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DEVELOPMENT OF EFFECTIVE TECHNOLOGY OF DEEP WATER TREATMENT FROM SUSPENDED SOLID PARTICLES FOR FORMATION PRESSURE MAINTENANCE AT THE OIL FIELDS

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ABSTRACT

Using for example Uzen oil and gas field, this article explores the peculiarities of oil production at fields located at the middle and late stages of development. Particular attention is paid to the need to pump water into the reservoir to maintain reservoir pressure. The main methods of purification of oilfield wastewater are considered. The Uzen field was analyzed in detail, the requirements for water quality to maintain reservoir pressure, as well as presented results of monitoring of solids and oil products in the injected water of the Uzen field. According to the injected reservoir water data at the Uzen field, we have built a projection model that takes into account the content of mechanical additions. The tests made in the reservoir of wastewater pumped at Uzen formation proposed experimental setup for water purification to maintain reservoir pressure. Experiments on water purification showed significant results.

KEYWORDS

Uzen oil and gas field, reservoir pressure maintenance, oil field wastewater purification, mechanical additions control.

1. INTRODUCTION

Oil production at the fields at the intermediate and late stages of development is characterized by the need to inject water into the reservoir to maintain reservoir pressure (RPM). It is generally accepted that adding water will not only increase the speed of recovery, but we also help to achieve the maximum recovery rate of hydrocarbons.

Requirements for oil field wastewater as a working agent for water flooding are described by three main indicators: the content of emulsified oil (oil products) and particulate solids, its microbiological and chemical compatibility with formation water and reservoir rocks. In order to avoid complications when pumping water into the formation, the injected water must meet certain quality standards according to ST RK 1662-2007 where mechanical additions and oil products should not be more than 50 mg / l.

The article analyzes the Uzen oil and gas field, which was put into commercial development in 1965, and is currently at a late stage of operation. The complex of facilities for the recovery and treatment of oil, gas and water available in this field includes a large set of complex facilities for the main and auxiliary purposes.

2. THEORETICAL OVERVIEW

The main methods of cleaning oilfield wastewater in the industry are mechanical and physic-chemical [1]. The most common is the method of settling as the simplest and cheap, in many cases providing the necessary water quality requirements. On most objects, only this method is used, and on some, in combination with filtration and physicochemical methods. The method of settling, though simple, has drawbacks: the high dependence of the quality of purification on the characteristics of polluting inclusions (dispersion, stability, etc.), the duration of the process, etc. Therefore, in recent years, to improve equipment performance and the depth of wastewater treatment, new tools such as thin-layer settling tanks, with a coalescing filter, filters, three-product hydrocyclones, etc. have been developed.

Most studies show that water quality is a very important parameter for reservoir processes. A group of researchers recommend the introduction of cascade technology for formation of water purification to maintain reservoir pressure in the Yuzhno-Romashkinsk area of the Romashkinsk field [2].At the same time, the recommended technology is expensive, requires additional water treatment equipment, and if it is located in remote areas, there is also the need to build additional low-pressure water lines.

The existing problem of treatment of wastewater pumped into the system for maintaining reservoir pressure outlined by a scholar in his article [3]. The consequence of inadequate supervision of injection is contamination of the formations and low oil recovery rate. Blockage of the reservoir is caused by the presence of fine particles, oil residues and mechanical impurities in the water, which in turn cause clogging of pores, channels and cracks. In addition, the constant increase in the water of content of the extracted products has led to the fact that the existing water treatment equipment cannot cope with such large volumes of products and do not bring the water to the required quality. To solve these problems, it is proposed to use the cluster discharge equipment, which allows utilizing the bulk of the produced water directly to the field, having brought it to the relevant standards. Several options for instrumentation of cluster dump objects are considered. The diagrams of the proposed equipment are shown as introduced into production. The expected results, which are planned to be obtained after the introduction of cluster dumping facilities into the development of oil fields in the early stages of oil gathering are taken into account. However, the use of cluster discharge equipment has a number of disadvantages compared to the proposed device for deep purification of formation water. Insufficient efficiency, due to the fact that the quality of water supplied to the injection well is poorly controlled, and its quantity is constant.

