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APPLICATION OF A NEW CLASS OF NANOCOMPOSITES IN THE ECOLOGICAL MANAGEMENT OF FORMATION WATERS AT THE BIBIHEYBAT OIL AND GAS FIELD

(*Представлено членом редакційної колегії д-ром геол. наук, ст. наук. співроб. О.Л. Шевченком*)

B a c k g r o u n d *. A new utilization technology has been developed to ensure the rational reuse of toxic formation waters extracted from the oil fields of Bibiheybat OGPD in secondary technological processes and to restore ecological balance. The study presents a comparative analysis of the environmental impact mechanisms of nanocomposites N-1, N-2, and N-4.*

M e t h o d s *. Formation water samples collected from the receiving reservoirs of the Bibiheybat OGPD oil fields were treated with various nanocomposites to evaluate their effects. Additionally, oil samples taken from the surface of formation water were analyzed for changes in rheological parameters, and the primary contaminant-mechanical impurities were treated using nanocomposites from the N-series.*

R e s u l t s *. The proposed new utilization technology has proven to be both ecologically and economically efficient in increasing the effectiveness of reusing formation water in secondary technological processes and minimizing its environmental impact. Without requiring the installation of new facilities in old oil fields, a closed-loop water supply system can be established using either N-2 or N-4 nanocomposites, depending on geological conditions.*

C o n c l u s i o n s *. According to the research findings, nanocomposites N-2 and N-4 alter the type of formation water, converting it from "acidic" to "alkaline". These composites also enhance the rheological properties of oil. Within the framework of environmental safety standards, a closed-loop, zero-waste water supply system utilizing nanocomposites N-2 or N-4 is proposed as an eco-technological scheme for preparing formation water to meet required conditions.*

K e y w o r d s : *formation water, toxic components, environment, utilization technology, nanocomposite.*

Background

Purpose of the Work. The purpose of this work is to substantiate the development of environmentally safe technologies to optimize the disposal of formation waters that are harmful to environmental objects and unsuitable for use in technological processes.

Global climate change has made environmental protection and pollution control measures a primary focus worldwide in recent years. It is no coincidence that the President of the Republic of Azerbaijan declared 2024 as the "Year of Solidarity for a Green World", bringing to the forefront the implementation of environmental remediation measures across various sectors in the country. Since the oil industry remains a priority in our current stage of economic development, adherence to environmental norms and rules in the improvement of technological approaches plays a crucial role in forming a healthy lifestyle and living environment.

Produced waters affect all environmental objects – hydrosphere, atmosphere, and lithosphere through techno-physical impacts (Lee at al., 2005; Mammadova, 2022; Neff, 2002; Steinar, al., 2017; Sunda, 2012). Globally, the demand for oil and gas production increases the harmful environmental impacts of formation waters. Industries generating large volumes of waste should be replaced by "green" technologies that reduce the impact of pollutants arising from the use of technologies not meeting environmental safety standards. By using the environmentally safe potential of innovative technologies for neutralizing waste, complex-action chemical reagents, sorbents, membranes, and catalysts can be employed (Mammadova, 2023; Boysen, Boysen, & Larson, 2011; Al-Mohammad, Al-Kaabi, & Mohammad, 2019).

The volume and chemical composition of formation waters produced from oil fields vary both between different fields and over different stages of exploitation of the same field (Al-Mohammad, Al-Kaabi, & Mohammad, 2019; Mehmood, Khan, & Muneer, R. 2016). According to projections, this ratio will increase by 2025, raising the demand for new technologies in the reuse of produced water (Fig. 1) (Al-Mohammad, Al-Kaabi, & Mohammad, 2019; Boysen, Boysen, & Larson, 2011; Mammadova, 2023; Miller, 2006).

The composition of formation waters includes dangerous pollutants such as oil and oil products, chemicals, acids, alkalis, surfactants, as well as solid mineral (Mammadova, 2022; 2023; Murvatov, Mammadov, & Mammadov, 2014). Formation waters affect all areas of the environment – including the hydrosphere, atmosphere, and lithosphere – through technophysical impact. They degrade the qualitative characteristics of natural components. During operations on offshore oil and gas platforms, formation water discharged into the aquatic environment becomes a source of polyaromatic hydrocarbons. Hazardous substances such as alkylphenols and aromatic hydrocarbons accumulate in benthic communities and are toxic to aquatic organisms, potentially entering and circulating through the food chain. These toxic components also impair the reproductive functions of marine microfauna. Additionally, they can destroy genetic biomarkers in benthic communities and significantly affect oxygen consumption in water (Beyer at al., 2020).

Formation waters are adsorbed by soil infiltrate into groundwater and alter its physicochemical properties – including salinity, alkalinity, water-air balance, and the carbon-nitrogen ratio. The negative impact of mineralized water on soil cover is more intense than that of oil and petroleum products. As a result of technogenic processes, elemental migration occurs in the soil (Kovaleva, Trofimov, & Cheng, 2020; Mengxue, 2020).

