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Research on the effect of a new multifunctional composition on corrosion and paraffin deposition in crude oil samples

Badanie wpływu nowej kompozycji wielofunkcyjnej na korozję i osadzanie parafiny w próbkach ropy naftowej

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ABSTRACT: Effective management of asphaltene-paraffin-resin deposits in the installations of oil and gas distribution systems, along with corrosion control, is one of the most pressing issues. One of the important issues arising from today's demand is the development and testing of new multifunctional complex inhibitors and compositions based on them designed to combat asphaltene-resin-paraffin deposits and corrosion under laboratory and mine conditions. This paper reports on the laboratory testing of a new multifunctional composition that inhibits the formation of asphaltene-resin-paraffin deposits and corrosion processes in the oil well-gathering-transportation system. The effect of Difron-4201 depressant additive and ED composition on the freezing temperature of a high-paraffin crude oil sample, the formation of asphaltene-paraffin-resin deposits, and the surface tension coefficient were studied for the first time under laboratory conditions. It was found that, compared to the Difron-4201depressant additive, the ED composition exhibited higher efficiency. Specifically, at an optimal consumption concentration of 900 g/t for the Difron-4201 depressant additive and 700g/t for the composition, the highest efficiency was 190% and 200% respectively for freezing temperature reduction, 89.8% and 96.1% for the formation of asphaltene-paraffin-resin deposition, and 63.3% and 76.6% for surface tension reduction. Furthermore, the effect of the IB-1 inhibitor and the ED composition on the viability of sulfate-reducing bacteria in Postgate-B-nutrient medium along with corrosion rate in aggressive media containing hydrogen sulfide, carbon dioxide, and a combination of both were studied. Laboratory experiments determined the optimal consumption rate of the IB-1 inhibitor determined to be 25 mg/l. The corrosion protection effect at the optimal concentration of the inhibitor and the ED composition was 97.1% and 99.2% in hydrogen sulfide medium, 94.6% and 95.4% in carbon dioxide medium, and 93.6% and 94.7% in a combines hydrogen sulfide and carbon dioxide medium, respectively.

Key words: depressant additive, inhibitor, composition, corrosion, protection effect, freezing temperature, asphaltene-resin-paraffin deposition, surface tension.

STRESZCZENIE: Efektywne zapobieganie powstawaniu osadów asfaltenowo-żywiczno-parafinowych w instalacjach systemów dystrybucji ropy naftowej i gazu ziemnego, wraz z przeciwdziałaniem korozji, jest jednym z priorytetowych wyzwań. Obecnie jednym z ważniejszych zagadnień jest opracowanie i testowanie nowych wielofunkcyjnych kompleksowych inhibitorów i opartych na nich kompozycji, zapobiegających powstawaniu osadów asfaltenowo-żywiczno-parafinowych, jak również korozji w warunkach laboratoryjnych i kopalnianych. W niniejszym artykule opisano badania laboratoryjne nowej wielofunkcyjnej kompozycji, która ogranicza powstawanie osadów asfaltenowo-żywiczno-parafinowych i hamuje procesy korozyjne w systemie zbierania i transportu ropy naftowej. Po raz pierwszy w warunkach laboratoryjnych zbadano wpływ dodatku depresującego Difron-4201 i kompozycji ED na temperaturę krzepnięcia próbki wysokoparafinowej ropy naftowej, tworzenie się osadów asfaltenowo-żywiczno-parafinowych oraz współczynnik napięcia powierzchniowego. Stwierdzono, że w porównaniu z dodatkiem depresyjnym Difron-4201, kompozycja ED wykazała wyższą skuteczność. W szczególności, przy optymalnym stężeniu wynoszącym 900 g/t dla dodatku depresyjnego Difron-4201 i 700 g/t dla kompozycji, najwyższa wydajność wynosiła odpowiednio 190% i 200% dla obniżenia temperatury krzepnięcia, 89,8% i 96,1% dla tworzenia się osadów asfaltenowo-żywiczno-parafinowych oraz 63,3% i 76,6% dla obniżenia napięcia powierzchniowego. Ponadto zbadano wpływ inhibitora IB-1 i składu ED na żywotność bakterii redukujących siarczany w pożywce Postgate-B oraz szybkość korozji w agresywnych mediach zawierających siarkowodór, dwutlenek węgla oraz ich kombinację. W eksperymentach laboratoryjnych określono, że optymalna wartość wykorzystania inhibitora IB-1 wynosi 25 mg/l. Efekt ochrony przed korozją przy optymalnym stężeniu inhibitora i składzie ED wynosił odpowiednio 97,1% i 99,2% w medium zawierającym siarkowodór, 94,6% i 95,4% w medium zawierającym dwutlenek węgla oraz 93,6% i 94,7% w medium zawierającym zarówno siarkowodór i dwutlenek węgla.

