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# Investigation of the efficiency of multifunctional compositions against corrosion and salt precipitation

## Badanie skuteczności kompozycji wielofunkcyjnych zapobiegających korozji i wytrącaniu się soli

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ABSTRACT: One of the most important tasks facing petroleum engineers today is the implementation of comprehensive measures to prevent corrosion and salt precipitation processes in the storage and transportation system of high-paraffin oils. In order to prolong the service life of oil field facilities, this article presents the results of laboratory research on a multifunctional compound composition with high efficiency against salt precipitation and electrochemical corrosion. Analyzing the results of numerous research works revealed that a concentration of 100 mg/l of composition M-5 exhibited high efficiency against both corrosion and salt precipitation in alkaline and neutral formation waters and in different solvent media (kerosene and diesel fuel). In case of kerosene solvent medium, in hard formation water the corrosion rate was 0.0087 $g/m^2 \cdot h$ (efficiency 98%), salt precipitation was 0.41 g/l (efficiency 93%); in alkaline formation water, the corrosion rate was 0.0625 $g/m^2 \cdot h$ (efficiency 92%), salt precipitation was 0.42 g/l (efficiency 90%); in neutral formation water, the corrosion rate was 0.1024$g/m^2 \cdot h$ (efficiency 90%), salt precipitation was 0.32 g/l (efficiency 91%). These indicators were also evaluated o in diesel fuel medium, where in hard formation water the corrosion rate was 0.0129 $g/m^2 \cdot h$ (efficiency 99.9%), salt precipitation was 0.12 g/l (efficiency 98%); in alkaline formation water the corrosion rate was 0.0234 $g/m^2 \cdot h$ (efficiency 97%), salt precipitation was 0.29 g/l (efficiency 93%); in neutral formation water the corrosion rate was 0.0819 $g/m^2 \cdot h$ (efficiency 92%), salt precipitation was 0.72 g/l (efficiency 98%).

Key words: electrochemical corrosion, salt precipitation, protection effect, inhibitor, solvent.

STRESZCZENIE: Jednym z najważniejszych zadań stojących obecnie przed inżynierami z sektora naftowego jest wdrożenie kompleksowych środków zapobiegających procesom korozji i wytrącania się soli w systemie magazynowania i transportu ropy wysokoparafinowej. W celu przedłużenia żywotności instalacji na polach naftowych, w niniejszym artykule przedstawiono wyniki badań laboratoryjnych nad wielofunkcyjną kompozycją związków wykazujących wysoką skuteczność przeciwdziałania wytrącaniu się soli i korozji elektrochemicznej. Analiza wyników licznych prac badawczych wykazała, że kompozycja M-5 o stężeniu 100 mg/l wykazuje wysoką skuteczność zarówno przeciwko korozji, jak i wytrącaniu się soli w alkalicznych i neutralnych wodach złożowych oraz w różnych mediach rozpuszczalnikowych (nafta i olej napędowy). W przypadku rozpuszczalnika naftowego, w twardej wodzie złożowej wskaźnik korozji wynosił 0,0087 $g/m^2 \cdot h$ (98% skuteczność), a wytrącanie soli wynosiło 0,41 g/l (93% skuteczność). Z kolei dla alkalicznej wody złożowej wskaźnik korozji wyniósł 0,0625 $g/m^2 \cdot h$ (92% skuteczność), a wytrącanie soli 0,42 g/l (90% skuteczność). W neutralnej wodzie złożowej wskaźnik korozji wyniósł 0,1024$g/m^2 \cdot h$ (90% skuteczność), a wytrącanie soli 0,32 g/l (91% skuteczność). Wskaźniki te zostały również zbadane dla oleju napędowego i wyniosły: w twardej wodzie złożowej wskaźnik korozji wyniósł 0,0129 $g/m^2 \cdot h$ (99,9% skuteczność), wytrącanie soli 0,12 g/l (98% skuteczność), w alkalicznej wodzie złożowej wskaźnik korozji wyniósł 0,0234 $g/m^2 \cdot h$ (97% skuteczność), wytrącanie soli 0,29 g/l (skuteczność 93%), natomiast w neutralnej wodzie złożowej wskaźnik korozji wyniósł 0,0819 $g/m^2 \cdot h$ (92% skuteczność), wytrącanie soli 0,72 g/l (98% skuteczność).

Słowa kluczowe: korozja elektrochemiczna, wytrącanie soli, efekt ochronny, inhibitor, rozpuszczalnik.

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## Introduction

Most oil fields in countries with developed oil industry are in the final stages of exploitation, where oil production occurs under conditions of high dilution. The presence of large amounts of formation waters in technological systems of oil fields introduces several serious complications in the processes of production, storage, preparation, and transportation of oil. These complications disrupt the normal operation of oil field facilities. Formation waters are highly aggressive due to the presence of dissolved hydrogen sulfide, carbon dioxide, oxygen, mechanical compounds, salt ions such as $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $SO_4^{2-}$, $Cl^{-}$, water-soluble naphthenic and mineral acids and bases, as well as microorganisms (Gurbanov and Abdullaeva, 2017; Gurbanov et al., 2019a; 2019b; Miralamov et al., 2019).

Corrosion of metals, in its various forms, is one of the most serious and complex issues that lead to a significant reduction in the resources of oilfield facilities and an increased risk of emergency conditions. In addition to the presence of aggressive components in technological media, the development of corrosion is strongly influenced by the high intensity of the technological operation modes of the equipment (high pressure, temperature and flow rates of the technological medium). These factors create significant mechanical stresses in metals, which, when combined with the high corrosive aggressiveness of the media, lead to rapid corrosive-mechanical destruction of oil field facilities (Maksutin et al., 2014; Sultanova et al., 2016; Sultanova and Mardashov, 2016).