Thus, formation water alters the state of ecosystems it enters and leads to the degradation of biocenoses. Formation waters with high salt concentrations have adverse effects on soil and vegetation. Due to the high concentrations of dissolved salts (primarily sodium chloride, $NaCl$), the soil becomes saline. The chloride content is toxic to many biological species. Sodium acts as a natural dispersant, affecting the swelling and absorption capacity of the soil, contributing to salinization, and ultimately causing the destruction of vegetation. Although swollen soil may retain its natural structure, once disintegration occurs, its structure is lost. This loss of structure impedes the infiltration and movement of water through the soil, increasing the potential for erosion. Furthermore, the salts in formation waters disrupt the ability of plants to absorb water and nutrients (Kovaleva, Trofimov, & Cheng, 2020; Mengxue, 2020).

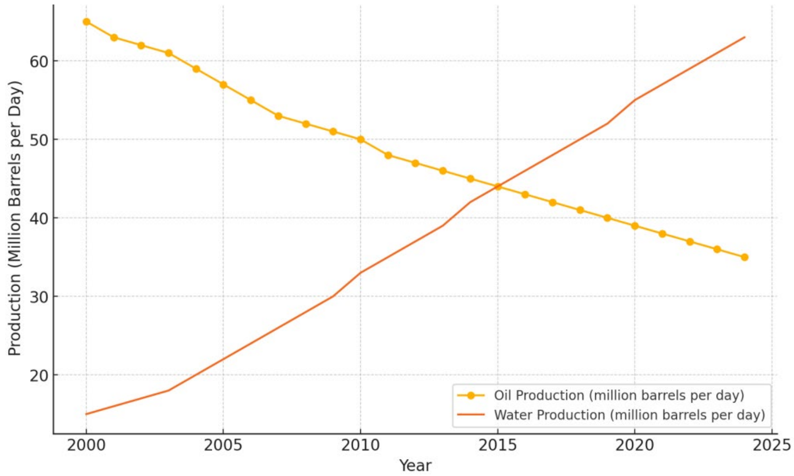

Fig. 1. Global oil and water production

Formation water disposal is carried out in very limited cases (Andreev, 2003). In the Bibiheybat OGPD, there is no special procedure for treating formation waters. After basic preliminary treatment, these waters can be used to restore reservoir pressure in oil field water-flooding systems or as a source for washing out underground salt layers (Sunda, 2012; Steinar, at al., 2017). Depending on the intended use, formation waters must be treated to meet the required standards (Abdulaziz, Hatem, & Mahdi, 2021; Al-Mohammad, Al-Kaabi, & Mohammad, 2019). Currently, for water injected to maintain reservoir pressure, the technical and environmental requirements are as follows (Ganotskaya, 2015):

- the water should not contain large amounts of mechanical impurities, iron, oil or oil products;
- to prevent corrosion, it should not contain H_2S or carbonic acid;
- it should not contain organic pollutants (bacteria and algae);
- it should be chemically inert with respect to the formation fluids.

In secondary technological processes, the water is used to displace oil from reservoir collectors to the bottom of the well. For this purpose, the water must be purified from insoluble salts and other compounds such as algae and microorganisms that may form under reservoir conditions, in order to prevent a reduction in the injectivity of injection wells. (Mammadova, 2024; Murvatov, Usubaliyev, & Mammadova, 2022). Additionally, the water used in technological processes should not produce foam, should not cause scale formation in pump-compressor pipes and equipment, and should not corrode metal. Given that the development of a new "zero-waste" civilization involves highly multifunctional nanotechnology, the application of nanostructured systems in preparing the composition of formation waters to required conditions in closed water supply systems is of great theoretical and practical interest.

In general, the inability to condition formation waters to the required standards means that as the pressure of the water injected into injection and disposal wells increases, those waters – harmful to the natural environment around the wells come to the surface around the wells. Fig. 2 shows that the extremely old state of the existing communication lines and inadequate treatment of the formation water cause major problems in water injection and acceptance (Ilchenko, 2000; Silin, & Magadova, 2013). For example, various geo-ecological risks can arise during the water-flooding process, so the utilization wells technology must be designed taking into account the geotechnical conditions of the field (Murvatov, Mammadov, & Mammadov, 2014; Murvatov, Usubaliyev, & Mammadova, 2022).

Fig. 2. Griffon formation in layer water utilization wells

Because the utilization of formation waters containing toxic components is not universally achievable, their treatment requires substantial capital and specific technological conditions (Abdulaziz, Hatem, & Mahdi, 2021; Ganotskaya, 2015; Igunnu, & Chen, 2012; Mammadova, 2023; Munirasu, Abu, & Banat, 2016). Waters used for restoring reservoir pressure in oil fields are disposed of using open and closed treatment facilities. In open-type water treatment technology, regardless of the water's content, pressure, or gas saturation, formation waters and atmospheric runoff waters are treated in a single stream and then injected together into water injection wells. However, contact of these waters with atmospheric oxygen increases the corrosive activity of the water.