In the Kazan State University of Architecture and Civil Engineering, has developed and implemented hydrocyclone installations for the preparation of water used for flooding productive horizons [4]. To reduce the concentration of oil products and mechanical impurities in oil-field wastewater up to 10 mg / l after processing in installations such as "block hydrocyclone – settling tank" or "hydrocyclone block – cylindrical chambers – settling tank", it is advisable to direct the after- treatment into filter installations consisting of high-speed filters. Block hydrocyclone plants have a high specific performance, compactness, they are fully automated, they are blocks produced at factory; they provide an opportunity to create an effective technology for cleaning oilfield wastewater at the lowest material and energy costs. The disadvantage of this technology is a low degree of separation, the complexity of the removal of pop-up substances.

A. Isangulov and others. A previous researcher summarized the experience of introducing filters for fine cleaning of water in the system for maintaining the reservoir pressure of the South Khylchuya field [5,6].

The disadvantage of this technical solution is that the additionally adopted artificial mesh, woven and membrane filters are short-lived. There is also a need for a certain pressure for pushing water through the membrane and retaining beneficial microelements.

It should be noted that studies conducted at the Perm National Research Polytechnic University by a researcher to improve and increase the reliability of operation of the FPD systems, reduce costs, taking into account the requirements for water quality, developed a system for field water treatment [7]. The main differences of the proposed system from the previously developed ones are the creation of a vacuum in the intake manifold and the provision of water movement at the inlet of the centrifugal pump by installing a jet pump. However, this system is constrained by the lack of clearly reasoned theoretical ideas about how to solve the problems of deep purification of produced water from suspended solids.

In any water treatment system, a certain amount of suspended solids always remains in the water, which gradually pollutes the filter surface of the bottom hole formation zone. The intensity of filtering attenuation depends on the nature of the suspension and the size of the pore channels of the watering formation [8,9]. The permeability of the formation in the bottom hole zone due to severe pollution of the filtration surface decreases tenfold, and industrial injection of water becomes impossible. Therefore, systematic progressive contamination of the filtering surfaces of injection wells should not be allowed [10].

Despite the importance of the issue and a fairly large number of publications devoted to the research of deep purification of water from suspended solids and its uniform injection into the oil reservoir, the above problem remains relevant today.

3. MATERIAL AND METHODS

The development of Uzen fields is carried out with the maintenance of reservoir pressure (MRP). The source of water used for pumping into productive strata is Alb-Cenomanian formation water, coming from UPSV-1, UPSV-2, CPPN and comprising about 70% of the injected water, and the sea water of the Caspian Sea, which is by volume about 30% of the injected water (supplied to the field via the Aktau-Uzen seawater aqueduct through the 4-pump water-lifting system) and wastewater from preliminary and commercial oil preparation facilities.

Requirements for the quality of water for PPD on ST RK 1662-2007 "Water for water-flooding of oil reservoirs" are given in Table 1 and 2.

Table 1: Physical and chemical parameters of water according to the requirements of ST RK-1662-207

The permeability of the porous environment of the collector, micron ²	**Reservoir Fracture Ratio**	**Permissible content in water, mg / l**	
		mechanical additions	**of oil**
up to 0.1 incl.	-	up to 3	up to 5
over 0.1	-	up to 5	up to 10
up to 0.35 incl.	from 6.5 to 2 incl.	up to 15	up to 15
over 0.35	less than 2	up to 30	up to 30
up to 0.6 incl.	from 3.5 to 3.6 incl.	up to 40	up to 40
over 0.6	less than 3.6	up to 50	up to 50

Table 2: Requirements for the quality of injection water

No.	**Parameters**	**Requirements**
1	Stability	-stability
2	Swelling	-absent
3	The content of mechanical additions	- taking into account the heterogeneity of reservoir properties
4	Suspended particle size	-90% less than 5 microns
5	Oil content	- according to the reservoir properties, no more than 10-30 mg / l
6	Oxygen content	- less than 0.5 mg / l
7	Iron content	- less than 1 mg / l
8	Hydrogen sulfide content	-absent
9	Content of SVB	-absent
10	Corrosion rate	- less than 0.1 mm / year
11	Formation water compatibility	-compatible, reduction not more than 20%

A distinctive feature of the field operation is the annual increase in the water content of the produced products, which currently exceeds 88% on average, which in turn significantly complicates the operating conditions of the objects for collecting oil? gas and water (Figure 1).