Furthermore, regardless of the methods employed for the development and exploitation of oil fields, at all stages of production, transportation, and processing of oil, salt deposits commonly form on the walls of lifting pipes, pump equipment, and the inner surfaces of oil field facilities during oil processing and storage. Salt precipitation process results in shorter maintenance intervals for wells, operational complications, increased corrosion, and reduced oil production (Kazimov et al., 2010; Mursalova and Mirzadzhanov, 2010; Kunakova et al., 2011; Omelyanyuk, 2012; Gasanova, 2015; Shakhbazov et al., 2015; Sibiryakov et al., 2016).

Salt precipitation is particularly prevalent during the exploitation of wet wells in the final stages of operation. Key factors contributing to salt precipitation include the mixing of formation waters with incompatible chemical compositions, changes in thermobaric conditions, water degassing, evaporation in oil production facilities, dissolution of minerals in reservoirs, and the injection of water with different compositions and chemicals used for production of residual oil (waterflooding process).

The salt precipitation process significantly impacts the performance and reliability of facilities and pipelines. These deposits, often associated with local corrosion processes, account for approximately 40% of stoppages in oil and gas mining facilities. This is related to the fact that timely detection of local corrosion in pipelines is challenging due to salt formation. In many cases, salt deposition increases oilfield pipeline operating pressure by 3–4 times within three months. Pipelines and other facilities operating under such conditions are subjected to corrosion fatigue and local corrosion, leading to rapid deterioration. Studies have shown that, during the transportation of oil, a 1.5 mm thick layer of salt deposits in pipes with a 150 mm diameter increases electricity consumption up to 15%, while a 13 mm thick layer raises it by as much as 60%, which indicates a high level of related economic losses due to complications.

Thus, the failure of oil field facilities due to salt precipitation and corrosion is one of the major challenges in the oil industry. To reduce production costs and extend the service life of oil-field facilities, the development of new technologies, their investigation under laboratory conditions, and their application in the industry remains a pressing issue.

In the fight against corrosion and salt deposits, the use of complex-effective inhibitors has proven to be an effective solution. These inhibitors function through adsorption processes, adhering to the primary crystal embryos of salt compounds, preventing crystal growth, altering their shape and size, and inhibiting their adhesion to each other, as well as the adhesion of crystals to metallic surfaces (Plotnikova and Shein, 2013; Shangaraeva and Petukhov, 2013; Shangaraeva and Sulianova, 2015; Menshikov and Shein, 2016; Gurbanov et al., 2020; Anatolievich and Borisovna, 2017; Iskendarov et al., 2017; Menshikov and Shein, 2018; Gurbanov and Adygezalova, 2022).

Currently, the development of inhibitors with complex efficacy is considered an effective technique. Such inhibitors must meet a range of technological requirements for protection against both corrosion and salt precipitation. Complex-effective inhibitors must combine physical-chemical stability, corrosion protection, and salt deposition prevention. For this purpose, it is expedient to develop and research new compound compositions with a complex effect against corrosion and salt precipitation in oil wells, underground and surface facilities, including protective pipelines, compressor pump, rods, discharge lines, and other internal mine pipelines.

The goal of the work is to prepare effective compositions against salt precipitation and corrosion and to investigate them under laboratory conditions.

## Performance of work

Ct 3 grade steel samples were used to investigate the corrosion intensity in hard, alkaline and neutral formation water media (Table 1).

**Table 1.** Chemical composition of Ct 3 grade steel [%]
**Tabela 1.** Skład chemiczny stali klasy Ct 3 [%]

| Type | C | Mn | Si | P | S | Cr | Ni | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Ct 3 | 0.2 | 0.5 | 0.15 | 0.04 | 0.05 | 0.30 | 0.20 | 0.20 | 98.36 |

The corrosion rate of Ct3 grade steel samples was determined using the gravimetric method, based on the mass loss. Experiments were conducted using 12 compositions (20, 30, 40, 50; 70; 100 and 120 mg/l) under laboratory conditions for 24 hours at a temperature of 25°C. Steel plates measuring 30 × 20 × 1 mm, prepared from Ct3 grade steel, were ground, cleaned with acetone and alcohol, and weighed on an analytical scale. The experiments were performed in both composite and non-composite media under identical conditions for comparison. The surface area of the samples used in the experiments was calculated using the following formula:

$$S_n = 2ah + 2ab + 2hb \tag{1}$$

where:
$S_n$ – surface area of the steel sample [m$^2$],
$a$ – sample length [mm],
$b$ – sample width [mm],
$h$ – sample height [mm].

Given $a = 30$ mm, $b = 20$ mm, $h = 1$ mm, the surface area of the steel sample used in the experiment was $S_n = 2 \cdot 30 \cdot 1 + 2 \cdot 30 \cdot 20 + 2 \cdot 20 \cdot 1 = 1300$ mm$^2$ = 0.0013 m$^2$.