Methods

Study Area

One of the oil-gas-condensate fields on the Absheron Peninsula is the Bibiheybat field. The field is located on the coast of the Caspian Sea, 3–4 km south of the capital (Baku). Its geological structure includes the Absheron, Akchagil, and Productive Series deposits. In some parts of the field, the deposits are transgressively overlain by Ancient Caspian and Modern epoch sediments consisting of carbonate sandy clays and pebbly conglomerates. The Productive Series sediments consist of a highly irregular alternation of clay and sand layers, with a total thickness of about 1950 m. The Bibiheybat oil field has an asymmetric brachy-anticlinal structure, measuring 6 km in length, 3.5 km in width, and 1100 m in height, oriented northwest–southeast.

In order to clarify the situation, samples were taken from the produced waters and oils of the study area. Physico-chemical analysis of the water was carried out according to standards GOST 4011-72, GOST R 52407-2005, GOST 4192-82, GOST 4245-72, GOST 4388-72, GOST 4389-72, GOST 18164-72, GOST 18876-73, GOST R 51211-98, ISO 6060:1989, and Standard Methods 5210B.

The density and kinematic viscosity of oil samples were determined using an Anton Paar SVM 1001 viscometer. The dynamic viscosity of oil was measured using an Anton Paar MCR 302 rheometer. Mechanical impurities were determined according to ASTM D473. The resin content was determined according to ASTM D381. Water content was determined according to ASTM D4006-16 (E1).

Results

Experimental Part

Utilizing formation waters with nanotechnologies at the atomic-molecular level and developing the mechanism of their impact on the well bottom zone are set as urgent tasks. For this purpose, taking into account the geological and technological conditions, we have selected and presented in Tab. 1 the component content of certain N-series nanocomposites used in the treatment of produced formation waters (co-produced with oil) to increase their efficiency in secondary technological processes.

A 250 ml formation water sample was taken from the formation water collection station of the Bibiheybat oil and gas field. We added 7.5 ml of 1.0 % composite mixtures of BAF-1 and BAF-2 nanostructured polycrystalline powders – obtained by treating a kerosene fraction with an alkaline waste (KFAW) and an alkaline-treated diesel fraction waste (ADFW) – to this sample, and performed physico-chemical analyses. Additionally, using ADFW together with 0.5 % aluminum nanoparticles, a nanocomposite was prepared and tested.

Table 1

Component content of the compositions according to conventional names

Name	Component content of the compositions
N-1	KFAW + (BAF-1+BAF-2)
N-2	ADFW + (BAF-1+BAF-2)
N-4	ADFW + 0.5% Al (40-60 nm)

A formation water sample taken from the field's water disposal facility was treated by adding 7.5 ml each of the N-1, N-2, and N-4 nanocomposites, and physico-chemical analyses were carried out on the water.

As seen in Tab. 2, the addition of the N-1 nanocomposite led to a slight decrease in HCO_3^- and Na^++K^+ ions, and a slight increase in Ca^{2+} and Mg^{2+} ions, resulting in a reduction in the Cl^- ion content. The total mineralization of the water sample decreased by 2.84 g/l, but its hardness increased by 2.15 mg-eq/l. According to Tab. 2, the addition of the N-2 nanocomposite to the formation water increased the CO_3^{2-} and HCO_3^- ions, while a decrease in Na^++K^+ ions was observed. Although Ca^{2+} and Mg^{2+} ions increased, a decrease in the Cl^- ion content was recorded. Comparative analysis shows that the effect of the new N-1 and N-2 nanocomposites on the formation water samples led to certain positive changes in water characteristics in the first case, but the hardness increased significantly (by 2.15 mg-eq/l), i.e. the water shifted from soft to moderately hard. In the second case, the mineralization of the formation water sample decreased markedly (by 3.74 g/l) and, although its hardness increased slightly (by 1.59 mg-eq/l), its type changed to alkaline.

Table 2

The effect of N-series nanocomposites on the chemical indicators of formation water (mg/l)

Composition	Additive volume, ml	Chemical composition content of formation water, mg/l						Type of water
		CO3-	HCO3-	Na++K+	Cl-	Ca2+	Mg2+	
N-1	0	-	1.2695	2.9904	2.3844	1.1222	1.1419	CaCl2
	7.5	-	1.2599	2.999	2.2972	1.0211	1.1497	CaCl2
N-2	0	-	1.2695	2.3844	2.9913	1.1222	1.1419	CaCl2
	7.5	1.147	1.2887	2.1972	2.779	1.1269	1.1448	Alkaline water
N-4	0	1.32	3.26	58.36	58.75	2.01	3.96	CaCl2
	7.5	1.82	3.82	59.52	57.69	1.38	2.43	Alkaline water

Furthermore, the chemical composition of a high-viscosity formation water sample (100 ml) changed from a hard water to an alkaline water after the addition of the N-4 nanocomposite.

Thus, based on the comparative experimental research results, the N-2 and N-4 nanocomposites – which improve the effectiveness of the water type for technological processes – changed the type of aggressive formation waters, converting a hard water into an alkaline water. The nanocomposites reduced the Ca^{2+} and Mg^{2+} divalent cations held on the surface of negatively charged clay particles in the oil, replacing them with Na^+ ions. This created an opportunity to use the synergistic effect obtained from the application of N-2 and N-4 nanocomposites in the water-flooding method.

Continuing the research, nanocomposites were added to the oil sample taken from the surface of formation waters of Bibiheybat OGPD, and the obtained results were systematized in the Tab. 3.

