone), which is supplied through the holes of perforated tubes 9 evenly distributed over the area and the exhaust gas *V*– is removed through the outlet pipe 10.



a *b*

Drawing 3 - Schemes of a granular filter (a) with variable particle sizes and a set of equipment (b) for the treatment of formation water without suspended clay particles.

The granular filter is pressed on both sides by perforated plates to keep the granular particles in a dense state. Suspended solids accumulated in the lower compartment of the unit are periodically discharged through the lower outlet by water injection. Purified from suspended solids, the water is sent to maintain reservoir pressure and uniform displacement of oil from the reservoir.

Based on this method of deep water purification, a new technology for the preparation of formation water for injection into oil reservoirs has been developed. The layout of the equipment set for the implementation of this technology is shown in Figure 3b. The complex of equipment consists of tanks 1 and 2 for purified water *I* and purified *II*, two granular filters 3 and 4, as well as a pumping unit 5 and 6. The flow of purified water from the reservoir 1 enters one of the two granular filters 3 or 4 and is subjected to purification from suspended solid clay particles. Then the purified water is sent to the tank 2 for its further supply to the wells using a pumping station.

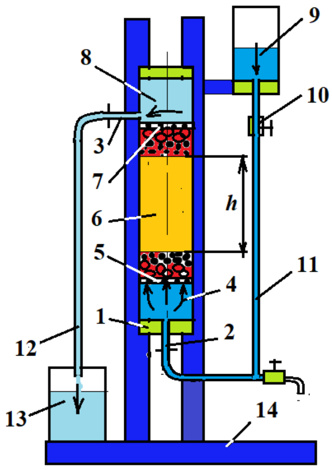
As clay particles accumulate in the lower part of the granular filter, the supply of purified water is stopped at the set time. Through the lower branch pipe 8, the accumulated clay particles *III* are removed by the pressure of purified water after their cogulation with reagents. At the same time, another granular filter is put into operation to purify the formation water. The *IV* gas is supplied through holes of perforated tubes evenly distributed over the area and the exhaust gas *V* – is discharged through the exhaust pipe.

To establish the rational parameters of the recommended new water treatment technology to maintain reservoir pressure, an experimental study of the process of reservoir water filtration through a granular filter with variable particle sizes was carried out. The experimental setup (Figure 3 a and b) consists of a vertical cylindrical body 1 (Figure 4a) made of Plexiglas and inlet 2 and outlet 3 nozzles. The length of the cylindrical body is 670 mm, and its diameter is 90 mm. Inside the cylindrical body, the lower compartment 4, the lower perforated metal disk 5, the filter 6 from several layers of granular materials, the upper perforated metal disk 7 and the upper compartment 8 are successively located. The upper and lower perforated dixy are pressed against each other in the middle by a bolted connection.

The purified water is supplied from the tank 9 made of plexiglass through the valve 10 and the tube 11 into the lower compartment of the cylindrical body. The purified water flows through the tube 12 into the tank 13. The cylindrical body and the water tanks are mounted on the frame 14.

The granular filter consists of five layers with variable particle sizes: in order from the bottom, the first and fifth layers are composed of ceramic balls with particle sizes from 3 to 5 mm and have a height of 25 mm; the second and fourth layers are composed of small pebbles and coarse sand with particle sizes from 1 to 2 mm and also have a height of 25 mm; the third working layer is composed of sand with a particle size of 0.7 to 1.0 mm and has a height *h*. All layers of the filter, except for the middle (thirds), have a constant height and contribute to a gradual decrease and increase in filter pores. Variable particle sizes of the filter layers increase the efficiency of deep treatment of formation water from suspended solid clay particles. Since all layers are pressed on both sides by perforated discs, the pores of the working layer of the filter do not change under the pressure of the flow of purified water. The values of the thickness of the working layer of the granular filter were taken as follows: h = 50, 100, 200, 300 mm.

a



b

Drawing 4 - General view (a) and schematic diagram (b) of an experimental installation for the treatment of formation water from suspended clay solids.