After the experiments, the steel samples were removed from the medium. The corrosion products on their surfaces were removed by soaking in a solution of 10% hydrochloric acid and 40% formalin. The samples were then wiped with cotton, washed under running water, and dried in acetone. They were then stored in a desiccator for 10–12 hours to stabilize their weight. The samples were reweighed on an analytical scale with an accuracy of $5 \cdot 10^{-5}$ g. Metal loss ($\Delta m$) was calculated using the following equation.

$$\Delta m = m_1 - m_2 \tag{2}$$

The following mathematical expression was used to calculate the corrosion rate.

$$K = \frac{m_1 - m_2}{S \cdot \tau} \tag{3}$$

where:
$m_1$ – weight of steel plate before laboratory experiment [g],
$m_2$ – weight of the steel plate after removing the corrosion products [g],
$S$ – surface area of the steel plate [m$^2$],
$\tau$ – duration of the laboratory experiment [hours].

The following mathematical expression was used to calculate the retardation factor.

$$\gamma = \frac{K_0}{K_{inh.}} \tag{4}$$

where:
$K_0$ – corrosion rate in a non-composite medium [g/m$^2$ · hour],
$K_{inh.}$ – corrosion rate in a composite medium [g/m$^2$ · hour].

The protection effect of the composition was calculated using the following formula.

$$Z = \frac{K_0 - K_{inh.}}{K_0} 100\% \tag{5}$$

where:
$K_0$ – corrosion rate in a non-composite medium [g/m$^2$ · hour],
$K_{inh.}$ – corrosion rate in a composite medium [g/m$^2$ · hour].

The penetration depth was determined using the following formula based on the corrosion rate.

$$K_p = 1.12 \cdot K_{inh.} \text{ mm/yr} \tag{6}$$

where:
$K_p$ – penetration depth [mm/yr],
$K_{inh.}$ – corrosion rate [g/m$^2$ · hour].

Experiments to evaluate precipitation of salt crystals on metal surfaces under laboratory conditions were conducted using the “Cold Finger Test” method.

## Experimental part

Under laboratory conditions, the effect of MARZA-2 inhibitor—a triple-bond organic compound containing carbon, hydrogen, oxygen, halogen, and other elements (Gurbanov and Adygezalova, 2020)—and ammonium chloride on corrosion and salt precipitation was investigated. These compositions were tested separately in kerosene and diesel fuel media to confirm their multifunctionality. Twelve compositions were prepared with varying percentages (Table 2).

The efficiency of the new compositions, namely a mixture of ammonium chloride with salt precipitation-reducing properties, MARZA-2, which slows the corrosion rate, and kerosene and diesel fuel solvents in varying percentages, has been tested under laboratory conditions in hard, alkaline, and neutral formation waters collected from oil fields. The results of these extensive experiments are presented in Table 3 and 4.

As observed from Tables 3 and 4, the corrosion rates in non-composite hard, alkaline, and neutral formation waters were 0.4326, 0.7812, and 1.0200 g/m$^2$ · h, respectively, while salt precipitation values were 5.86, 4.2, and 3.6 g/l, respec-

**Table 2.** Composition and brand of composites

**Tabela 2.** Skład i marka kompozytów

| No. | Components of the composition | Percentage amount in the composition [%] | Brand of the composition |
|---|---|---|---|
| 1. | MARZA-2 + $NH_4Cl$ + kerosene | 5:45:50 | M-1 |
| 2. | MARZA-2 + $NH_4Cl$ +kerosene | 7:43:50 | M-2 |
| 3. | MARZA-2 + $NH_4Cl$ + kerosene | 9:41:50 | M-3 |
| 4. | MARZA-2 + $NH_4Cl$ + kerosene | 11:39:50 | M-4 |
| 5. | MARZA-2 + $NH_4Cl$ + kerosene | 13:37:50 | M-5 |
| 6. | MARZA-2 + $NH_4Cl$ + kerosene | 15:35:50 | M-6 |
| 7. | MARZA-2 + $NH_4Cl$ + diesel | 5:45:50 | M-7 |
| 8. | MARZA-2 + $NH_4Cl$ + diesel | 7:43:50 | M-8 |
| 9. | MARZA-2 + $NH_4Cl$ + diesel | 9:41:50 | M-9 |
| 10. | MARZA-2 + $NH_4Cl$ + diesel | 11:39:50 | M-10 |
| 11. | MARZA-2 + $NH_4Cl$ + diesel | 13:37:50 | M-11 |
| 12. | MARZA-2 + $NH_4Cl$ + diesel | 15:35:50 | M-12 |

tively. When compositions M-1, M-2, M-3, M-4, M-6, M-7, M-8, M-9, M-10 and M-12 were used, their protection effect against corrosion and salt deposits in kerosene and diesel fuel solvents remained below 90%. Consequently, these compositions did not meet the requirements for complex reagents. The best performance was observed with compositions M-5 and M-11 at a concentration of 100 mg/l. In the case of kerosene solvent medium, in hard formation water the corrosion rate was 0.0087 $g/m^2 \cdot h$ (efficiency 98%), salt precipitation was 0.41 g/l (efficiency 93%); in alkaline formation water the corrosion rate was 0.0625 $g/m^2 \cdot h$ (efficiency 92%), salt precipitation was 0.42 g/l (efficiency 90%); in neutral formation water the corrosion rate was 0.1024 $g/m^2 \cdot h$ (efficiency 90%), salt precipitation was 0.32 g/l (efficiency 91%). In the case of diesel fuel medium, in hard formation water the corrosion rate 0.0129 $g/m^2 \cdot h$ (efficiency 99.9%), salt precipitation 0.12 g/l (efficiency 98%); in alkaline formation water the corrosion rate was 0.0234 $g/m^2 \cdot h$ (efficiency 97%), salt precipitation was 0.29 g/l (efficiency 93%); in neutral formation water the corrosion rate was 0.0819 $g/m^2 \cdot h$ (efficiency 92%), salt precipitation was 0.72 g/l (efficiency 98%).