Table 3

(50 °C) with the addition of N nanocomposites to the oil sample taken from the formation water surface of the Bibiheybat OGPD

№	Indicators	As usual	N-1	N-2	N-4
1	Specific gravity of oil, kg/cm^3	915.0	915.0	915.0	915.0
2	Mechanical mixtures, %	26.67	6.67	3.33	25
3	Resin, %	0	0	0	0
4	Water separated from oil, %	0.03	0.16	0.27	0.04
5	Pure oil in the sample, %	73.30	93.17	96.4	74.69
6	Kinematic viscosity, sSt	27.10	12.1	3.2	21.45
7	Dynamic viscosity, sPz	26.67	11.99	3.14	21.41

Although no resin was detected in the composition of the oil, the kinematic viscosity of the sample was calculated at 27.1 sSt, and the dynamic viscosity at 26.27 sPz. However, after the addition of the N-1 nanocomposite, the amount of mechanical impurities decreased up to 4 times, the kinematic viscosity reduced to 15 sSt, and the dynamic viscosity to 14.282 sPz. Along with this, the amount of water separated from the oil increased by 5.3 times, and the volume of pure oil increased by 19.87 %.

When the N-2 nanocomposite was added to the same sample, the physical-chemical indicators were monitored. An increase was observed in the amount of mechanical impurities, kinematic and dynamic viscosity, the amount of separated water, and pure oil. This can be explained by the more effective impact of the N-2 nanocomposite on the oil components collected from the water surface.

As seen from the table, with the addition of 60 ml of N-4 nanocomposite to the oil sample collected from the surface of formation waters, the mechanical impurities in the oil decreased from 26.67 ml to 25 ml, and an increase in the volume of water separated from the oil was observed – from 0.03 to 0.04. At the same time, both kinematic and dynamic viscosity significantly decreased.

The systematized experimental results obtained by affecting the oil sample collected from the surface of formation waters at the reservoir of formation water intake (RFWI) of Bibiheybat OGPD with new N-series nanocomposites are presented in Fig. 3.

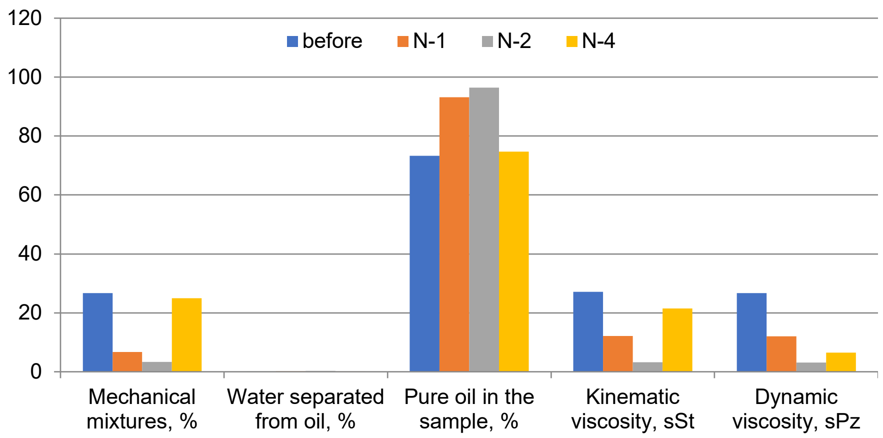

Fig. 3. The results obtained from variable indicators by adding N nanocompositions to the oil sample collected from the water surface from "Bibiheybat OGPD"

Thus, according to the results of the impact of nanocomposites on mechanical impurities – which are the main pollutants in formation waters 30 ml of N-4 nanocomposite was added to 13 g of mechanical impurities taken from the Bibiheybat OGPD, and the resulting mixture was filtered after 3 days. After filtration, 4 g of mechanical impurity remained. In the second case, 30 ml of N-2 nanocomposite was added to another 13 g of mechanical impurities, and after 3 days the mixture was filtered again, 4 g of impurities remained. Finally, 30 ml of N-1 nanocomposite was added to a third 13 g mechanical impurity sample. After 3 days and subsequent filtration, 6 g of impurities were found to remain.

As a result, it is evident that nanocomposites N-2 and N-4 are more effective in reducing (dissolving) mechanical impurities.

Discussion and conclusions

As of 01.01.2023, 29 production horizons are being exploited in the field. Until the present period, a total of 3829 wells have been drilled at the Bibiheybat OGPD. The number of wells currently in operation is 491, 44 wells are pending liquidation, 54 are inactive, 40 are in the water injection, 10 are absorbing wells, and 3155 have been liquidated. Of the liquidated wells 2326 were closed due to geological reasons, and 829 due to technical reasons. The daily production at the field is presented in the Tab. 4.

