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COMPARATIVE ANALYSIS OF NEWLY PROPOSED AND EXISTING REAGENTS FOR THE PREVENTION OF SALT DEPOSITION IN OIL PRODUCTION

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ABSTRACT

The physicochemical processes taking place in produced waters during oil and gas field operations are key factors that directly impact hydrocarbon production. The formation of salt sediments is of particular importance among these processes. Changes in temperature, pressure, salinity and ionic composition of produced waters lead to the precipitation of calcium, magnesium, barium and other ions in various sulphate and carbonate forms, forming poorly soluble compounds. These sediments accumulate in operating equipment, wellbores, tubing and collector array, leading to reduced production rate, equipment failure and increased operating expenses (OPEX). To prevent these problems, the chemical composition of the produced waters is continuously monitored during operation, the water compatibility is checked before injection, and special scale inhibitors are applied. Scale inhibitors are chemicals applied to prevent or slow the formation of hard-to-dissolve scale deposits in produced waters and process systems during the exploitation of oil and gas fields. Nowadays, it is possible to predict deposition risk in advance using thermodynamic modelling methods, which facilitates the making of more efficient decisions from both technical and economic perspectives. Thus, the correct assessment of the physicochemical processes occurring in wellbore fluids is one of the key conditions for the long-term and safe operation of oil and gas fields. For comparative evaluation in laboratory experiments, we used inhibitors developed by us under the conditional names “BR-2”, “KBRSAM-2”, “NKBR-14”, as well as foreign-made inhibitors “Inkredol” and “PAF-13”. Conducted studies have shown that the inhibitor NKBR-14 has a higher protective properties than the other inhibitors. 40-50 mg/l inhibitor consumption showed a high protective effect against the precipitation of calcium and magnesium sulphate salts.

Keywords: oil production; salt sediments; produced water; salt precipitation inhibitor; nanocomposition; protective effect; potassium sulphate; magnesium sulphate.

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1. Introduction

Salt sediments forming in oilfield equipment during well operation gradually lead to a reduction in the cross-sectional area of the pipes. As a result, well overhaul period (OHP) is reduced, production levels decline, oilfield equipment fails prematurely, and additional well repairs are required. Such problems ultimately have a negative impact on the technical-economic values of oil and gas production departments (OGPD). Salt sediments that form on structures, process equipment, pipelines, and tanks during oil production, processing, and refining accelerate corrosion and lead to their rapid failure [1].

Preventive measures, chemical, mechanical, and technological methods can be cited as methods for combating salt deposition during well operation. To reduce the risk of scale formation in wells, the ion composition, hydrogen index (pH), and degree of mineralization of the formation waters must be continuously monitored. The prompt analysis of changes in production indicators allows for the early detection of scale formation.

Chemical methods include the continuous or periodic injection of scale inhibitors into the well, the application of chelating agents, and the injection of inhibitors into the bottom-of-well zone [2].

Mechanical and technological methods include the mechanical cleaning of pump-jacker pipes, the complete removal of deposits during well repair, acidizing, and subsequent passivation operations.

The relevance of the issue. In the oil and gas industry, the reliable and uninterrupted operation of transportation and processing processes is of great importance, alongside production. Formation water extracted along with the oil contains high amounts of dissolved mineral salts, which leads to the formation of salt deposits in process systems. Salt deposits reduce the permeability of pipelines, worsen heat exchange, and increase the risk of equipment failure. In this regard, the scientific study of scaling problems and the development of effective countermeasures remains a relevant issue.

The formation of salt deposits is closely related to the

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chemical composition and thermodynamic conditions of the formation waters. A decrease in temperature, pressure changes, and water evaporation cause the saturation limit of the solutions to be exceeded, and the crystallization process begins. The most common precipitates include calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), and barium sulfate ($BaSO_4$). These compounds accumulate intensively, especially in the constriction zones of pipelines, pump equipment, and heat exchangers [3, 4].

In the transportation phase, the primary focus is on preventive measures to reduce the risk of scale deposition. Regular monitoring of the ionic composition of the formation water and the optimization of temperature and pressure regimes are of great importance. The application of scale inhibitors in pipelines prevents the formation of crystal nuclei and weakens the adhesion of deposits to surfaces.

Additionally, the application of PIG (Pipeline Inspection Gauge/Pipeline Intervention Gadget) technology allows for the mechanical cleaning of the internal surfaces of pipelines. This method reduces hydraulic resistance and helps maintain a stable transportation process.

In oil refineries, the desalination of crude oil at the initial stage is a key requirement for preventing salt deposits. Electrodehydrators separate water droplets from the oil and reduce the amount of chlorides to a regulated level. This plays a crucial role in protecting distillation columns and heat exchangers.

The periodic chemical washing and acid cleaning of heat exchangers allow for the removal of existing deposits. Meanwhile, monitoring the quality of the water used in the processing minimizes the risk of scale formation.