As can be seen from the percentages of compounds in the compositions, the amount of MARZA-2 reagent increases in compositions M-1–M-6, while the amount of ammonium chloride decreases, and the amount of kerosene does not change. An increase in the amount of MARZA-2 inhibitor in the composition to a certain extent not only reduces the corrosion rate, but also has a significant impact on the salt precipitation process,

**Table 3.** Efficiency of the compositions against corrosion and salt precipitation in different formation waters (solvent: kerosene)

**Tabela 3.** Skuteczność kompozycji zapobiegających korozji i wytrącaniu się soli w różnych wodach złożowych (rozpuszczalnik: nafta)

| Brand of the composition | Amount of composition [mg/l] | Salt precipitation |  | Corrosion rate |  | Retardation factor, $\gamma$ | Penetration depth, $K_p$ [mm/year] |
|---|---|---|---|---|---|---|---|
|  |  | [g/l] | Efficiency [%] | $[g/m^2 \cdot h]$ | Efficiency [%] |  |  |
| **Hard formation water** |  |  |  |  |  |  |  |
| – | 0.00 | 5.86 | – | 0.4326 | – | – | – |
| M-1 | 50 | 2.17 | 63 | 0.1860 | 57 | 2.33 | 0.208 |
|  | 100 | 1.99 | 66 | 0.1601 | 63 | 2.70 | 0.179 |
|  | 120 | 1.88 | 68 | 0.1514 | 65 | 2.86 | 0.169 |
| M-2 | 50 | 2.05 | 65 | 0.1644 | 62 | 2.63 | 0.184 |
|  | 100 | 1.76 | 70 | 0.1082 | 75 | 3.99 | 0.121 |
|  | 120 | 1.82 | 69 | 0.1384 | 68 | 3.13 | 0.155 |
| M-3 | 50 | 1.69 | 71 | 0.0995 | 77 | 4.35 | 0.111 |
|  | 100 | 1.41 | 76 | 0.0606 | 86 | 7.14 | 0.068 |
|  | 120 | 1.52 | 74 | 0.0908 | 79 | 4.76 | 0.102 |
| M-4 | 50 | 0.99 | 83 | 0.0605 | 86 | 7.15 | 0.068 |
|  | 100 | 0.76 | 87 | 0.0346 | 92 | 12.50 | 0.039 |
|  | 150 | 0.82 | 86 | 0.0649 | 85 | 6.67 | 0.073 |

cont. Table 3/cd. Tabela 3

| Brand of the composition | Amount of composition [mg/l] | Salt precipitation | | Corrosion rate | | Retardation factor, $\gamma$ | Penetration depth, $K_p$ [mm/year] |
|---|---|---|---|---|---|---|---|
| | | [g/l] | Efficiency [%] | [g/m$^2 \cdot$ h] | Efficiency [%] | | |
| **Hard formation water** | | | | | | | |
| M-5 | 50 | 1.11 | 81 | 0.0606 | 86 | 7.14 | 0.068 |
| | 100 | 0.41 | 93 | 0.0087 | 98 | 49.72 | 0.009 |
| | 120 | 0.94 | 84 | 0.0692 | 84 | 6.25 | 0.077 |
| M-6 | 50 | 1.05 | 82 | 0.0562 | 87 | 7.69 | 0.063 |
| | 100 | 0.82 | 86 | 0.0389 | 91 | 11.12 | 0.044 |
| | 120 | 0.94 | 84 | 0.0952 | 78 | 4.54 | 0.107 |
| **Alkaline formation water** | | | | | | | |
| – | 0.00 | 4.20 | – | 0.7812 | – | – | – |
| M-1 | 50 | 1.34 | 68 | 0.4609 | 41 | 1.69 | 0.516 |
| | 100 | 1.13 | 73 | 0.3749 | 52 | 2.08 | 0.419 |
| | 120 | 1.09 | 74 | 0.3672 | 53 | 2.13 | 0.411 |
| M-2 | 50 | 1.05 | 75 | 0.3437 | 56 | 2.27 | 0.385 |
| | 100 | 0.84 | 80 | 0.3047 | 61 | 2.56 | 0.011 |
| | 120 | 1.01 | 76 | 0.3594 | 54 | 2.17 | 0.402 |
| M-3 | 50 | 0.97 | 77 | 0.2422 | 69 | 3.25 | 0.271 |
| | 100 | 0.63 | 85 | 0.1719 | 78 | 4.54 | 0.192 |
| | 120 | 0.79 | 81 | 0.2344 | 70 | 3.33 | 0.011 |
| M-4 | 50 | 0.71 | 83 | 0.1719 | 78 | 4.54 | 0.192 |
| | 100 | 0.55 | 87 | 0.1016 | 87 | 7.69 | 0.114 |
| | 120 | 0.67 | 84 | 0.1875 | 76 | 4.17 | 0.209 |
| M-5 | 50 | 0.76 | 82 | 0.1172 | 85 | 6.67 | 0.131 |
| | 100 | 0.42 | 90 | 0.0625 | 92 | 12.49 | 0.069 |
| | 120 | 0.97 | 77 | 0.1484 | 81 | 5.26 | 0.166 |
| M-6 | 50 | 0.79 | 81 | 0.1406 | 82 | 5.56 | 0.157 |
| | 100 | 0.59 | 86 | 0.0859 | 89 | 9.09 | 0.096 |
| | 120 | 0.71 | 83 | 0.1797 | 77 | 4.35 | 0.201 |
| **Neutral formation water** | | | | | | | |
| – | 0.00 | 3.6 | – | 1.0240 | – | – | – |
| M-1 | 50 | 1.08 | 70 | 0.3686 | 64 | 2.78 | 0.413 |
| | 100 | 0.94 | 74 | 0.2969 | 71 | 3.45 | 0.333 |
| | 120 | 0.97 | 73 | 0.2464 | 73 | 4.16 | 0.309 |
| M-2 | 50 | 0.90 | 75 | 0.3584 | 65 | 2.86 | 0.401 |
| | 100 | 0.76 | 79 | 0.2355 | 77 | 4.35 | 0.264 |
| | 120 | 0.10 | 72 | 0.3686 | 64 | 2.78 | 0.413 |
| M-3 | 50 | 0.86 | 76 | 0.2355 | 77 | 4.35 | 0.264 |
| | 100 | 0.65 | 82 | 0.1229 | 88 | 8.33 | 0.138 |
| | 120 | 0.68 | 81 | 0.2560 | 75 | 4.00 | 0.287 |
| M-4 | 50 | 0.61 | 83 | 0.1843 | 82 | 5.57 | 0.206 |
| | 100 | 0.50 | 86 | 0.1126 | 89 | 9.09 | 0.126 |
| | 120 | 0.54 | 85 | 0.2662 | 74 | 3.85 | 0.298 |
| M-5 | 50 | 0.61 | 83 | 0.1638 | 84 | 6.25 | 0.183 |
| | 100 | 0.32 | 91 | 0.1024 | 90 | 10.00 | 0.115 |
| | 120 | 0.47 | 87 | 0.2458 | 76 | 4.17 | 0.275 |
| M-6 | 50 | 0.79 | 78 | 0.1741 | 83 | 5.88 | 0.195 |
| | 100 | 0.90 | 75 | 0.1434 | 86 | 7.15 | 0.161 |
| | 120 | 1.01 | 72 | 0.3174 | 69 | 3.23 | 0.356 |