Słowa kluczowe: dodatek depresujący, inhibitor, skład, korozja, efekt ochronny, temperatura krzepnięcia, osadzanie związków asfaltenowo-żywiczno-parafinowych, napięcie powierzchniowe.

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Introduction

A significant increase in the share of heavy oils with high viscosity and high freezing temperature in total oil production volume causes complications in the storage-transportation system. Consequently, addressing the main issues that arise during the production, storage, and transportation of such oils is considered an urgent necessity. Asphaltene-resin-paraffin compounds are integral components of almost all oil dispersion systems. Asphaltene-resin-paraffin deposition (ARPD) are one of the key challenges that complicate the operation of technological facilities, tanks, and pipelines during production, storage and transportation of oil. ARPD creates serious difficulties in all processes from oil production to its processing. Despite on going efforts to combat ARPD in the oil industry for many years, this problem remains significant. Currently, the number of oil fields rich in asphaltene-resin components, as well as hard-melting paraffin hydrocarbons, is increasing. Oils with th ese characteristics are marked by high freezing temperature and high viscosity. In particular, during the storage and transportation of heavy oils in cold climates, the formation and accumulation asphaltene-resin-paraffin at the bottom of tanks and on the inner surface of pipelines intensify. This results in reduced tank and decreased oil yield coefficient of pipelines (Semenova et al., 2002; Abdullayev and Aliyeva, 2003; Mursalova and Akhmedova, 2016; Kelbaliev et al., 2017; Gurbanov and Abdullaeva, 2018; Ramazanova et al., 2018; Abbasova, 2019).

The difficulties encountered in the production, storage, and transportation system of high-paraffin oils are primarily due to the accumulation of paraffin deposits on the inner surfaces of pipelines and technological facilities. Despite ongoing research, there is still no universally accepted mechanism for the formation of oil deposits. Research in this area has been largely limited to addressing the technological aspects combating these deposits. The main factor influencing the formation and precipitation of solid phasesis the decrease in the solubility of paraffin hydrocarbons in the dispersed oil system, which is significantly affected by oil temperature. Thus, the primary reason for paraffin hydrocarbon crystals to aggregate and form a solid lattice structure is the temperature decrease factor. The formation of large crystals sharply increase the viscosity of the oil, reducing its flow rate and sometimes completely halting the fluidity. The mechanism of asphaltene-resin-paraffin deposition on the inner surfaces of facilities involves the formation and growth of paraffin hydrocarbon crystals during mechanical contact with surface cracks and roughness followed by further formation and growth of crystals within the already formed paraffin-resin coating. Due to the diversity and complexity of the composition of the produced oils, the issues related to the prevention or elimination of ARPD remain unresolved. Th is is primarily because there has been a lack of systematic research considering the role of oil component composition, taking into account the temperature factor in the process of deposition formation.