As seen in the Tab. 4, the wells at the Bibiheybat field are highly watered, and the large volumes of produced water are treated only through mechanical methods. Considering that mechanical methods cannot completely remove all impurities from formation water (Abdulaziz, Hatem, & Mahdi, 2021; Al-Mohammad, Al-Kaabi, & Mohammad, 2019; Igunnu, & Chen, 2012; Murvatov, Usubaliyev, & Mammadova, 2022), this leads to frequent blockages and leaks in pipelines and collectors (Murvatov, Usubaliyev, & Mammadova, 2022). Various complex-composition systems are used (taking into account the field's geotechnical parameters) to condition the physico-chemical properties of formation waters for technological processes (Murvatov, Usubaliyev, & Mammadova, 2022). If the physico-chemical properties of such systems are not compatible with the characteristics of the well-reservoir system, the efficiency of the implemented technological operations and processes will not be at the required level.

Table 4

Daily production at the Bibiheybat OGPD

№	Well №	Average daily production			
		Oil, t/g	Water, t/g	Gas, m3/g	Water %
1	3884	0.7	5	107	88
2	2496	0.1	1	36	91
3	3657	1.1	5.5	89	83
4	3676	1.4	15	107	91
5	3864	1.3	5.8	107	82
6	3872	1.1	6.7	107	86
7	3833	0.6	3	10	83
8	2565	1.3	11	89	89
9	2766	1.4	7.1	89	84
10	3817	0.1	1	35	91
11	3824	0.6	3	4	83
12	3838	0.5	3	3	86
13	2597	1	10	89	91
14	3882	0.6	6.7	180	92
15	3885	2.3	21.7	214	90
16	3479	0.8	6	250	88
17	3480	3.7	13.3	250	78
18	2732	1.1	8.6	89	89
19	3825	1.5	2.5	42	63
20	3835	1.9	2.5	18	57
21	3849	0.8	3	6	79
22	3855	1.3	2	27	61
23	3891	0.7	3	11	81
24	3837	0.2	0.5	11	71
25	3474	4	1.5	3	27
26	3477	2.1	7.6	214	78
27	3478	0.8	5	250	86
28	3679	1.1	9.3	180	89
29	3476	4	16	180	80
30	3860	1.1	15	107	93
31	3862	1.3	15	107	92
32	3485	1.3	15	89	92
33	3815	2.5	10	107	80
34	3868	1.8	3	4	63
Total	**34**	**46.1**	**244.3**	**32.11**	

Hydrogeochemical systems are known to be dynamic. A technology for utilizing formation waters with various nanocomposites to mobilize oil in reservoir conditions can ensure the rational use of resources (Bera, Mandal, & Belhaj, 2017; Cheraghian, & Hendraningrat, 2016; Cheraghian, Khalilinezhad, & Kamari, 2014; Shahbazov, Bagirov, & Aliyev, 2018). Nanocomposites help reduce surface tension at the interface, improve the wetting ability of rocks, and increase permeability. They also cause increased layer leaching and flow rate due to reduced adhesion and capillary forces. Consequently, at lower surface tension values, layer fluid deformation is easier, and less work is required to displace oil droplets from collectors, which increases their movement speed within the layer. Through interaction, the nanocomposite aids in breaking down the oil film covering the rock surface (Bera, Mandal, & Belhaj, 2017; Cheraghian, & Hendraningrat, 2016; Cheraghian, Khalilinezhad, & Kamari, 2014; Shahbazov, Bagirov, & Aliyev, 2018).

As seen in the Tab. 3, oil displacement with nanocomposite-treated water is explained by its effect on the oil's rheological properties. Heavy hydrocarbons in oil, such as asphaltenes, resins, and paraffin deposits, contribute to the formation of structure and high viscosity in abnormal oils. The nanocomposite-based technology we developed for the utilization and reuse of formation waters in technological processes weakens the interaction between these structure-forming components of oil by adsorbing them. As a result, the physicochemical properties of the formation fluid improve.

Currently, there is quite a lot of classification of natural waters by chemical composition, but few have become widespread. The most commonly used in oil and gas hydrogeology are the classifications of R. Palmer and V. A. Sulin. Based on this, we characterized the water samples of these deposits according to these classifications.

According to the classification of waters, according to V. A. Sulin, these waters are divided into four genetic groups:

- sodium-sulfate (SS);
- sodium-bicarbonate waters (SB);
- calcium-chloride waters (CC);
- magnesium-chloride waters (MC).

According to Palmer, classes are distinguished by the ratio of the sums of metal and acid ions. R. Palmer identifies salt characteristics. The first salinity is due to salts of bases and strong acids. The second salinity is determined by salts of alkaline earth metals and strong acids. The first alkalinity is due to alkali metal salts and salts of weak acids. The second alkalinity is the presence of salts of alkaline earth metals and weak acids. As seen in the Tab. 5, hydrogeochemical analysis of water samples taken from the Bibiheybat field in 2022–2024, the produced waters are mainly of the calcium chloride type and are of high viscosity. As depth increases in the reservoir, the degree of water mineralization gradually decreases; however, according to V. A. Sulin's classification, these waters are "hard" – being of the magnesium chloride and calcium chloride types.

