Anti-corrosion properties of oil compositions based on combined corrosion inhibitor M-531

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Abstract

The anticorrosive properties of coatings on steel containing conservation materials based on industrial (I-20A), commercial motor ($M10G_{2(k)}$) and waste motor (WMO) oils modified with combined corrosion inhibitor M-531 containing a VCI were studied. The compositions based on petroleum oils with the M-531 additive well wet a surface of steel with a contact angle $\theta < 30°$, they themselves are wetted by water with $\theta < 48°$ and are characterized by low surface tension $\sigma < 27$ mN/m. The temperature dependence of the kinematic viscosity of the oil compositions studied in the range of 20–60°C is described by the Reynolds–Filonov formula. The protective effect (Z) of the coatings upon short-term exposure to a 0.5 M NaCl solution, calculated on the basis of polarization curves, is 99% at 7–10 wt.% M-531 in the I-20A and WMO oils. The same high value of Z was obtained in corrosion tests performed in a thermal moisture chamber for 960 hours. The protective effect of the coatings does not exceed 70% in long-term corrosion tests (336 hours) in 0.5 M NaCl solution, and a particularly low value is typical of compositions based on I-20A oil (<25%). Salt spray chamber tests of steel samples covered with the oil coatings containing 20% M-531 showed that the best protection was characteristic of a composition based on WMO. The same composition turned out to be ineffective under natural conditions: already after 3 months, the samples protected by it were completely covered with corrosion products, indicating the inexpediency of using an additive with volatile inhibitors in protective compositions in an open atmosphere. They can be used for short-term inter-operational storage of metal products.

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Introduction

Inhibitor protection is one of the simplest and most technologically advanced methods of combating metal corrosion [1, 2]. The following products are used as corrosion inhibitors:

- individual inhibitory compounds;
- wastes of chemical and petrochemical industries, which are mixtures of several substances similar in structure and chemical composition, which can be used as corrosion inhibitors (CI) even without additional treatment;
- specially designed mixtures of substances that provide synergistic effects that mutually increase the protective effectiveness.

A mixture of inhibitory compounds, both specially created [3, 4] and present, for example, in the distillation residues of chemical and petrochemical industries [5], is usually understood as combined CIs.

Individual oil-soluble CIs of a complex structure, which have several functional groups in their molecules, due to which they have mixed characteristics of the donor, acceptor, and screening types [6], are also called combined CIs.

Oil compositions containing various types of CI are used for temporary anti-corrosion protection of equipment against atmospheric corrosion. Previously, we studied a protection of carbon steel against atmospheric corrosion by coatings that combine petroleum oils with Cortec VpCI-368D additive. This additive is a composition of an organic solvent with a volatile inhibitor (30%) [7]. This composition is supplied by Cortec Corporation, USA (in Russia and CIS countries, the official representative is CORTEC RUS LLC).

The same company offers an anti-corrosion additive with oil-based volatile corrosion inhibitors M-531 for introduction into petroleum and synthetic oils, in which it is highly soluble. It is assumed that a presence of M-531 in oil coatings provides effective protection of machinery and equipment against atmospheric corrosion both on open surfaces and in hard-to-reach places, such as cracks and gaps.

The purpose of this work is to study the protection of carbon steel against atmospheric corrosion by coatings based on the compositions of petroleum oils with M-531 additive.

Experimental

Industrial (I-20A), commercial motor ($M10G_{2(k)}$) and waste motor (WMO) oils were used as a solvent-support in the oil compositions. The concentration of M-531 additive was 3–20 wt.%.

The studies were carried out on samples of carbon steel St3 with a composition, wt.%: C 0.20; Mn 0.51; Si 0.15; P 0.04; S 0.05; Cr 0.32; Ni 0.21; Cu 0.23; Fe 98.29. The oil composition coatings were deposited by immersion of the samples (30×30×3 mm) into the bath containing the composition at room temperature for 10 seconds. After that, the samples were kept in a suspended state for one day to drain off the excess oil composition and to form a protective film. The thickness of the oil film h (m) on the metal surface was determined by the formula:

$$h = \Delta m \cdot 10^6/(S \cdot \rho)$$

where Δm is the change in the mass of the sample after a formation of the coating, kg; S – surface area, m^2; ρ is the density of the preservation material, kg/m^3.

The kinematic viscosity of compositions with M-531 was measured according to the Brookfield method using a rotational viscometer Smart L (Fungilab company).

The contact angles (θ) of the oil compositions were determined using the EASYDROP device and the calculation method [8].

The values of surface tension (σ) were obtained by the method of tearing off the ring on the Du-Nui device, and the value of the adhesion work (W_a) was calculated by the formula:

$$W_a = \sigma(1 + \cos\theta) \tag{1}$$

Gravimetric corrosion tests were carried out in a G-4 thermal moisture chamber (GOST 9.054-75), 0.5 M NaCl solution (GOST 9.042-75) and natural conditions.