For the experiments, formation water samples with suspended clay particles of 1.8 and 3.2 g/l of the Ozen field (Kazakhstan) were taken. The main criteria for evaluating the operation of a granular filter with variable particle sizes of the experiment were taken: the mass in mg of suspended particles in one liter of formation water C (g/l) and the maximum particle sizes of suspended particles in microns in formation water before and after it passes through the filter.

Purified water from suspended clay particles from the lower compartment of the cylindrical body moves vertically from the bottom to the top and passes sequentially through the layers of a granular filter with variable particle sizes. Due to the fact that the lower and upper layers of the granular filter have gradually decreasing particle sizes, the suspended solids do not clog in the pores of the filter and go down and accumulate in the lower part of the cylindrical body. Water moves from bottom to top freely passes through the pores of the filter. Purified formation water is discharged through the outlet pipe of the cylindrical body. The mass of suspended solids in formation water before and after treatment was determined by the standard method, i.e. passing water through paper filters and weighing dried solids.

The economic efficiency of the proposed water treatment technology is expressed in terms of profit from additional oil production. In this case, all cost items are taken into account: the cost of preparatory work, water purification through a filter, operating costs, electricity costs, tax calculations.

Drawing 5 – Quantity and cost of oil produced in the process of water treatment for FPM.

From the results of the above calculations it follows that the annual economic efficiency of one well after water treatment for reservoir pressure maintenance is 22937672 tenge.

CONCLUSION

This dissertation paper shows theoretical and experimental studies of the technology of deep purification of formation water from suspended solids to maintain reservoir pressure in oil fields, from which the following conclusions were made:

− An analysis of literature sources and an assessment of the development of fields in Kazakhstan such as Kumkol, Aryskum, Uzen, Alibekmola and Zhanatalap and others showed that the predominant factor in high water cut at fields up to 90% is poor-quality water injected into the reservoir, prepared for reservoir pressure maintenance, and quality mismatch water supplied for injection into the reservoirs, the requirements of the regulatory documentation of the Republic of Kazakhstan. Also, a violation of the settling time of products in technological devices leads to a deterioration in water parameters.

− For the Uzen field, based on the data of porosity and reservoir properties of reservoir rocks, there is a need to ensure the preparation of injected water to the standard for the content of mechanical impurities in accordance with the requirements of the RoK standard. On the basis of the developed model of water injection into the reservoir, it was established from the core of the Uzen field that the reservoir properties of the reservoir are deteriorating.

− A method for deep water purification using a granular filter with variable particle sizes has been developed to solve the problem of reducing the permeability of the bottomhole zone and the injectivity of injection wells. Purified water from suspended clay particles from the lower compartment of the cylindrical filter housing moves vertically from the bottom to the top and passes successively through granular layers with variable particle sizes. Due to the fact that the lower and upper layers of the granular filter have gradually decreasing particle sizes, the suspended solids do not clog in the pores of the filter and go down and accumulate in the lower part of the cylindrical body.

− Established rational parameters of a granular filter with variable pore sizes for treatment of formation water with suspended clay particles to maintain formation pressure. The use of granular filters with variable particle sizes in the reservoir water treatment system to maintain reservoir pressure will significantly increase the flow rates of production wells (at least 1.5 - 2 times) due to an increase in the permeability of the oil reservoir and the injectivity of injection wells.

− It has been experimentally revealed that with a granular layer height of more than 100 mm in formation water after its purification, the amount of suspended solid particles reaches zero. To improve the reliability of the filter, the height of the granular layer can be taken within 200 - 300 mm. The values of the coefficient of resistance to the movement of water through a granular filter depending on the height of the granular layer were experimentally determined, which make it possible to establish the power consumption of pumping units.

− Development of scientific recommendations for a new technology for deep treatment of formation water from suspended clay particles to maintain reservoir pressure, which ensures an increase in oil recovery of the deposit and an increase in well flow rate.

− The technical and economic efficiency of the proposed technology for increasing the oil recovery factor was substantiated by calculations. This method is cost-effective not only for this field, but also for all fields located in similar conditions.