which can be explained by the fact that it forms a coating on the originally formed salt crystals and prevents their growth (Gurbanov and Adygezalova, 2022).

In order to obtain accurate results from laboratory experiments, research was conducted for concentrations of 20, 30, 40, 50, 70, 100, 120 mg/l of the composition.

**Table 4.** Efficiency of the composition against corrosion and salt precipitation in different formation waters (solvent: diesel)

**Tabela 4.** Skuteczność kompozycji zapobiegających korozji i wytrącaniu się soli w różnych wodach złożowych (rozpuszczalnik: olej napędowy)

| Brand of the composition | Amount of composition [mg/l] | Salt precipitation | | Corrosion rate | | Retardation factor, $\gamma$ | Penetration depth, $K_p$ [mm/year] |
|---|---|---|---|---|---|---|---|
| | | [g/l] | Efficiency [%] | [$g/m^2 \cdot h$] | Efficiency [%] | | |
| **Hard formation water** | | | | | | | |
| – | 0.00 | 5.86 | – | 0.4326 | – | – | – |
| M-7 | 50 | 1.99 | 66 | 0.1730 | 60 | 2.50 | 0.194 |
| | 100 | 1.82 | 69 | 0.1471 | 66 | 2.94 | 0.011 |
| | 120 | 2.05 | 65 | 0.1255 | 71 | 3.45 | 0.141 |
| M-8 | 50 | 1.93 | 67 | 0.1483 | 65 | 2.92 | 0.166 |
| | 100 | 1.76 | 70 | 0.0932 | 78 | 4.64 | 0.104 |
| | 120 | 1.88 | 68 | 0.1384 | 68 | 3.13 | 0.155 |
| M-9 | 50 | 1.26 | 71 | 0.1101 | 74 | 3.93 | 0.123 |
| | 100 | 1.41 | 76 | 0.0593 | 86 | 7.29 | 0.066 |
| | 120 | 1.52 | 74 | 0.0889 | 79 | 4.87 | 0.099 |
| M-10 | 50 | 1.29 | 78 | 0.1059 | 75 | 4.00 | 0.119 |
| | 100 | 0.94 | 84 | 0.0381 | 91 | 11.35 | 0.043 |
| | 120 | 0.94 | 79 | 0.0635 | 85 | 6.81 | 0.071 |
| M-11 | 50 | 0.88 | 85 | 0.0519 | 88 | 8.34 | 0.058 |
| | 100 | 0.12 | 98 | 0.0129 | 99.9 | 33.53 | 0.014 |
| | 120 | 0.53 | 91 | 0.0692 | 84 | 6.25 | 0.078 |
| M-12 | 50 | 0.82 | 86 | 0.0605 | 86 | 7.15 | 0.068 |
| | 100 | 0.70 | 88 | 0.0346 | 92 | 12.50 | 0.039 |
| | 120 | 0.99 | 83 | 0.0995 | 77 | 4.35 | 0.111 |
| **Alkaline formation water** | | | | | | | |
| – | 0.00 | 4.20 | – | 0.7812 | – | – | – |
| M-7 | 50 | 1.30 | 69 | 0.3749 | 52 | 2.08 | 0.419 |
| | 100 | 1.18 | 72 | 0.2969 | 62 | 2.63 | 0.011 |
| | 120 | 1.09 | 74 | 0.3672 | 53 | 2.13 | 0.411 |
| M-8 | 50 | 1.13 | 73 | 0.2734 | 65 | 2.86 | 0.306 |
| | 100 | 1.01 | 76 | 0.2265 | 71 | 3.45 | 0.254 |
| | 120 | 0.84 | 80 | 0.2812 | 64 | 2.78 | 0.315 |
| M-9 | 50 | 1.05 | 75 | 0.2422 | 69 | 3.25 | 0.271 |
| | 100 | 0.79 | 81 | 0.1719 | 78 | 4.54 | 0.192 |
| | 120 | 0.63 | 85 | 0.2031 | 74 | 3.85 | 0.227 |
| M-10 | 50 | 0.76 | 82 | 0.1406 | 82 | 5.56 | 0.157 |
| | 100 | 0.59 | 86 | 0.0781 | 90 | 10.00 | 0.087 |
| | 120 | 0.67 | 84 | 0.1484 | 81 | 5.26 | 0.166 |
| M-11 | 50 | 0.71 | 83 | 0.1094 | 86 | 7.14 | 0.123 |
| | 100 | 0.29 | 93 | 0.0234 | 97 | 33.34 | 0.026 |
| | 120 | 0.92 | 78 | 0.1406 | 82 | 5.56 | 0.157 |
| M-12 | 50 | 1.18 | 72 | 0.1328 | 83 | 5.88 | 0.149 |
| | 100 | 0.97 | 77 | 0.0703 | 91 | 11.11 | 0.079 |
| | 120 | 1.13 | 73 | 0.1641 | 79 | 4.76 | 0.184 |