Statement of the problem. Produced water extracted together with oil plays a key role in the formation of salt sediments. In recent years, the widespread use of water injection in oil production, the use of alkaline reagents and carbon dioxide has further increased the intensity of scaling processes. For effective control of salt sediments in mineral extraction, it is important to thoroughly study the problem. In other words, understanding the nature of the physical and chemical phenomena occurring during oil production, correctly identifying the causes of scaling, and ensuring control over this process create the conditions for the timely elimination of the existing problem, as well as for choosing the most economically and technologically optimal method of combating it [5-7].

To determine the main causes of scaling, it is first necessary to study the chemical composition of produced waters and the solubility of various salts in these waters. Usually, the composition of produced waters and associated waters in which a certain amount of sediment is separated is determined in the laboratory. Laboratory studies have shown that the solubility of salts depends on their chemical composition, the hydrogen index (pH) of the solution, temperature, pressure, as well as gas composition and other factors [8-10].

Scientific studies have shown that the most effective approach to scale control is to prevent its formation. For this technological, chemical, physical, and combined methods are used [11]. Among these methods, the use of chemicals, i.e., salt precipitation inhibitors, is considered the most preferable. Scaling inhibitors include low-molecular-weight polycarboxylic acids, polymers and copolymers of acrylic and maleic polycarboxylic acids, sulphuric acid derivatives, organic derivatives of phosphate and phosphoric acid, as well as various compositions prepared on their basis [12].

Scaling inhibitors must meet certain technological requirements. In the produced water of the exploited field, the inhibitor must not separate and form a precipitate. At the specific reagent consumption rate, the rate of salt precipitate formation on the surface must be reduced by 80%. On steel plates immersed in the inhibitor solution (grade Cт.3 or X18H9T), the corrosion rate must not exceed 0.05 mm/year. Also, during the preparation process, the inhibitor requires that the oil does not increase the water and salt content in it, is deemulsified with a demulsifier, and retains its effectiveness in a solution at temperature up to 130 °C [13, 14].

The scientific novelty of the issue discussed in the paper lies in the development of new inhibitors that are more effective than foreign-made inhibitors and are also economically advantageous.

2. Reagents used

Inhibitor compositions based on mono-, di- and triethanolammonium phosphates (BR-1-3), as well as mono-, di- and tritetramethylethylenediammonium phosphates and nanoparticles (NKBR-13-15) have been developed [15, 16]. To prevent the precipitation of mineral salts, new composite mixtures containing quaternary amines were synthesized as a result of the interaction of ethylenediamine and orthophosphoric acid with the addition of hydrochloric acid and aluminum nanoparticles, into which the surfactant Laprol-4202-2B-30 (KBRSAM-1-3) was introduced. During synthesis, the compositions, no hard-to-find or expensive reagents were used [17].

Amine-containing substances destroy the oil film on the surface of salt deposits, improving their wettability, and surfactants reduce the surface tension at the phase boundary [18-21]. As a result of these effects, the process of salt dissolution is activated and the rate of deposit decomposition increases. Orthophosphate ions formed during the dissociation of tetraatomic amines prevent the precipitation of calcium and magnesium phosphates, ensuring that these cations remain suspended in solution. Orthophosphate ions have a positive effect on the mitigation of corrosion processes in the system. Applying nanoparticles to the surface in small quantities promotes their uniform distribution over the entire surface and prevents negative and side reactions [22-26]. Foreign-made inhibitors of the brands “Inkredol” and “PAF-13” were used for comparative studies [27].

Conducting research and discussing the results. At the initial stage, comparative experiments were conducted in laboratory conditions to evaluate the effectiveness of the scale inhibitors Inkredol, PAF-13, BR-2, KBRSAM-2, and NKBR-14.

At the first stage, a physicochemical analysis of the produced water sample was carried out to determine its parameters. The water density was 1.0364 g/cm^3, and the mineralization was 51.530 mg/l. According to Sulin's classification, it belongs to the MCH (magnesium-chlorine) type. In this water sample, the amount of Na^++K^+ ions was 18 488.39 mg/l, the amount of Ca^{2+} ions was 561.12 mg/l, the amount of Mg^{2+} ions was 340.2 mg/l, the amount of Cl^- ions was 29485.66 mg/l, and the amount of HCO_3^- ions was 1058.96 mg/l. CO_3^{2-} and SO_4^{2-} ions were detected. The properties of the well water were determined to be a pH of 6.5, a specific electrical conductivity of 56.7 mS/cm, and a specific electrical resistance of 17.64 Om·cm. According to Palmer, the water's

Table 1

Physical and chemical composition of produced water

Component quantity, mg/l							Total hardness, mg-eq/l	Salinity, mg/l	Water type according to V.A.Sulin	Palmer classification				pH	Density, g/cm^3	Specific electric conductivity, mSm/cm	Specific electric resistance, Om·cm
Na^++K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}				S_1	$5S_2$	A_1	A_2				
18488.39	561.12	340.20	29485.66	0	1058.96	0	56.00	51530	MCH	93.49	3.24	0	3.28	6.5	1.0364	56.7	17.64

I salinity (S_1) is 93.49%-eq, II salinity (S_2) is 3.24%-eq, and II alkalinity (A_2) is 3.28%-eq. The total hardness was 56.00 mg-eq/l. The analyses results are shown in table 1.