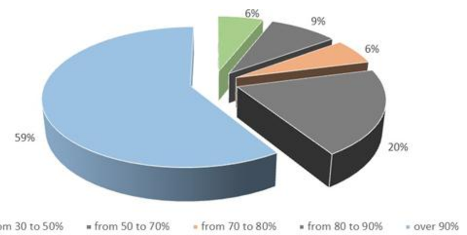

Figure 1: Distribution of wells in the field by average water level as of 07/01/2014 [11].

An analysis of the distribution of wells by the average water level showed that as of July 1, 2014, in the XIII-XVIII horizons of the field as a whole, the average water content of the wells increased from 82% to 86% (by 4%), and in the XIII and XIV wells – from 82.74% to 88.01% (by 5.27%) and from 86.00% to 88.4% (by 2.46 %). More than half of the operating fund (58, 7%) with a water content of more than 90% is highly abundant with water. The number of wells with a water level of up to 30% is only 2.

The technology currently used for the preliminary discharge of secondary water (UPSV-1, UPSV-2) is complicated by the receipt of large volumes of liquid from oil fields, which exceeds the design capacity of these objects. Existing water treatment technologies are shown in Figure 2.

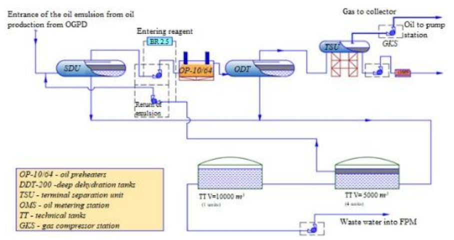

Figure 2: Existing water treatment technologies UPSV-1 and UPSV-2 at the Uzen field

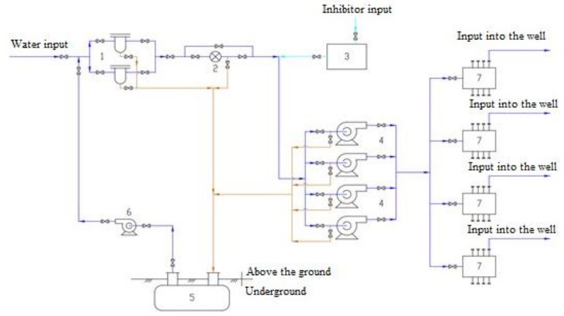

Figure 3: The chart of the modernized BKNS PPD system (reservoir pressure maintenance)

The total volume of produced water from the subsoil exceeds 45 million cubic meters per year. Cleaning of such volumes requires significant material, energy and labor costs. Design capacity and actual workload of UPSV-1 and 2 are shown in Table 3.

Table 3: Design capacity and actual load capacity

Name	USPV 1			USPV 2		
	Project capacity, thousand m^3 / year	Actual production for 2012		Project capacity, thousand m^3 / year	Actual production for 2012	
		thousand m^3 / year	%		thousand m^3 / year	%
Liquid	16,425	22,772	139	16,425	21 150	128
Waste water	10,950	19,229	175	10,950	17,990	164
Oil	5,475	3,542	65	5,475	3,159	58

As follows from the data presented, the design capacity of each UPSV for liquids – 16.4 million m3 / year (45 thousand m^3 / day). The actual load of UPSV-1 and 2 in 1.3 times the design capacity.

In addition, due to the increased load on the fluid supplied to UPSV-1 and UPSV-2, there is a violation of the product sludge time in technological devices, which leads to deterioration of the parameters of water prepared for PPD, and the quality of the water supplied for injection reservoirs, the requirements of the regulatory documentation of the Republic of Kazakhstan.

Laboratory studies have found that at UPSV 1 and 2, the optimal time for the 1st stage of sludge water-oil emulsion (discharge of free water) is 50-60 minutes; The optimal time for the 2nd stage of sewage sludge (cleaning of mechanical impurities and oil products) is 4 hours, which is not provided by the actual installed equipment. The conducted studies show that in the productive strata of deposits take place active processes of the development of the biocenosis of sulfate-reducing bacteria, which come from sea water. This leads to the intensification of corrosion processes and the rapid deterioration of oil field equipment and pipeline.

These factors negatively affect the turnaround time of producing wells, due to premature failure of underground equipment due to clogging of deep-well equipment with various mechanical impurities, due to increased corrosive activity of the produced products, increased salinity of mining deposits and intensive formation of various types of scaling (Table 4) .Solid particles in the injected water directly affect the injection pressure and the degree of deterioration of the reservoir properties of low-permeable sandstone.