Table 5

Physical properties of formation waters from the Bibiheybat OGPD (2022–2024)

Well №	Depth, m	Density, kg/m³	Mineralization, mg/l	According to Palmer's classification			
				S_1	S_2	A_1	A_2
3855	1743	1010.6	20781	53.36	0	45.07	1.57
2837	527	1077.0	115047	88.48	10.62	0	0.90
3420	579	1072.6	108406	90.99	8.17	0	0.84
3496	443	1075.9	111353	83.70	15.37	0.00	0.92
3461	734	1061.7	94357	94.39	3.16	0	2.45
3753	490	1083.1	121067	84.70	14.69	0	0.61
557	463	1070.8	97738	85.46	13.44	0	1.10
924	467	1076.5	106253	86.43	12.91	0	0.66
3820	757	1045.2	64370	92.44	4.23	0.3	3.33
3868	1807	1016.7	28894	76.32	0	20.54	3.14
3890	1643	1036.0	56940	93.94	0	4.37	1.69
2023							
519	527	1030.4	45919	89.49	7.30	0	3.22
3227	631	1072.7	104633	90.33	8.43	0	1.24
3479	1716	1035.8	54192	89.87	7.29	0	2.84
3480	1744	1015.4	25967	84.60	0	7.08	8.32
3864	1780	1024.1	37705	82.92	0	15.70	1.38
3305	676	1074.5	104620	89.46	9.54	0	1.00
548	504	1088.3	123393	89.57	9.83	0	0.59
796	908	1050.9	80066	90.30	0	6.93	2.78
1182	574	1065.7	93825	88.02	10.80	0	1.18
3310	544	1065.4	94368	88.04	10.97	0	0.98
3350	518	1080.2	109260	89.28	10.07	0	0.65
2024							
1118	279	1074.4	101711	81.85	17.28	0	0.87
3162	1233	1026.2	40190	85.75	0	13.93	0.32
3287	294	1083.7	113546	82.67	16.73	0	0.60
3461	734	1060.7	85108	94.44	3.46	0	2.11
3476	1693	1017.6	16065	51.62	0	47.12	1.26
3761	471	1036.4	51937	89.00	6.52	0	4.48
548	504	1087.7	128921	83.02	16.46	0	0.53
1167	228	1068.1	101192	90.70	7.90	0	1.40
3321	247	1058.3	86690	85.18	13.24	0	1.58
1264	743	1058.9	85997	81.34	17.66	0	1.00
3282	493	1083.6	114313	83.80	15.50	0	0.71

As seen from Tab. 6, the presence of both acidic and alkaline conditions in the field, and the mixing of these waters in settling tanks, combined with their considerable aggressiveness, cause the equipment and pipes used in water injection to fail quickly. In such cases, the ecological balance is disrupted.

According to the 2022–2024 hydrogeochemical analysis results, the formation waters are primarily calcium chloride type with high salinity and viscosity. With increasing depth, the water's mineralization tends to decrease, but by V. A. Sulin's classification they remain "hard" waters of magnesium chloride and calcium chloride types. The data in Tab. 5, also indicate that in 2022 the field's produced waters included both sodium bicarbonate type and calcium chloride type waters, while deeper wells yielded a magnesium chloride type water. By 2024, after interventions and treatment, the water types from new or treated wells shifted mostly to calcium chloride or became alkaline in character.

Since oil is retained in the oil reservoir environment by capillary forces, a reduction in these forces leads to increased oil production. This is achieved by reducing rock wettability and the interfacial surface tension between the formation fluid and the rock surface (Bera, Mandal, & Belhaj, 2017; Cheraghian, & Hendraningrat, 2016; Cheraghian, Khalilinezhad, & Kamari, 2014; Shahbazov, Bagirov, & Aliyev, 2018; Murvatov, Usubaliyev, & Mammadova, 2022).

The formation waters extracted from the Bibiheybat OGPD have been classified according to their physical and chemical composition using various approaches. It has been shown that at the IV stage of field development, production and well injectivity have decreased, the amount of extracted water has increased, and as a result, the environmental landscape has been damaged, leading to inevitable ecological complications.

Since the disposal of formation waters containing toxic components is not universal, their treatment requires substantial capital investment and specific technological conditions. There is no standardized procedure for the treatment of formation waters in the oil industry. However, in order to displace oil from reservoir collectors to the bottom of the well and to avoid reducing the injectivity of injection wells, the water must be purified from insoluble salts and other compounds such as algae and microorganisms that may form under reservoir conditions.

Water intended for reuse in secondary technological processes must not cause foaming, must not form scale in pump-compressor pipes and equipment, and must not induce corrosion in metal components.

At the Bibiheybat OGPD, most of the mining infrastructure and hydraulic engineering facilities created for the management of formation waters are technically outdated and in an unserviceable condition. The inability to properly condition formation water makes its reuse in technological processes a source of various geoecological risks to the surrounding environment.