A representation of the results obtained is presented as a pie chart in figure 1.

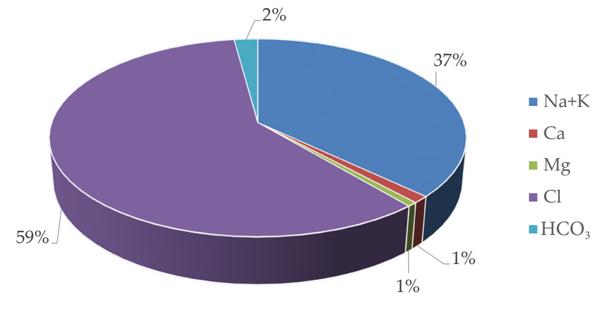

Fig. 1. Diagrammatic representation of the analysis results (mg/l)

In the next stage, laboratory studies were conducted to prevent precipitation of calcium and magnesium sulfate salts by adding the specified inhibitors to the produced water at concentrations of 40, 45, and 50 mg/l. The obtained results are shown in table 2. In the next stage, laboratory studies were conducted to prevent the precipitation of calcium and magnesium sulfate salts by adding the specified inhibitors to the produced water at concentrations of 40, 45, and 50 mg/L. The results are presented in table 2.

Table 2

Results of experimental studies to determine the protective effect of inhibitors

Inhibitor name	Inhibitor consumption rate, mg/l	Protective effect of the inhibitor, %
BR-2	40	76.5
	45	79.7
	50	81.8
KBRSAM -2	40	76.8
	45	81.2
	50	81.9
NKBR -14	40	77.8
	45	82.5
	50	84.9
İnkredol	40	77.9
	45	82.4
	50	84.5
PAF -13	40	76.9
	45	81.8
	50	83.4

As can be seen from the table, the new composition, codenamed BR-2, prevented the formation of salt sediments by 76.5–81.8 % in the flow rate range of 40–50 smg/l. The composition of KBRSAM-2 containing SAM showed higher results and when used in concentrations of 40, 45 and 50 mg/l, the protective effect was 76.8, 81.2 and 81.9 %, respectively. The new nanocomposition NKBR-14 with the addition of nanoparticles showed excellent results, demonstrating higher efficiency in the range of 77.8–84.9 % in the range of 40–50 mg/l. This also confirms that the inhibitor has a stronger protective effect.

The protective effect of the Inkredol inhibitor at concentrations of 40, 45, and 50 mg/l was 77.9, 82.4, and 84.5 %, respectively. The PAF-13 inhibitor showed efficacy ranging from 76.9 to 83.4 % for the indicated amounts.

Histograms of the dependence of the inhibitors' protective effects on their consumption are presented in figures 2-6.

As can be seen, the NKBR-14 composition shows slightly higher results at a concentration of 50 mg/l compared to the Inkredol branded inhibitor. Additionally, its greater accessibility and cost-effectiveness make it more suitable for practical application in a number of technological processes in oil extraction [28-33].

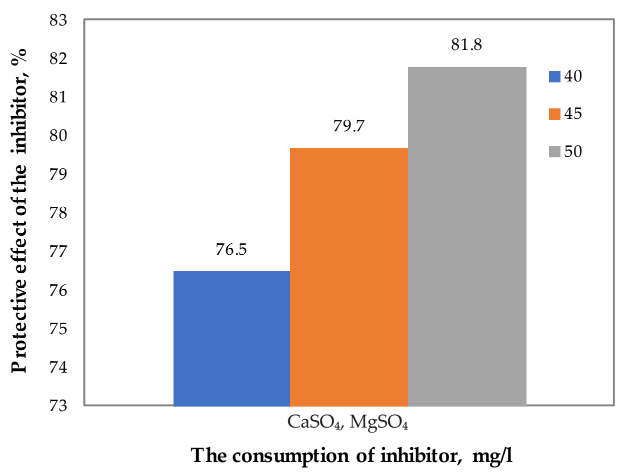

Fig. 2. Dependence of the protective effect of the BR-2 composition on its concentration