Table 4: The composition of mechanical impurities retrieved from the working elements of the pump (May 2012)

Composition of samples	Content in samples, % of the mass.			
	well No.3595, TK-52	well No.7144, GU-51	well No.2135, GU-52	well No.6462, GU-5
Water	0.03	0.03	0.03	2.56
Oil products	4.92	4.22	5.9	0.94
Mech impurities	95.05 (sand 30%; salt – 70%)	95.75 (sand – 20%; salt – 80%)	94.07 (sand – 14%; salt – 86%)	96.5 (sand – 90%; salt – 10%)

As follows from the presented data, the mechanical impurities selected from the pump elements are mainly sand (14–90%) and crystalline salt (10–86%). The negative impact of mechanical impurities on the operation of the plunger pumps showed in the wear of the plunger pair of pumps, in the receiving and discharge valves, etc. (Figure 4).

Figure 4: Wear class pair due to admission to the pump of mechanical impurities

The need to protect underground equipment from mechanical impurities is due to the fact that take-out or insertion of them downhole leads to premature wear of the production well and elements of pumping equipment, which causes repairs.

Control over the composition of the injected water and analysis of petroleum products and mechanical impurities in the injected water is carried out daily. The results of the quality control of the injected water at this field are shown in Table 5.

Table 5: Results of monitoring of mechanical impurities and oil (monthly average) in the injection water Uzen

Indicator		Name of company		
		LLC RN-UfaNIPIneft	KazNIPIneft	LLC "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
Total 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		$10\text{-}10^2$	$10\text{-}10^5$	no data
The content of oil output from (mg / l)	COTC	8-780	87-530	21-270
	UPSV-1	19,8-87	51-702	32-150
	UPSV-2	38.4-71.8	110-803	32-180
The content of mechanical impurities at the outlet (mg / l):	COTC	160-760	2.5-470	22-52
	UPSV-1	310-350	54-237	27-42
	UPSV-2	320-360	50-163	26-59
The content of mechanical impurities at the inlet of block-pumping station		300-1030	40-176	no data

According to the data obtained, it is clear that the content of mechanical impurities in the injected water at the inlet of the block-pumping station is set to concentrations exceeding the standard values. Consequently, the water treatment process requires improvements in the removal of mechanical impurities.

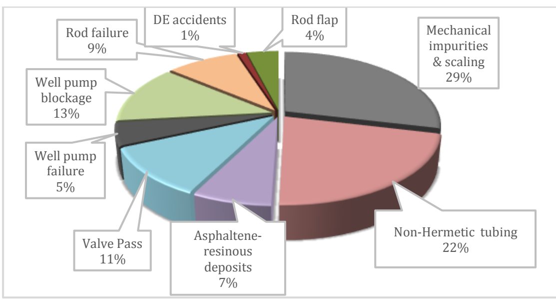

Figure 5. Distribution of well production maintenance (WPM) for the 1st half of 2012 due to the reasons for changing the plunger pump [11]

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As follows from the data presented, the main causes of UWR: pump change due to mechanical impurities and scaling – 29%, tubing leakage – 22%, jamming of the pump – 13%, breakage of rods – 9%. Asphalt, resin and paraffin deposits, salt deposits and mechanical impurities indirectly affect such types of failures as pump blocking and rod breakage. The reasons for the high percentage of UWR due to mechanical impurities and scaling (29%) which is extremely difficult to repair, since in this case it requires an integrated approach using mechanical and chemical (inhibitory) remedies [12,13].

Table 6: Physic-chemical properties of the reservoir and ground water samples passing Uzen field

Indicators	Wells					OGDU					
	4733	**4733**	**9127**	**9127**	**9128**	**1**	**1**	**1**	**1**	**1**	**3**
Date	02.10	27.09	01.10	02.10	06.10	01.10	01.10	02.10	02.10	01.10	27.09
Depth, (location), m	1121.4	1160.5	1359.4	1218.4	1330	PG 88	PG 89	GU-4	GU-85	GU-87	GU-77
Contents mechanical impurities mg / dm ^{3} (iron-sand,%)	2100 (75% - 25%)	3800 (70% - 30%)	600 (65% - 35%)	1500 (70% - 30%)	4615.6 (75% - 25%)	718 (70% - 30%)	5320 (75% - 25%)	1068.8 (65% - 35%)	497 (75% - 25%)	5030 (70% - 30%)	257.6 (65% - 35%)

As follows from the data presented, in the samples of the formation water, the content of mechanical impurities (according to GOST 26449.1-85 p.2) is significant (from 600 to – 4615.6 mg / dm^3 or from 0.06 to 0.46 wt.%) Presented in mainly iron salts (65-75%) and sand (25-35%).