cont. Table 4/cd. Tabela 4

| Brand of the composition | Amount of composition [mg/l] | Salt precipitation | | Corrosion rate | | Retardation factor, $\gamma$ | Penetration depth, $K_p$ [mm/year] |
|---|---|---|---|---|---|---|---|
| | | [g/l] | Efficiency [%] | [g/m$^2 \cdot$ h] | Efficiency [%] | | |
| **Neutral formation water** | | | | | | | |
| – | 0.00 | 3.60 | – | 1.0240 | – | – | – |
| M-7 | 50 | 1.12 | 69 | 0.3482 | 66 | 2.94 | 0.389 |
| | 100 | 0.97 | 73 | 0.2253 | 78 | 4.55 | 0.252 |
| | 120 | 0.90 | 75 | 0.2867 | 72 | 3.57 | 0.011 |
| M-8 | 50 | 0.94 | 74 | 0.2969 | 71 | 3.45 | 0.333 |
| | 100 | 0.83 | 77 | 0.1843 | 82 | 5.66 | 0.206 |
| | 120 | 0.65 | 82 | 0.3174 | 69 | 3.23 | 0.356 |
| M-9 | 50 | 0.79 | 78 | 0.2150 | 79 | 4.76 | 0.241 |
| | 100 | 0.65 | 82 | 0.1434 | 86 | 7.14 | 0.161 |
| | 120 | 0.61 | 83 | 0.2865 | 73 | 3.57 | 0.309 |
| M-10 | 50 | 0.54 | 85 | 0.1946 | 81 | 5.26 | 0.218 |
| | 100 | 0.39 | 89 | 0.1126 | 89 | 9.09 | 0.126 |
| | 120 | 0.72 | 80 | 0.2662 | 74 | 3.85 | 0.298 |
| M-11 | 50 | 0.58 | 84 | 0.1586 | 85 | 6.46 | 0.172 |
| | 100 | 0.72 | 98 | 0.0819 | 92 | 12.50 | 0.092 |
| | 120 | 0.39 | 89 | 0.2048 | 80 | 5.00 | 0.229 |
| M-12 | 50 | 0.86 | 76 | 0.1638 | 84 | 6.25 | 0.184 |
| | 100 | 0.90 | 75 | 0.1024 | 90 | 10.00 | 0.115 |
| | 120 | 0.97 | 73 | 0.2560 | 75 | 4.00 | 0. 287 |

**Table 5.** Protection effect of the composition against salt deposits in hard formation water
**Tabela 5.** Działanie ochronne kompozycji zapobiegające osadzaniu się soli w twardej wodzie złożowej

| No. | Concentration [mg/l] | Protection effect [%] | | | |
|---|---|---|---|---|---|
| | | M-5 | | M-11 | |
| | | salt precipitation | corrosion rate | salt precipitation | corrosion rate |
| 1 | 20 | 76 | 79 | 79 | 81 |
| 2 | 30 | 77 | 81 | 81 | 84 |
| 3 | 40 | 79 | 84 | 84 | 85 |
| 4 | 50 | 81 | 86 | 85 | 88 |
| 5 | 70 | 90 | 92 | 93 | 95 |
| 6 | 100 | 93 | 98 | 98 | 100 |
| 7 | 120 | 84 | 84 | 91 | 87 |

**Table 6.** The protection effect of the composition against salt deposits and corrosion in neutral formation water
**Tabela 6.** Działanie ochronne kompozycji zapobiegające osadzaniu się soli w neutralnej wodzie złożowej

| No. | Concentration [mg/l] | Protection effect [%] | | | |
|---|---|---|---|---|---|
| | | M-5 | | M-11 | |
| | | salt precipitation | corrosion rate | salt precipitation | corrosion rate |
| 1 | 20 | 75 | 78 | 77 | 80 |
| 2 | 30 | 79 | 82 | 80 | 83 |
| 3 | 40 | 81 | 84 | 82 | 85 |
| 4 | 50 | 82 | 85 | 83 | 86 |
| 5 | 70 | 88 | 89 | 90 | 92 |
| 6 | 100 | 90 | 92 | 93 | 97 |
| 7 | 120 | 77 | 81 | 78 | 82 |