Tests in the salt fog chamber were carried out for 48 hours in the following mode: 8 hours in salt fog, which was created by spraying 5% NaCl solution at a temperature of 40°C, and 16 hours with the chamber closed and turned off. Periodically, a visual assessment of the surface of the samples was carried out in order to detect corrosion products.

Potentiodynamic (0.66 mV/s) polarization measurements were performed using an IPC-Pro MF potentiostat, according to [7]. Potentials were recalculated to the standard hydrogen scale. Coatings on the electrodes for polarization measurements were formed by keeping them in an air atmosphere at room temperature for 15 minutes after applying a protective composition to them. The coating thickness was 11–14 μm.

The protective effect of the oil composition was calculated according to the data of gravimetric corrosion tests (2) and polarization measurements (3):

$$Z, \% = 100 \cdot (K_0 - K)/K_0 \tag{2}$$

$$Z, \% = 100 \cdot (i_0 - i)/i_0 \tag{3}$$

where K_0 (i_0) and K (i) are the corrosion rates in the absence and in the presence of the oil composition, respectively.

Results and Discussion

The quality of wetting and spreading of the compositions over the steel surface affects the appearance, continuity, adhesive strength and protective ability of coatings.

The hypothesis of the existence of discontinuities in oil coatings in the form of channels of variable cross section was put forward in the works of V.I. Vigdorovich with co-authors [8, 9]. It was confirmed by their high moisture permeability. The total cross section of such the discontinuities is constant in time, depends on the nature and concentration of the surfactant, decreasing with its increase. In the first approximation, it can be assumed that the driving force of the penetration process of an aqueous corrosive medium through the oil film to the metal surface will be similar to capillary pressure, the value of which for a cylindrical capillary is calculated using the Young–Laplace formula:

$$P = 2\sigma \cdot \cos\theta / r \tag{4}$$

where σ is the surface tension of the liquid, for water at 20°C σ = 72.75 mN/m; θ is the contact angle of wetting the capillary wall with liquid; *r* is the radius of the capillary.

The values of the wetting angles (θ_1) of the oil compositions under study with water, obtained using the EASYDROP device, do not exceed 48° (Table 1), therefore, steel surfaces with oil coating are hydrophilic, and water actively wets them. The values of the contact angles of wetting decrease with an increase in the concentration of M-531 in the oil. This corresponds to an increase in hydrophilicity.

The contact angles of wetting a surface of St3 steel with the oil compositions (θ_2) were calculated according to the method [10] due to their smallness and the inability to use the EASYDROP device. The contact angles (θ_1 and θ_2) for compositions based on $M10G_{2(k)}$ and WMO oils exceed the corresponding values of the compositions based on I-20A oil. The θ_2 values of the compositions are much lower than the corresponding values for distilled water (77°), therefore, all the studied compositions should effectively displace the surface phase water layers. However, water wetting of the oil coatings promotes a penetration of the aqueous medium through the pores present in them to the metal surface. The values of θ_2 increase with increasing concentration of M-531 in the oils.

Table 1. Wetting angles of the oil compositions with water (θ_1) and steel with the oil compositions (θ_2), surface tension and adhesion work of M-531 oil compositions on St3 steel.

Oil	C_{M-531}, wt.%	θ_1,°	θ_2,°	σ, mH/m	$\sigma \cdot \cos\theta_1$	$W_a = \sigma \cdot (1+\cos\theta_2)$, mH/m
I-20A	3	21	4.6	21.43	20.0	42.8
	5	19	6.9	22.48	21.3	44.8
	7	16	9.4	26.23	25.2	52.1
	10	10	10.9	27.16	26.7	53.8
$M10G_{2(k)}$	3	48	24.8	16.30	10.9	31.1
	5	38	27.3	16.55	13.0	31.3
	7	27	29.0	18.16	16.2	34.0
	10	22	30.0	18.29	16.8	34.1
WMO	3	47	19.0	16.86	12.3	32.8
	5	43	19.5	18.36	13.4	35.7
	7	30	20.0	18.73	16.2	36.3
	10	22	20.5	18.83	17.5	36.5

The values of surface tension (σ), determined by means of the Du-Nui device (Table 1), increase with increasing concentration of M-531 in the oils and, according to (4), the driving force of the penetration process of the aqueous medium to the steel surface through the oil coating increases. Accordingly, the process of moisture penetration through the oil film increases with increasing concentration of M-531, while the corrosion inhibitor is delivered to the steel surface from the oil film with moisture.