4. RESULTS AND DISCUSSION

The simulation results according to the Uzen field show a gradual decrease in the permeability and infectivity of the bottom hole formation zone of well No. 1 when pumping waste water with a high content of mechanical impurities into well No. 2 (Figure 7).

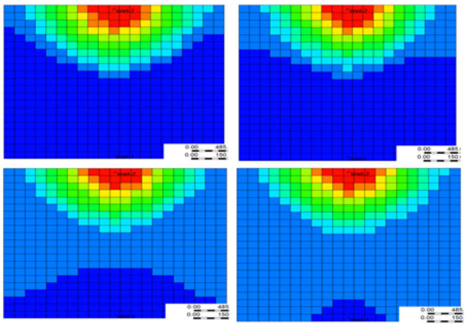

Figure 6: Impact of high concentration of suspended solids on the bottomhole formation zone

A new technology has been developed and the result of the invention allows to increase the efficiency of purification of industrial wastewater and field formation water with suspended solid particles, sulfide-reducing bacteria by supplying purified water 1 from the lower compartment 2 of the unit with the outlet 3 vertically from bottom to top successively through the perforated partition 4 and granular layers 5 with variable particle sizes in the vertical direction, the lower layer of which has maximum overall dimensions of particles, and the upper layer – the minimum overall dimensions of particles .When in this upper compartment water purified from suspended solids and sulfide-reducing bacteria subjected to uniform exposure of the oxidizing gas supply which is performed through openings uniformly distributed over the area of perforated tubes 6, 7 and 8.

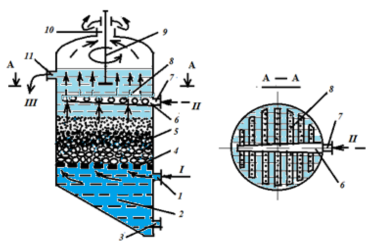

Figure 7: Diagram of experimental setup for purification of produced water from the particulate matter

Suspended solids accumulated in the lower compartment of the installation are periodically discharged through the lower outlet nozzle by water injection. Purified from suspended solids water is directed to maintain reservoir pressure and uniform displacement of oil from the reservoir [14].

Thus, the supply of purified water vertically from bottom to top consistently through a perforated partition and layers of granular material, oxidizing gas, can significantly improve the efficiency of water purification from suspended solids, sulfide-reducing bacteria, prevent clogging of pores with suspended solids and significantly increase plant capacity [15].

In the laboratory at KazNRTU n. a. Satpayev analyzed the reservoir waste water injected into the reservoir "Uzen". The number of suspended particles in the formation water was determined according to ST RK 1662-2007. As a result of the analysis, it was established that the mass of mechanical impurities was Uz = 3.2 g / l, that is, it is much higher than the standard data. After the cleaning, the results showed Uz-4 = 1.75 g / l (Figure 8).

Figure 8: Type of solid suspended particles before and after cleaning (without using the layer of the sand working area)

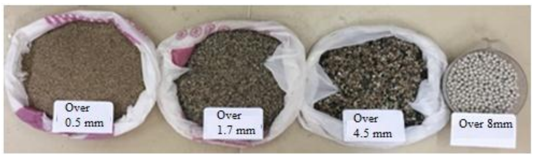

Figure 9: General view of the used granular material for cleaning

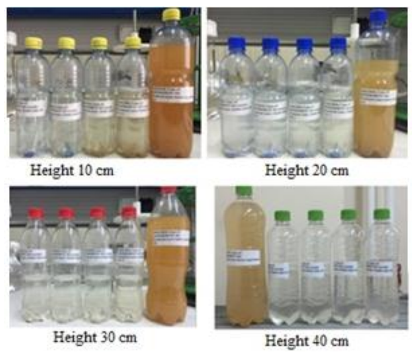

Figure 10: Produced water before and after cleaning according to the height of the working area of the sand

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The granular filter consists of three layers: the lower and upper supporting layers with variable particle sizes - from 5.0 to 1.0 mm; the middle working layer consisting of river sand with particle sizes from 0.7 to 1.0 mm. These three granular layers are pressed between the lower and upper perforated metal partitions with screws and nuts.