Table 6

Chemical composition of formation waters from the Bibiheybat OGPD (2022–2024)

Well №	Depth, m	Chemical composition of formation water, mg/l					Type of water (V.A. Sulin)
		$Na^{+}+K^{+}$	Ca_2^{+}	Mg_2^{+}	Cl^{-}	$HCO_3^{-}+CO_3^{2}$	
2022							
3855	1743	5766.61	48.10	19.44	4818.85	5294.80	$NaHCO_3$
2837	527	40310.72	1895.52	1623.04	69594.66	704.36	$CaCl_2$
3420	579	38807.15	2145.20	729.37	65188.34	559.90	$CaCl_2$
3496	443	37074.19	3098.59	1934.47	67643.98	716.55	$CaCl_2$
3461	734	34452.11	1019.23	463.96	54884.58	1593.61	$CaCl_2$
3753	490	40784.51	3725.86	1632.23	73771.02	510.14	$CaCl_2$
557	463	32996.56	2565.12	1409.40	58858.82	563.64	$CaCl_2$
924	467	36332.01	3687.36	777.60	64366.07	495.32	$CaCl_2$
3820	757	23061.25	480.96	704.70	37173.99	1690.92	$MgCl_2$
3868	1807	9068	48.10	126.36	11014.52	3989.40	$NaHCO_3$
3890	1643	20985	215.49	60.09	30910.10	2546.49	$NaHCO_3$
2023							
519	527	16054	601.20	631.80	26763.54	1285.88	$CaCl_2$
3227	631	36943.00	2164.32	777.60	62258.92	544.12	$CaCl_2$
3479	1716	18771	881.76	583.20	31282.06	814.96	$CaCl_2$
3480	1744	8106.20	440.88	121.50	11414.14	2208.20	$NaHCO_3$
3864	1780	13141.26	285.76	97.20	17031.34	5061.00	$NaHCO_3$
3305	676	36700.95	2885.76	534.60	62604.80	527.04	$CaCl_2$
548	504	43471.86	4408.80	523.00	74364.82	495.32	$CaCl_2$
796	908	28992.23	320.64	243.00	41505.95	6758.80	$NaHCO_3$
1182	574	32452.96	2565.12	777.60	56163.17	636.84	$CaCl_2$
3310	544	38312.90	4008.00	631.80	56378.91	204.96	$CaCl_2$
3350	518	38312.90	4008.00	291.60	65717.75	397.72	$CaCl_2$
2024							
1118	279	33188.37	3206.40	1944.00	61956.69	597.80	$CaCl_2$
3162	1233	14277.01	16.03	14.58	18931.21	4377.30	$NaHCO_3$
3287	294	37312.99	4408.80	1458.00	68820.53	451.40	$CaCl_2$
3461	734	31235.08	801.60	486.00	49909.56	1285.88	$CaCl_2$
3476	1693	4313.02	16.03	19.44	3475.78	3835.90	$NaHCO_3$
3761	471	17857.50	641.28	778.60	29544.16	1847.08	$MgCl_2$
548	504	42718.15	4328.64	1992.60	78900.30	544.12	$CaCl_2$
1167	228	35884.10	2004.00	729.00	60131.06	799.10	$CaCl_2$
3321	247	29077.16	2304.00	1458.00	51789.18	771.04	$CaCl_2$
1264	743	28070.05	2404.80	1944.00	52663.19	915.00	$CaCl_2$
3282	493	38060.04	3607.20	1701.00	69515.68	439.20	$CaCl_2$

As a result, rapid contamination of the bottom zone of injection wells and a significant decrease in permeability are frequently observed. Consequently, the reduced injectivity of these wells leads to increased pressure in the injection communications, the formation of surface leaks (griphons), the spread of formation water into surrounding areas, and contamination of open water bodies.

The currently available methods for treating formation water are either too costly or fail to achieve sufficient purification efficiency. Moreover, they require the installation of large-scale auxiliary facilities at the oil fields, such as reagent storage systems, sludge (waste) reservoirs, and other supporting infrastructure.

At the Bibiheybat OGPD, the mechanical method applied for water treatment is not considered effective in removing oil, petroleum products, and dissolved elements from the water composition.

In addition, many chemical treatment methods, which are often expensive, result in the generation of hazardous waste, the disposal of which becomes another critical issue.

From this perspective, the application of nanostructured systems in the preparation of formation water to meet conditioning standards within closed-loop water supply systems presents significant theoretical and practical interest.

Based on the research, there's a need to improve the existing technology for restoring the formation-well system in injection wells at the Bibiheybat OGPD to treat formation waters, and to increase the oil recovery factor. Research studies indicate that treating formation waters with small-sized metal nanoparticle-based compositions should also change the collector properties of the formation as these particles penetrate the pore boundaries. This is because compositions made from Al nanoparticles change the rheological parameters of oil and positively affect its movement in formation conditions (Mammadova, 2023; Shahbazov, Bagirov, & Aliyev, 2018).

Thus, to increase the efficiency of produced waters in secondary technological processes, we developed the technological scheme for treating them with N-2 and N-4 nanocomposites and returning them to the formations in a closed water cycle at the field is shown in Fig. 4.

Based on a comparative analysis of the research, it was shown that the N-2 and N-4 nanocomposites change the type of the formation water: aggressive "hard" water was converted into alkaline water. Additionally, the divalent Ca^{2+} and Mg^{2+} cations retained on the surface of negatively charged clay particles in the oil were reduced and replaced by Na^{+} ions. This enabled the removal of oil molecules from the rock pores and created the opportunity to use the synergistic effect obtained from the application of N-2 and N-4 nanocomposites in the water-flooding method.