The use of chemical reagents is one of the effective methods for preventing or inhibiting the formation of asphaltene-resin-paraffin deposition during the production and transportation of oil. One such chemical reagent is depressant additives. With their addition, paraffin hydrocarbons are precipitated in the form of small particles without forming solid agglomerates. Additionally, the adsorption of the additive on the surface of the formed crystals, promotes their outward growth. The resulting crystals are branched and needle-shaped, varying in thickness, length and width. Thus, in the oil dispersion system, there are modified crystals of different shapes that are less likely to aggregate. The additive combines with paraffin molecules, crystallizing with them and modifying their shape (Ramazanova et al., 2011; Samedov et al., 2017; Matiev et al., 2018; Panahov et al., 2019; Ahmed et al., 2022). Another significant problem during the pipeline transportation of high-paraffin oils is corrosion protection. Corrosion of facilities in the oil industry leads to substantial losses, due to the presence of highly corrosive components in the operational environment: mineral salts, molecular oxygen, carbon dioxide, hydrogen sulfide gas and, most importantly, sulfate-reducing bacteria. It should be noted that corrosion products are one of the factors that complicate oil flow during transportation. Therefore, to increase the efficiency of the storage and transportation system for high-paraffin oils, it is essential to address both paraffin deposition and corrosion simultaneously (Vigdorovich and Tsygankova, 2011; Milovzorov et al., 2012; Dubinskaya et al., 2013; Azimov et al., 2015; Gurbanov and Abdullaeva, 2018; Gurbanov and Mammadli, 2018; Menshikov and Shein, 2018; Gurbanov et al., 2019, 2020).

The goal of this work is to investigate the effect of individual reagents and a new composition on asphaltene-resin-paraffin deposition and corrosion in laboratory conditions.

Performance of work

Table 1 presents physical and chemical parameters of the oil taken from well No. 635 of OGPD named after N. Narimanov for conducting the research process in laboratory conditions.

As shown in the table, the oil sample taken for research belongs to the group of high-paraffin oils and is characterized by high paraffin hydrocarbon content and high freezing temperature. The effect of the Difron-4201depressant additive and a composition prepared in the ratio of 35:1 of Difron-4201

Table 1. Physico-chemical characteristics of oil
Tabela 1. Charakterystyka fizykochemiczna ropy naftowej

Parameters	Quantity	Determination method
Sulfur mass fraction [%]	0.19	SS 1437-75
Density, ρ_4^{20} [kg/m^3]	894.3	SS 3900-85
Freezing temperature [°C]	+10	SS 20287-91
Paraffin content [%]	22.6	SS 11851-85
Resin content [%]	10.8	SS 11851-85
Asphaltene content [%]	2.2	SS 11851-85

(conventionally named ED) and the IB-1 inhibitor on high-paraffin oil sample was investigated. For this purpose, the formation process of asphaltene-resin-paraffin deposition from a high-paraffin oil sample under laboratory conditions was determined using the Difron-4201 additive and ED composition at a temperature of 500°C for 3 hours, employing the "cold finger test" method. The essence of the method is based on the accumulation of asphaltene-resin-paraffin deposits on a cold metal surface. The "cold finger test" is widely used to determine the optimal rate of depressant additive in addition and evaluate its efficiency. Table 2 shows physical and chemical parameters of the Difron-4201 depressant additive.

Table 2. Physico-chemical properties of Difron-4201 depressant additive
Tabela 2. Właściwości fizykochemiczne dodatku depresyjnego Difron-4201

Properties	Difron-4201
Visual appearance	Yellow to brown liquid
Density at 20°C	Not more than 790 kg/m^3
Closed vessel ignition temperature	Not lower than –28°C
Solubility in water	Insoluble
Solubility in aromatic solvents	Soluble

During the laboratory research, the amount of sediments accumulated on the cold pipe surface of the oil sample, to which different amounts of Difron-4201 depressant additive and ED composition were added, was determined by weight method. The efficiency of the reagents was calculated using the following formula.

$$K = [(m_1 - m_2)/m_1]100\%$$

where:
K – reagent efficiency,
m_1 – the mass of ASP in reagent-free medium,
m_2 – the mass of ASP in the medium containing the reagent.

In order to determine the effect of the Difron-4201 depressant additive and ED composition on the freezing temperature of oil under laboratory conditions, a pre-defined volume of the oil sample was added to spherical seat test bottles with a 20 mm diameter and 160 mm height. After heating to a temperature of 55–60°C, the depressant additive of different concentrations was added separately, and the mixture was gradually cooled to a temperature of 30–40°C by adding the additive or composition. Then, the test bottles were placed in a thermostat to continue the cooling process. Every three-degree decrease in temperature, the test bottles were kept at a 45° angle, and the temperature at which the oil level in the test bottles remained stationary was recorded. The test bottles were then held in a horizontal position for 5 seconds. Complete solidification of the liquid was determined by the immobility of the upper liquid layer.