The main criteria for evaluating the operation of a granular filter with varying particle sizes of the experiment were taken: mass in mg of suspended particles in one liter of produced water before and after passing it through the filter, i.e. - concentration of suspended particles in mg / l and the maximum particle size of suspended particles in microns in water before and after passing it through the filter. The thickness of the working layer of the granular filter during the experiments were taken in the following ranges: δ = 100, 200, 300, 400 mm. The concentration of suspended clay particles in the initial water samples was used as the main factor.: C_susp= 0,8 ... 1000,0 g/l. (Figure 16).

As a result of the analysis by weighing on an analytical balance, it was found that the weight of mechanical impurities averaged 3.2 g / l before water treatment and after water treatment an average of 0.001 g / l (Figure 10).

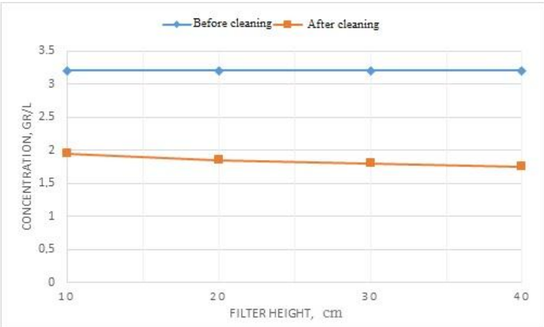

Figure 11: The results of the experiment, the content of mechanical impurities in the formation water of the Uzen field

Also on the Zetasizer device was accomplished nano measurement of the radius of mechanical impurities in the formation water before (Uz) and after treatment (Uz-3) at the Uzen field of Ozenmunaygas JSC .The results of Uz measurements showed (Figure 12 and 13) that particles with sizes from 0.5 to 1 μm make about 40 %.These sizes of solid suspended particles are comparable with the sizes of pores and capillaries. After purification, the results for Uz-3 form particles with sizes ranging from 0.08 to 0.09 microns which showed about 100%.

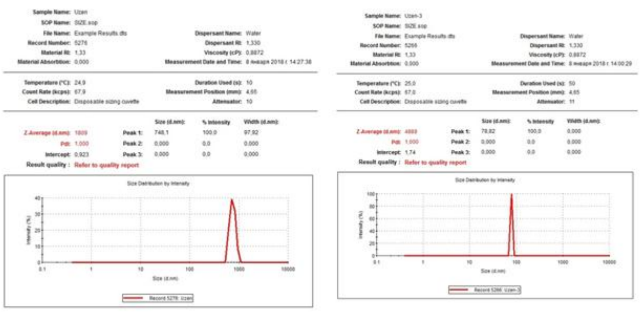

Figure 12: The intensity of the size distribution of solid suspended particles in the water injected into the reservoir before and after cleaning

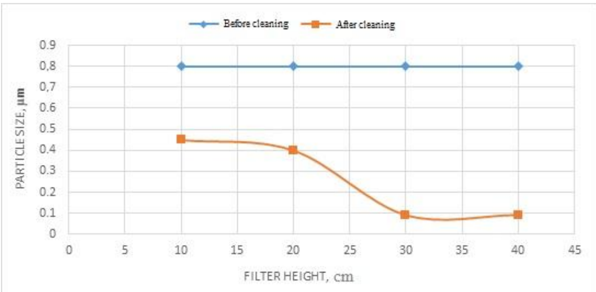

Figure 13: Sizes of mechanical impurities in water before and after cleaning at the Uzen field

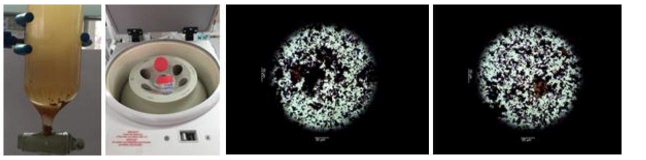

Figure 14: General view of the filter and an enlarged view of suspended particles from the Uzen deposit

The cleaning efficiency was described through the height of the working area of the filter. We applied clay, for a creation of the concentration of suspended particles in water.