As a result of treating oil samples (taken from the Bibiheybat OGPD) with N-2 and N-4 nanocomposites, it was determined that the amount of mechanical impurities in the oil decreased and the kinematic and dynamic viscosity of the oil were significantly reduced.

Within the framework of environmental safety regulations, a zero-waste closed water supply system is proposed for conditioning formation waters to required standards. The eco-technological scheme of this system, which involves treating formation waters with N-2 or N-4 nanocomposites, has been developed and demonstrated (Fig. 4) as an effective solution for environmentally safe reuse of formation water.

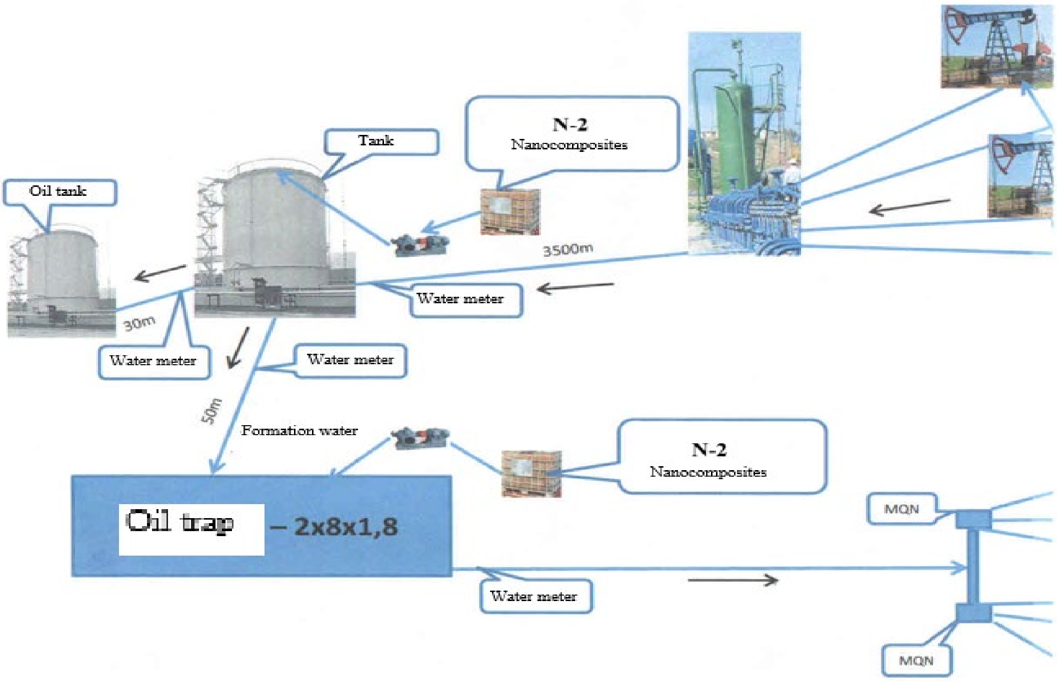

Fig. 4. Technological scheme for recirculation of formation waters

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ЗАСТОСУВАННЯ НОВОГО КЛАСУ НАНОКОМПОЗИТІВ В ЕКОЛОГІЧНОМУ УПРАВЛІННІ ПЛАСТОВИМИ ВОДАМИ НА НАФТОГАЗОВОМУ РОДОВИЩІ БІБІ-ЕЙБАТ

В с т у п *. **Розроблено нову технологію утилізації для забезпечення раціонального повторного використання токсичних пластових вод, видобутих з нафтових родовищ НГВУ "Бібіхейбат", у вторинних технологічних процесах та для відновлення екологічного балансу. Дослідження представляє порівняльний аналіз механізмів екологічного впливу нанокомпозитів N-1, N-2 та N-4.***

М е т о д и *. **Зразки пластової води, відібрані з приймальних резервуарів нафтових родовищ НГВУ "Бібіхейбат", обробляли різними нанокомпозитами для оцінки їхнього впливу. Додатково проаналізовано зразки нафти, взяті з поверхні пластової води, щодо змін реологічних параметрів, а основний забруднювач – механічні домішки –оброблено за допомогою нанокомпозитів серії N.***

Р е з у л ь т а т и *. **Запропонована нова технологія утилізації виявилася як екологічно, так і економічно ефективною для підвищення ефективності повторного використання пластової води у вторинних технологічних процесах та мінімізації її впливу на навколишнє середовище. Без необхідності встановлення нових об'єктів на старих нафтових родовищах може бути створена замкнута система водопостачання з використанням нанокомпозитів N-2 або N-4, залежно від геологічних умов.***

В и с н о в к и *. **Згідно з результатами дослідження, нанокомпозити N-2 та N-4 змінюють тип пластової води, перетворюючи її з "кислої" на "лужну". Ці композити також поліпшують реологічні властивості нафти. У рамках стандартів екологічної безпеки пропонується замкнута, безвідходна система водопостачання з використанням нанокомпозитів N-2 або N-4 як еколого-технологічна схема підготовки пластової води до необхідних умов.***

К л ю ч о в і с л о в а : ***пластова вода, токсичні компоненти, навколишнє середовище, технологія утилізації, нанокомпозит.***

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