The corrosion protection effect of the composition and inhibitor was determined using a Ct20 steel sample with dimensions of 30 × 20 × 1 mm. Table 3 shows the chemical composition of Ct20 steel.

Table 3. Chemical composition of Ct20 brand steel
Tabela 3. Skład chemiczny stali Ct20

Type	C	Mn	Si	P	S	Cr	Ni	Cu	As	Fe
Ct20	0.17–0.24	0.35–0.65	0.17–0.37	up to 0.04	up to 0.04	up to 0.25	up to 0.25	up to 0.25	0.08	~98

The corrosion rate of the steel sample was determined based on mass loss. For this, experiments were conducted over 6 hours at a temperature of 25°C with the IB-1 inhibitor (2,4-dichloro-1-{2-iodo-1[(prop-2-yn-1-yl)oxy]-ethyl} benzene) concentrations of 15, 20, 25, 30 mg/l and the ED composition concentrations of 100–900 g/t. 2,4-dichloro-1 {2-iodo-1[(prop-2-yn-1-yl)oxy]-ethyl}benzene was synthesized from 2,4-dichlorostyrene, propargyl alcohol, and crystalline iodine. Yield 66.8%, mp 90–92°C (from EtOH). IR spectrum, ν [cm^{-1}]: 3300, 3080, 3010, 2100, 1640, 1630, 1515, 1360–1340. 1270, 850–840, 560. ^{1}HNMR spectrum, δ [ppm]: 2.50 t (1H = CH, ^4J = 2.4 Hz), 3.22 d.d. and 3.42 d.d. (1H each, CH_2I, J = 10.3, 5.8 Hz), 3,83 d.d. and 4.04 d.d. (1H each. CH_2O, ^2J = 16.2, ^4J = 2.4 Hz), 4.42 d.d (1H, CH, J = 5.8, 9.0 Hz), 7.27 d.d (1H, C_6H, J = 8.8, 2.4 Hz), 7.53 d.d (1H, C6H, J = 8.8, 2.4 Hz), 7.72 d.d.t (1H, C_6H_3, J = 5.8, 9.0 Hz), 7.27 d.d. (1H, C_6H_3, J = 8.8, 2.4 Hz), 7.53 d.d (1H, C_6H_3, J = 8.8, 2.4 Hz), 7.72 d.d (1H, C_6H, J = 2.7, 0.4 Hz). ^{13}C NMR spectrum δ_C [ppm]: 55.3, 69.9, 80.5, 114.0, 117.4, 127.8, 131.9, 133.1 (C^4), 135.6 (C^2), 134.6, 159.6. Found [%]: C 37.42; H 3.18; Cl 19.47, I 35.55. $C_{11}H_{11}Cl_2IO$. Calculated [%]: C 37.01; H 3.11; Cl 19.86; I 35.55), (Talybov et al. 2020).

After polishing the surface of the steel plates on a grinding machine, they were cleaned with acetone and alcohol, washed with distilled water, and then treated with 15% HCl solution

for 60 seconds to activate the surface of the steel samples. The plates were then washed with running and distilled water, dried with filter paper, and kept in a desiccator for an hour. The mass was then determined using an analytical balance. For comparison, experiments were carried out in parallel in the same media without inhibitor, with inhibitor, and with composition. The area of the samples taken for testing was calculated using the following formula:

$$S_N = 2ah + 2ab + 2hb$$

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

The corrosion rate was calculated using the following mathematical expression.

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

where:
K – corrosion rate,
m_1 – weight of the steel plate before the laboratory test [g],
m_2 – weight of the steel plate after removing the corrosion product [gr],
S – steel plate area [m^2],
τ – duration of the laboratory test [hours].

The retardation factor was calculated using the following mathematical expression.

$$\gamma = \frac{K_0}{K_{inh}}$$

where:
γ – retardation factor,
K_0 – corrosion rate in a reagent-free environment (g/m^2 · h),
K_{inh} – corrosion rate in the reagent medium (g/m^2 · h).

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

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

where:
Z – protection effect,
K_0 – corrosion rate in a reagent-free environment (g/m^2 · h),
K_{inh} – corrosion rate in the reagent medium (g/m^2 · h).