The values of the adhesion work (W_a) increase with an increase in the concentration of M-531 in all the oil compositions, but the largest increase, like W_a itself, is observed for I-20A oil.

The protective ability of oil compositions, as a rule, is associated with the thickening ability of CI in relation to oils, which can be estimated from the viscosity–temperature dependences. Viscosity–temperature curves of the oil compositions in semi-logarithmic coordinates are shown in Figure 1 (a, b, c).

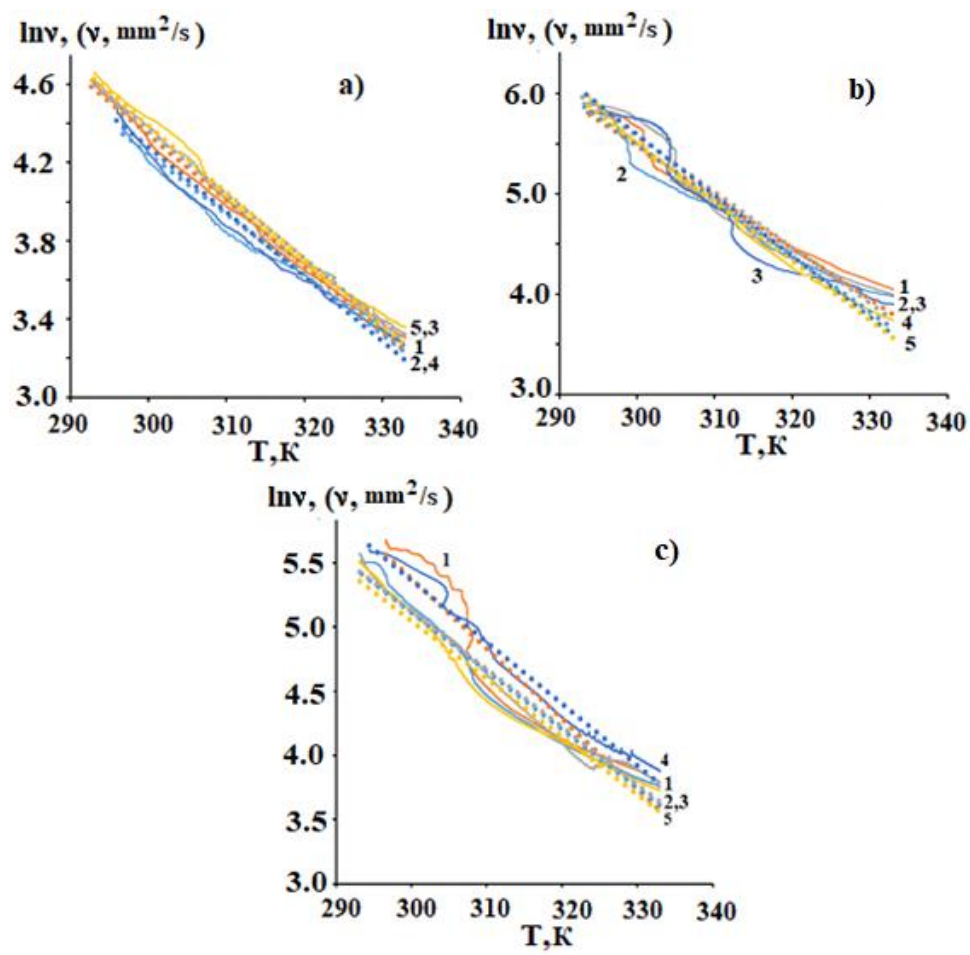

Figure 1. Viscosity–temperature curves of the compositions on base of oils: I-20A (a), $M10G_{2(k)}$ (b) and WMO (c) with M-531, wt.%:1 – 0; 2 – 3; 3 – 5; 4 – 7; 5 – 10. Dots show the approximation lines.

A linear approximation of the viscosity–temperature curves was performed in Microsoft Excel with an indication of the value of the approximation reliability. The linear approximation is depicted by dots in Figure 1 and obeys the Reynolds–Filonov formula [11]:

$$\log\nu = a + bT, \tag{5}$$

where ν is the kinematic viscosity of the oil composition; T is the temperature.

The coefficients of the Reynolds–Filonov equation for calculating the kinematic viscosity of the oil compositions at various concentrations of M-531 depending on the temperature in the range of 20–60°C and the reliability values of the linear approximation are shown in Table 2.

So, for the I-20A oil, the following coefficients were obtained: $a = 14.397$, $b = -0.0335$, and the empirical expression for the dependence of $\ln\nu$ has the form:

$$\ln\nu = 14.397 - 0.0335T \tag{6}$$

The viscosity–temperature curves are close to each other and can be approximated by straight lines with close values of the coefficients for the compositions based on I-20A and combined corrosion inhibitor M-531 at a concentration of 3–10 wt.%. The average values of the coefficients $a_{\text{average}} = 14.17$ and $b_{\text{average}} = -0.0328$ correspond to a high average approximation reliability index $R^2 = 0.9897$ in the temperature range of 20−60°C. This indicates the applicability of the Filonov–Reynolds equation to them.