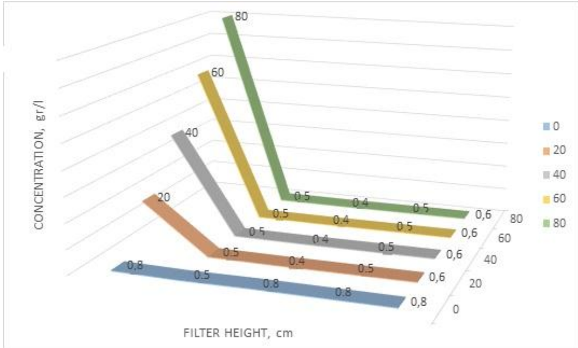

Figure 15: The dependence of the cleaning efficiency of the height of the working area of the filter with the use of clay

The results of the experiments showed that with an increase in the height of the working layer over 130 mm, the concentration of suspended particles in the reservoir water decreases significantly by about tens of times, and the maximum sizes of suspended particles do not exceed 100 microns. This suggests that increasing the height of the working granular layer to 400 - 500 mm, and reducing the particle size of grains less than 0.7 mm, and compacting the working layer of the filter can achieve complete purification of produced water

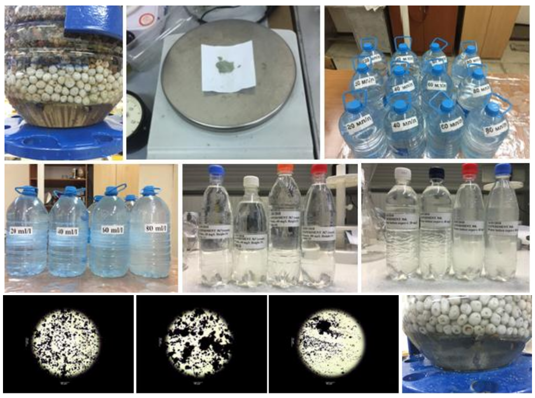

Figure 16: General view of the filter and an enlarged view of clay particles

The total mineralization of the formation water was determined by evaporation of the exact known volume of fluid to constant weight, followed by weighing on analytical scales. As a result of the analysis, the salinity of the Uz formation water was 49 g per liter, and after it was cleaned, Uz-4 was 35.6 g per liter.

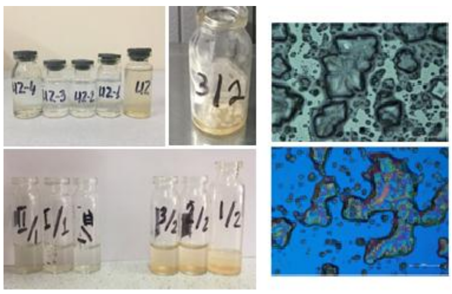

Figure 17: General view of the salt content in produced water

5. CONCLUSION

Scientific research work on this topic is carried out within the framework of the project of Financial Grant of the Ministry of Education and Science of the Republic of Kazakhstan for 2018–2020. “No. 2018 / AP05130484” on the subject: “Scientific rationale of creating an effective integrated technology for maintaining reservoir pressure and increasing oil well flow rate”, as well as HNIR for 2018. with PetroKazakhstan Kumkol Resources JSC for project No. 4.010.18 on the topic: “Scientific support in the implementation of new technologies and equipment in order to increase oil recovery and reduce watering”.

We have obtained a patent for a method for deep purification of formation waste water with suspended solid particles. The task and the technical result of the invention is to increase the efficiency of purification of industrial waste and field formation water with suspended solid particles, sulfide-reducing bacteria.

We estimated the degree of influence of suspended clay particles in the composition of water injected into oil reservoirs on the process of reducing the capacity of injection wells, i.e. reducing oil recovery.

We determined the dependencies of the reservoir permeability in the wellbore zone of wells on the size and concentration of clay suspended particles in the injected water and we described the regularities of the process of water preparation without suspended clay particles using a filter from granular materials with variable fraction size and lower water supply.

It was revealed that the solid suspended particles of the water injected into the reservoir are commensurate with the sizes of pores and cracks of the oil reservoir and clog the pores of the bottom hole formation.

The results of the experiment are of high importance both nationally and internationally. Scientific recommendations solve the problems of oil and gas companies such as enhancing the recovery of extracted oil, as well as reducing capital and operating costs.

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