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

$$K_p = \frac{8760 K_{inh}}{\rho} \cdot 10^{-3} \text{ mm/year}$$

where:
K_p – penetration depth,
K_{inh} – corrosion rate in the reagent medium [g/m^2 · h],
ρ – density of the studied metal [g/sm^2],
8760 – constant number of hours in a year.

The bactericidal property of IB-1 inhibitor and ED composition against sulfate-reducing bacteria was investigated in Postgate-B nutrient medium.

A nutrient medium with a pH in the range of 7–7.5 was prepared by calculating the reagents needed for one liter of water.

In parallel, the properties of the inhibitor and composition were investigated in the formation water containing hydrogen sulfide under laboratory conditions, and their corrosion protection effect was calculated. Desulfomicrobium and Desulfovibriodesulforicans bacterial strains were used during the research, and a formation water sample from well No. 1082 of Bibiheybatneft OGPD of SOCAR was used as the corrosion medium.

The growth factor of sulfate-reducing bacterial cells in the presence of bactericide is calculated by the following equation:

$$N[\%] = \frac{100(n_0 - n_{inh})}{n_0}$$

where:
N – growth factor of sulfate-reducing bacterial cells,
n_0 – number of microorganisms in the reagent-free medium,
n_{inh} – number of microorganisms in the reagent medium.

Based on the amount of hydrogen sulfide, the bactericidal effect of the reagent is calculated by the following formula:

$$S[\%] = \frac{C_0 - C_{inh}}{C_{inh}} 100$$

where:
S – bactericidal effect,
C_0 – concentration of biogenic hydrogen sulfide in the reagent-free medium,
C_{inh} – concentration of biogenic hydrogen sulfide in the reagent medium.

Table 4. Content of Postgate-B nutrient medium [g/l]
Tabela 4. Zawartość pożywki Postgate-B [g/l]

Name of the environment	NH_4Cl	K_2HPO_4	$MgSO_4 \cdot 7H_2O$	$CaSO_4$	Laktot-Ca	Na_2S	Na_2SO_3	$FeSO_4$ (5% solution in 1% HCl)
Postqeyt-B	1.0	0.5	2.0	1.0	2.6	0.2	2.0	0.5

Results and discussion

The effect of the Difron-4201 depressant additive and ED composition on the N. Narimanov oil sample was evaluated based on the amount of asphaltene-resin-paraffin deposition accumulated using the "cold finger test" method in laboratory conditions. The freezing temperature, surface tension coefficient, and effective viscosity of the oil were also determined in the presence of 100, 200, 300, 400, 500, 600, 700, 800, 900 g/t of Difron-4201 depressant additive and ED composition at 0°C for one hour. The values obtained from the experiments are presented in Table 5.

Thus, the effect of both Difron-4201 depressant additive and ED composition on the freezing temperature, paraffin deposition, and surface tension of N. Narimanov oil sample was studied for the first time. It was revealed that the composition shows higher efficiency. The highest efficiency was observed at a concentration of 900 g/t of Difron 4201 depressant additive and 700 g/t of ED composition. Therefore, the highest effect of Difron 4201 depressant additive on the freezing temperature at the optimal consumption rate was 190%, and for the ED composition, it was 200%. The protection effect against ARPD was 89.8% and 96.1%, respectively, and in surface tension this indicator was 63.3% and 76.6% (Table 6).

Inhibitor and bactericidal properties of IB-1 inhibitor and ED composition were studied under laboratory conditions. Inhibitor property was examined in aggressive corrosion media where hydrogen sulfide, carbon dioxide and both gases coexist. The results of laboratory experiments conducted at room temperature for six hours are presented in Table 7.

Table 5. The effect of Difron 4201 depressant additive and ED composition on some properties of Narimanov oil (at +0°C temperature)
Tabela 5. Efekt dodatku depresującego Difron 4201 i kompozycji ED na niektóre właściwości ropy naftowej Narimanov (w temperaturze +0°C)