**Table 7.** The protection effect of the composition against salt deposits and corrosion in alkaline formation water

**Tabela 7.** Działanie ochronne kompozycji zapobiegające osadzaniu się soli w alkalicznej wodzie złożowej

| No. | Concentration [mg/l] | Protection effect [%] | | | |
|---|---|---|---|---|---|
| | | M-5 | | M-11 | |
| | | salt precipitation | corrosion rate | salt precipitation | corrosion rate |
| 1 | 20 | 75 | 76 | 77 | 80 |
| 2 | 30 | 78 | 80 | 79 | 81 |
| 3 | 40 | 80 | 83 | 82 | 84 |
| 4 | 50 | 83 | 84 | 84 | 85 |
| 5 | 70 | 89 | 88 | 95 | 89 |
| 6 | 100 | 91 | 90 | 98 | 92 |
| 7 | 120 | 87 | 76 | 89 | 80 |

Tables 5, 6 and 7 present the research results of the protection effect against salt deposits and corrosion of M-5 and M-11 compositions.

As can be seen from Tables 5–7, compositions M-5 and M-11 show less than 90% efficiency against corrosion and salt precipitation at concentrations below 40 mg/l. However, with the increase in concentration, except for the concentration of 120 mg/l, the efficiency against both salt precipitation and corrosion increases to 92–99% (Figures 1–6).

The technical results of processing the M-5 and M-11 compositions in formation waters of different pH and in two different solvent media are that, in the investigated compositions, a high effective and complex protection effect was achieved against both corrosion process and salt precipitation in oil field facilities. During the development of the compositions, particular attention was given to evaluating their physical-chemical and technological properties. In addition to exhibiting the required viscosity for salt precipitation and corrosion inhibition, the