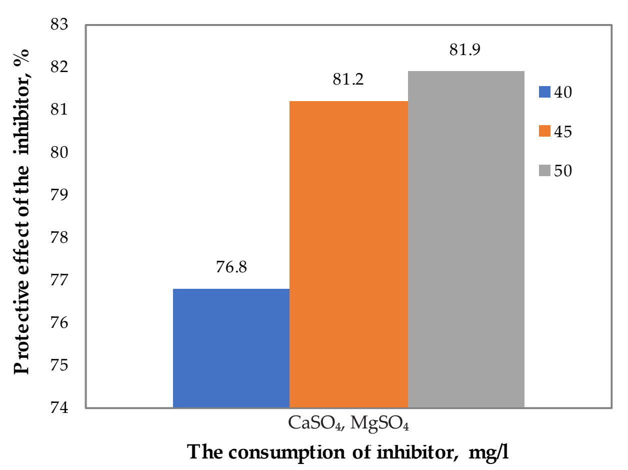

Fig. 3. Dependence of the protective effect of the KBRSAM-2 composition on its concentration

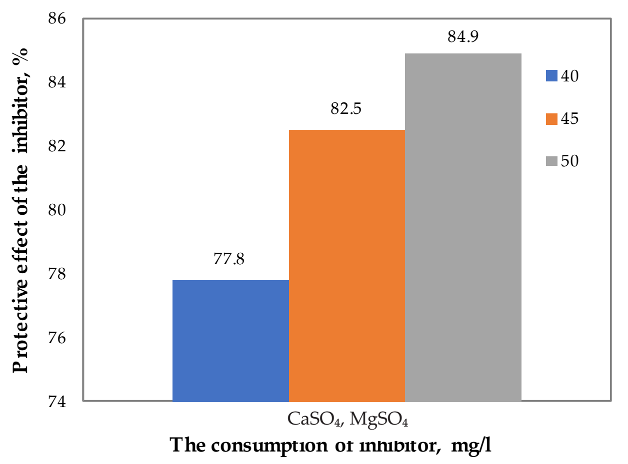

Fig. 4. Dependence of the protective effect of the NKBR-14 composition on its concentration

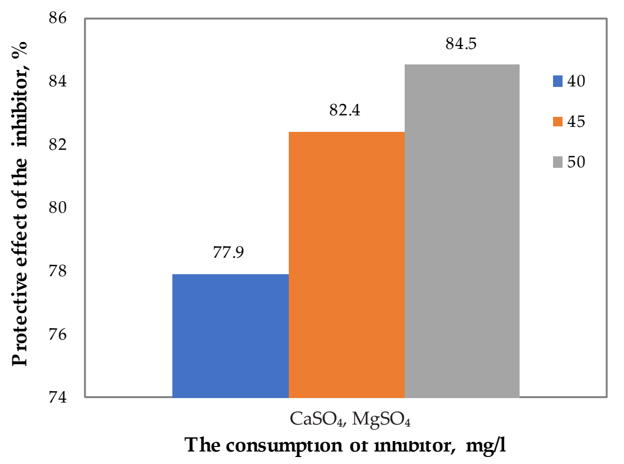

Fig. 5. Dependence of the protective effect of the Inkredol composition on its concentration

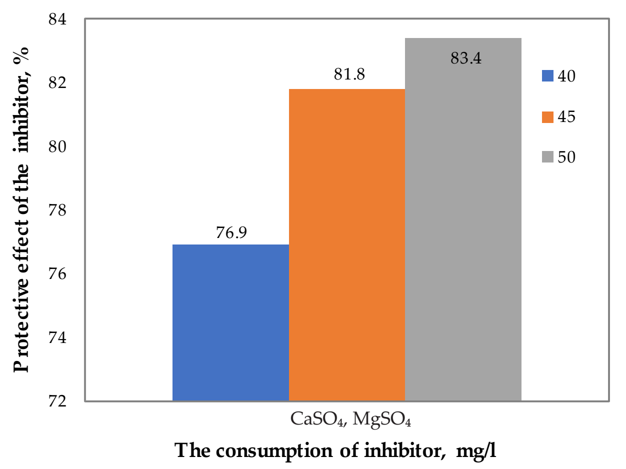

Fig. 6. Dependence of the protective effect of the PAF-13 composition on its concentration

Conclusions

1. High efficiency (84.9%) was achieved with the application of NKBR-14 nanocomposite at a concentration of 50 mg/l in the prevention of calcium and magnesium sulphate deposits.

2. The NKBR-14 nanocomposite showed higher efficiency in protecting against salt deposits compared to the expensive foreign-made inhibitors Inkredol and PAF-13.

3. Comparative experiments have shown that increasing the consumption of the NKBR-14 inhibitor further increases the effectiveness of scale control.

4. The results of laboratory studies provide a scientific basis for the widespread use of the NKBR-14 nanocomposite against the precipitation of calcium and magnesium sulphate and carbonate salts

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