Depressant additive and ED compound concentration	Freezing temperature [°C]		ARPD sediments content, δ [%]		Surface tension, σ [mN/m]	
	Difron-4201	ED	Difron-4201	ED	Difron-4201	ED
0	+10.0	+10.0	12.7	12.7	27.8	27.8
100	+8.3	+7.8	11.4	10.3	20.3	18.6
200	+7.2	+5.4	10.5	9.6	18.2	14.3
300	+5.6	+3.0	8.4	7.2	16.6	11.9
400	+2.0	–3.6	6.1	5.6	15.3	12.4
500	–2.0	–6.0	4.6	3.1	14.2	8.6
600	–4.8	–8.6	3.4	1.3	13.8	8.2
700	–6.0	–10.0	2.1	0.5	13.3	6.5
800	–7.8	–9.7	1.6	0.6	12.6	7.6
900	–9.0	–9.0	1.3	0.7	10.2	8.4

Table 6. The effect of Difron 4201 depressant additive and ED composition on some properties of Narimanov oil (at +0°C temperature) (t = +0°C)
Tabela 6. Efekt dodatku depresującego Difron 4201 i kompozycji ED na niektóre właściwości ropy naftowej Narimanov (w temperaturze +0°C) (t = +0°C)

Depressor additive and ED compound concentration	Effectiveness of decrease of freezing temperature [%]		ARPD protection effectiveness, K [%]		Surface tension efficiency, E_σ [%]	
	Difron-4201	ED	Difron-4201	ED	Difron-4201	ED
0	0.0	0.0	0.0	0.0	0.0	0.0
100	17	22	10.2	18.9	26.9	33.9
200	28	46	17.3	24.4	34.5	48.6
300	44	70	33.9	43.3	40.3	57.2
400	80	136	51.9	55.9	44.9	55.4
500	120	160	63.8	75.6	48.9	69.1
600	148	186	73.2	89.8	50.4	70.5
700	160	200	83.5	96.1	52.2	76.6
800	178	197	87.4	95.8	54.7	72.7
900	190	180	89.8	94.5	63.3	69.8

Table 7. Protective effect of IB-1 inhibitor and ED composition in aggressive corrosion environments

Tabela 7. Ochronne działanie inhibitora IB-1 i kompozycji ED w agresywnych środowiskach korozyjnych

C	S [m^2]	m_1 [g]	m_2 [g]	$m_1 - m_2$ [g]	K_0 [g/m^2 · h]	K [g/m^2 · h]	γ	K_p	Z [%]
IB-1 inhibitor in H_2S medium									
0	0.0013	8.6697	8.66910	0.00060	0.4359	–	–	–	–
10	0.0013	8.6697	8.66930	0.00040	0.4359	0.0510	8.55	0.05712	87.3
15	0.0013	8.6697	8.66950	0.00020	0.4359	0.0296	14.73	0.03315	92.2
20	0.0013	8.6697	8.66960	0.00010	0.4359	0.0179	24.35	0.02005	94.9
25	0.0013	8.6697	8.66964	0.00006	0.4359	0.0083	52.52	0.00929	97.1
30	0.0013	8.6697	8.66960	0.00010	0.4359	0.0157	27.76	0.01758	96.4
C_{comp} [g/t]	***ED composition H_2S medium***								
0	0.0013	8.6697	8.666300	0.003400	0.4359	–	–	–	–
300	0.0013	8.6697	8.669400	0.000300	0.4359	0.0371	11.75	0.04155	90.5
500	0.0013	8.6697	8.669500	0.000200	0.4359	0.0205	21.26	0.02296	94.3
700	0.0013	8.6697	8.669693	0.000007	0.4359	0.0009	484.33	0.00101	99.2
900	0.0013	8.6697	8.669650	0.000050	0.4359	0.0069	63.17	0.00773	97.4
IB-1 inhibitor in CO_2 medium									
0	0.0013	8.6697	8.66800	0.00170	0.2234	–	–	–	–
10	0.0013	8.6697	8.66934	0.00036	0.2234	0.0463	4.83	0.05186	78.3
15	0.0013	8.6697	8.66943	0.00027	0.2234	0.0342	6.53	0.03830	83.7
20	0.0013	8.6697	8.66959	0.00011	0.2234	0.0145	15.41	0.01624	92.5
25	0.0013	8.6697	8.66894	0.00076	0.2234	0.0098	22.79	0.01098	94.6
30	0.0013	8.6697	8.66960	0.00011	0.2234	0.0147	15.19	0.01646	93.4
C_{comp} [g/t]	***ED composition CO_2 medium***								
0	0.0013	8.6697	8.66800	0.00170	0.2234	–	–	–	–
300	0.0013	8.6697	8.66940	0.00030	0.2234	0.0414	5.39	0.04637	80.5
500	0.0013	8.6697	8.66950	0.00020	0.2234	0.0274	8.15	0.03068	86.7
700	0.0013	8.6697	8.66964	0.00006	0.2234	0.0080	27.93	0.00896	95.4
900	0.0013	8.6697	8.66961	0.00009	0.2234	0.0121	18.46	0.01355	93.6
IB-1 inhibitor in $H_2S + CO_2$ medium									
0	0.0013	8.6697	8.669200	0.000500	0.0623	–	–	–	–
10	0.0013	8.6697	8.669590	0.000110	0.0623	0.0147	4.24	0.01646	75.4
15	0.0013	8.6697	8.669650	0.000050	0.0623	0.0069	9.03	0.00773	87.8
20	0.0013	8.6697	8.669670	0.000035	0.0623	0.0045	13.84	0.00504	91.8
25	0.0013	8.6697	8.669673	0.000027	0.0623	0.0034	18.32	0.00381	93.6
30	0.0013	8.6697	8.669660	0.002690	0.0623	0.0048	12.98	0.00538	92.4
C_{comp} [g/t]	***ED composition $H_2S + CO_2$ medium***								
0	0.0013	8.6697	8.66920	0.000500	0.0623	–	–	–	–
300	0.0013	8.6697	8.66961	0.000094	0.0623	0.0121	5.15	0.01355	79.5
500	0.0013	8.6697	8.66966	0.000043	0.0623	0.0055	11.33	0.00616	90.2
700	0.0013	8.6697	8.66968	0.000021	0.0623	0.0027	23.07	0.00302	94.7
900	0.0013	8.6697	8.66967	0.000033	0.0623	0.0042	14.83	0.00470	92.3