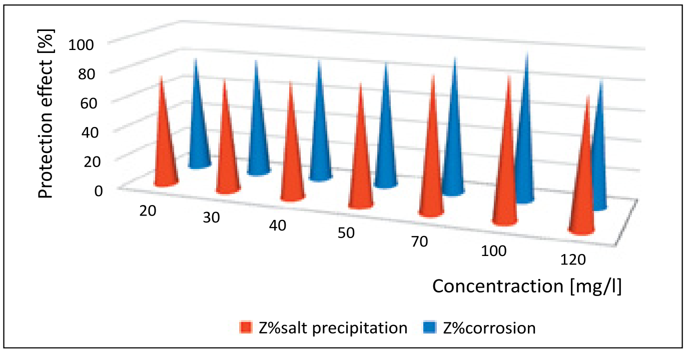

**Figure 1.** Dependence of protection effect of M-5 on the concentration in hard formation water

**Rysunek 1.** Zależność efektu ochronnego M-5 od stężenia w twardej wodzie złożowej

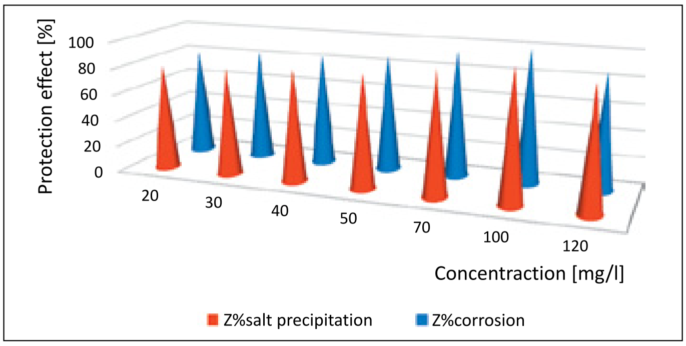

**Figure 2.** Dependence of protection effect of M-11 on the concentration in hard formation water

**Rysunek 2.** Zależność efektu ochronnego M-11 od stężenia w twardej wodzie złożowej

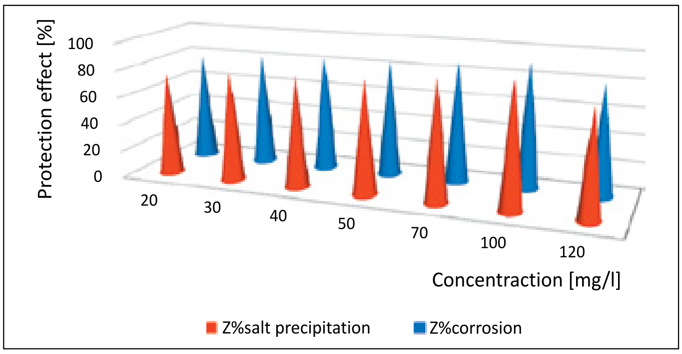

**Figure 3.** Dependence of protection effect of M-5 on the concentration in neutral formation water

**Rysunek 3.** Zależność efektu ochronnego M-5 od stężenia w neutralnej wodzie złożowej

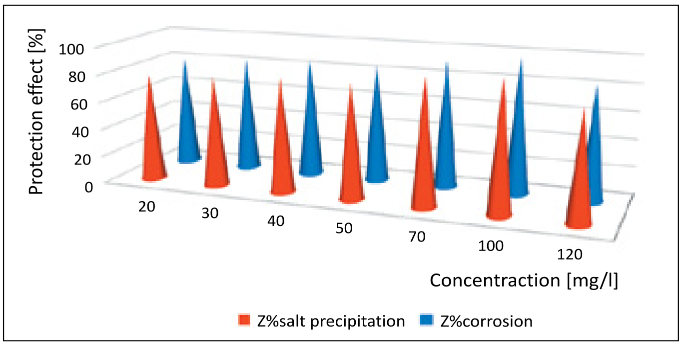

**Figure 4.** Dependence of protection effect of M-11 on the concentration in neutral formation water

**Rysunek 4.** Zależność efektu ochronnego M-11 od stężenia w neutralnej wodzie złożowej

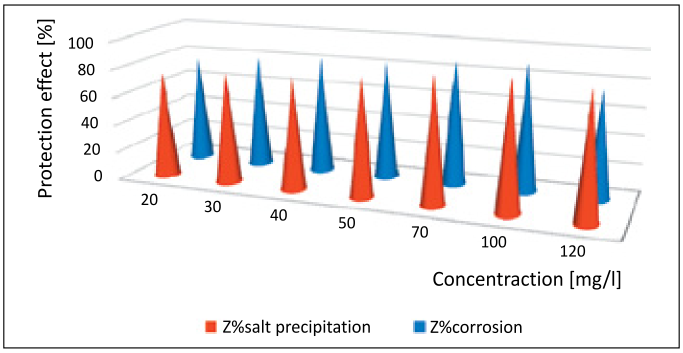

**Figure 5.** Dependence of protection effect of M-5 on the concentration in alkaline formation water

**Rysunek 5.** Zależność efektu ochronnego M-5 od stężenia w alkaicznej wodzie złożowej

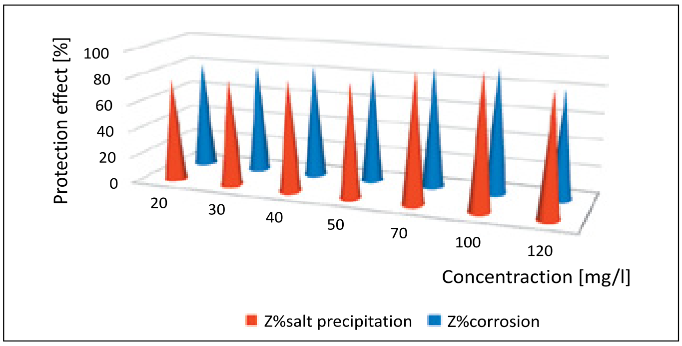

**Figure 6.** Dependence of protection effect of M-11 on the concentration in alkaline formation water

**Rysunek 6.** Zależność efektu ochronnego M-11 od stężenia w alkaicznej wodzie złożowej

compositions are homogeneous liquids that remain stable at formation temperatures, are resistant to freezing temperatures, and are compatible with formation waters and plug fluids. It was determined that composition M-5 meets the general requirements established by oil companies for the physical-chemical and technological properties of liquid inhibitors.

## Conclusion

1. For the first time, the efficiency of twelve compositions, prepared from different percentages of MARZA-2, ammonium chloride, kerosene, and diesel fuel components separately, against corrosion and salt precipitation in hard, alkaline, and neutral formation waters taken from oil fields, was investigated under laboratory conditions according to known methods, and the analysis of the results was carried out.
2. The results obtained from laboratory experiments revealed that the compositions prepared with different solvents exhibited high activity against corrosion and salt precipitation in all three formation water media. As the concentration of the compositions in the medium increased in the range of 20–120 mg/l, their efficiency also increased. A decrease in efficiency was observed when the amount of composition exceeded 120 mg/l. The highest effect was observed with 100 mg/l of the M-11 composition in hard, alkaline, and neutral media, especially in the diesel fuel medium.
3. Based on numerous laboratory experiments, it was determined that the optimal consumption of M-5 and M-11 compositions, which have the property of reducing corrosion and salt precipitation in oilfield facilities, is 100 mg/l. Thus, for 100 mg/l of composition M-5 in the kerosene solvent medium, in hard formation water the corrosion rate was 0.0087 g/m$^2 \cdot$ h (efficiency 98%), salt precipitation was 0.41g/l (efficiency 93%); in alkaline formation water the corrosion rate was 0.0625 g/m$^2 \cdot$ h (efficiency 92%), salt precipitation was 0.42 g/l (efficiency 90%); in neutral formation water the corrosion rate was 0.1024 g/m$^2 \cdot$ h (efficiency 90%), salt precipitation was 0.32 g/l (91% efficiency). These indicators were as follows for composition M-11: in hard formation water the corrosion rate was 0.0129 g/m$^2 \cdot$ h (efficiency 99.9%), salt precipitation was 0.12 g/l (efficiency 98%); in alkaline formation water the corrosion rate was 0.0234 g/ m$^2 \cdot$ h (efficiency 97%), salt precipitation was 0.29 g/l (efficiency 93%); in neutral formation water the corrosion rate was 0.0819 g/m$^2 \cdot$ h (efficiency 92%), and salt precipitation was 0.72 g/l (efficiency 98%).

## *Nomenclature*

$m_1$ – pretest weight of the sample [g],
$m_2$ – weight of the sample after removing the corrosion product [g],
$S$ – sample surface area [m$^2$],
$\tau$ – test duration [hours],
$K$ – corrosion rate [g/m$^2 \cdot$ h],
$Z$ – protective effect,
$\gamma$ – retardation factor,
$K_p$ – penetration depth,
$K_0$ – reagent free corrosion rate [g/m$^2 \cdot$ h],
$K_{inh.}$ – corrosion rate in the presence of the reagent [g/m$^2 \cdot$ h].

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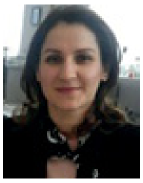

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