S – sample area [m^2],
m_1 – mass of the sample before testing [g], m_2 – mass after testing [g],
m_1–m_2 – sample mass loss [g],
K_0 – corrosion rate of the sample in reagent-free medium [g/m^2 · h],
K – corrosion rate in the presence of reagent [g/m^2 · h],
K_p – penetration coefficient,
γ – retardation factor, Z – corrosion inhibitor protection degree [%].

According to the results of the laboratory experiments presented in Table 7, the protective effect was observed to increase with the rise in concentration of 300–900 g/t of ED composition. The highest protective effect was achieved at a concentration of 700 g/t of the composition. Thus, the protective effect of the composition varies from 90.5 to 97.4% in a hydrogen sulfide medium, from 80.5 to 93.6% in a carbon dioxide medium, and from 79.5 to 92.3% in an aggressive medium where hydrogen sulfide and carbon dioxide coexist. The most significant protective effect is observed in hydrogen sulfide medium.

When comparing the results obtained for all three aggressive media, the ED composition showed a higher protective effect compared to the IB-1 inhibitor.

On the other hand, bactericidal property of IB-1 inhibitor and ED composition was investigated in Postgate-B nutrient medium. According to the results of the laboratory experiments conducted within 15 days, the vital functions of the two types of bacteria, Desulfomicrobium and Desulfovibriodesulforicans, used in the experiment was observed to decrease effectively. The inhibitor and bactericidal effect of the composition was assessed based on the change in the concentration of hydrogen sulfide (Figure 1).

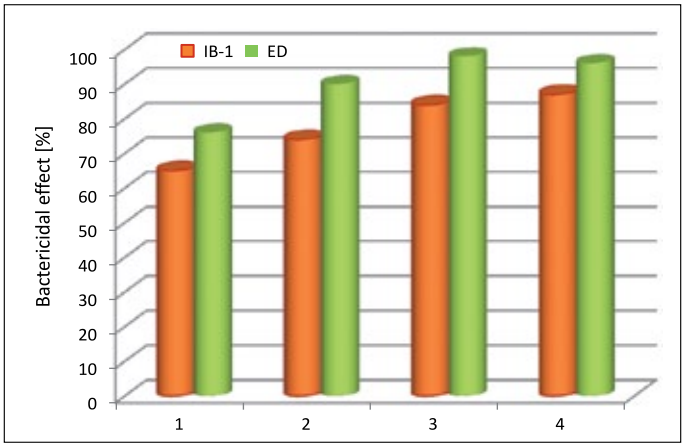

Figure 1. Bactericidal effect of IB inhibitor and ED reagent based on the amount of hydrogen sulfide: IB-1: 1 – 10, 2 – 15, 3 – 20, 4 – 25 mg/l; ED: 1 – 300, 2 – 500, 3 – 700, 4 – 900 g/t

Rysunek 1. Bakteriobójcze działanie inhibitora IB i odczynnika ED w zależności od ilości siarkowodoru: IB-1: 1 – 10, 2 – 15, 3 – 20, 4 – 25 mg/l; ED: 1 – 300, 2 – 500, 3 – 700, 4 – 900 g/t

As shown in the figure, bactericidal effect of the IB-1 inhibitor in the concentration range of 10–25mg/l is 65–87%, while the bactericidal effect of the ED composition is 76–96% in the concentration range of 300–900 g/t. The highest bactericidal effect was observed at the concentration of 25 mg/l of IB-1 inhibitor and the concentration of 700 g/t of ED composition. Thus, 25 mg/l of IB-1 inhibitor destroyed 87%, and 700 g/t of ED composition destroyed 96% of sulfate-reducing bacteria and halted their vital functions. As a result of the comparative analysis, it was found that 700 g/t of ED composition containing IB-1 inhibitor is more effective in stopping the vital functions of sulfate-reducing bacteria.

Conclusions

1. The effect of the Difron-4201 depressant additive and ED composition on the freezing temperature, paraffin deposition, and surface tension of highparaffin commodity N. Narimanov oil sample was studied. The anticorrosion effectiveness of the ED composition and IB-1 inhibitor were also investigated in the formation water containing hydrogen sulfide, carbon dioxide, and a mixture of these gases. For the first time, the effect of the ED composition and IB-1 inhibitor on the vital functions of sulfate-reducing bacteria in Postgate-B medium was studied under laboratory conditions.
2. The efficiency of the Difron-4201 additive at the optimal consumption rate of 900 g/t is 190% in reducing the freezing temperature, 89.8% in reducing paraffin deposition, and 6.3 in reducing surface tension. At the optimal consumption concentration of 700 g/t, the ED composition achieves these effects at 200%, 96.1%, and 76.6%, respectively. The corrosion protection effect of the IB-1 inhibitor and ED composition is 97.1% and 99.2% in a hydrogen sulfide medium, 94.6% and 95.4% in a carbon dioxide medium, and 93.6% and 94.7% in a hydrogen sulfide and carbon dioxide medium. The bactericidal effect of the IB-1 inhibitor at the mentioned concentration is 87%, and the bactericidal effect of the ED composition is 98%.
3. Extensive laboratory research determined that the optimal consumption concentration of the Difron-4201 depressant additive is 900 g/t, while it is 700 g/t for the ED composition. Although the optimal consumption amount of IB-1 inhibitor is 25 mg/l, this amount is 20 mg/l in the case of ED composition. The effect of the ED composition is higher compared to both the Difron-4201 depressant additive and the IB-1 inhibitor, which can be attributed to synergistic efficiency.

Nomenclature

K – efficiency of the reagents,
m_1 – mass of ARPD in reagent-free medium,
m_2 – mass of ARPD in medium containing the reagent,
S – area of the steel sample [m^2],
a – sample length [mm],
b – sample width [mm],
h – sample height [mm],

m_1 – weight of the steel plate before the laboratory test [g],
m_2 – weight of the steel plate after removing the corrosion product [gr],
τ – duration of the laboratory test [hours],
K_0 – corrosion rate in a reagent-free environment [g/m^2 · h],
K_{inh} – corrosion rate in the reagent medium [g/m^2 · h],
K – corrosion rate [g/m^2 · h],
ρ – density of the studied metal [g/sm^2],
8760 – constant number of hours in a year,
n_0 – number of microorganisms in the reagent-free medium,
N_{inh} – number of microorganisms in the reagent medium,
C_0 – concentration of biogenic hydrogen sulfide in the reagent-free medium,
C_{inh} – concentration of biogenic hydrogen sulfide in the reagent medium.

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