Table 2. The experimental values of the coefficients of the Reynolds–Filonov equation for the compositions under study in the range of 20–60°C.

Composition		**Coefficients in the Reynolds–Filonov formula**		**The reliability of approximation, R^2**
Oil	**$C_{M\text{-}531}$, wt.%**	***a***	***b***	
I-20A	0	14.397	0.0335	0.9951
	3	13.478	0.0308	0.9842
	5	14.146	0.0326	0.9958
	7	14.219	0.0331	0.9835
	10	14.634	0.0341	0.9892
$M10G_{2(k)}$	0	16.835	0.0364	0.9926
	3	17.984	0.0404	0.9711
	5	16.980	0.0361	0.9928
	7	16.731	0.0366	0.8993
	10	17.391	0.0389	0.9789
WMO	0	21.875	0.0550	0.9279
	3	18.809	0.0456	0.9662
	5	18.591	0.0449	0.9733
	7	19.813	0.0482	0.9839
	10	18.545	0.0450	0.9644

Fractures (Figure 1b, c) are available on viscosity–temperature curves of the motor oil $M10G_{2(k)}$ fresh and waste one (WMO) and the compositions based on them, caused by structural changes in these oils when temperature changes due to the presence of additives and aging products. These dependencies are close to linear in the temperature range of 20–60°C, but with a lower indicator of the reliability of linear approximation than in a case of I-20A-based compositions. As follows from the data given, the introduction of M-531 additive into the oils and an increase in its concentration leads mainly to a decrease in kinematic viscosity, especially significant in the WMO-based compositions.

Electrochemical studies make it possible to give an express assessment of the protective properties of the oil compositions. The polarization curves of a steel electrode with coatings by the compositions under study, measured in a 0.5 M NaCl solution after a 15-minute exposure are shown in Figures 2–4. The kinetic parameters of the steel electrode with the coatings under study and their protective efficiency are presented in Table 3.

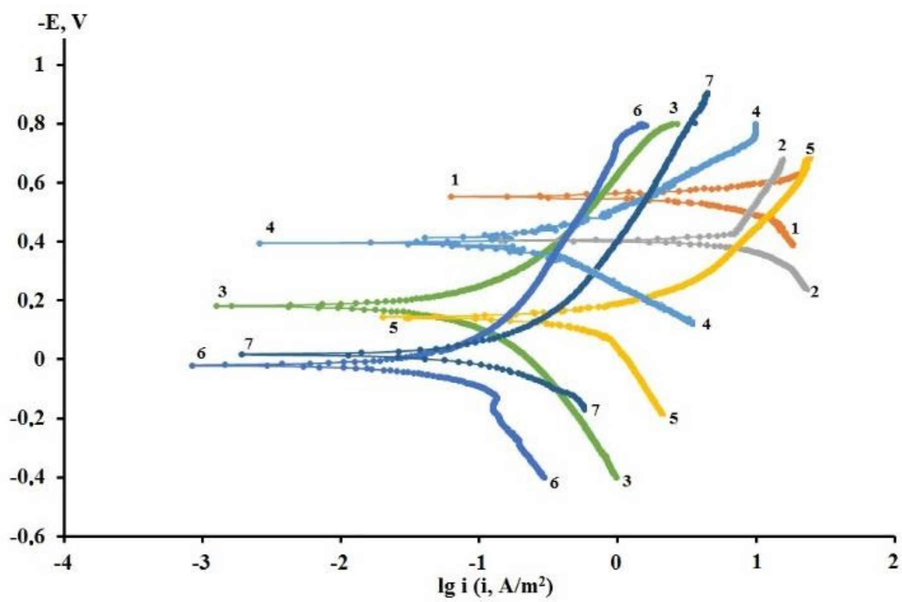

Figure 2. Polarization curves of a steel electrode covered with the compositions, based on I-20A oil, in a 0.5 M NaCl solution: 1 – no coating; 2 – I-20A; (3–7) I-20A with M-531, wt.%: 3 – 100, 4 – 3, 5 – 5, 6 – 7, 7 – 10.

The corrosion potential (E_{corr}) of a steel electrode without coating is –0.544 V, the corrosion current density in the solution (i_{corr}) is 7.08 A/m^2. The slope of the Tafel section of the anodic polarization curve is 55 mV, which is close to the value of 2.3 RT/F (where R is the universal gas constant; T is the absolute temperature; F is Faraday constant) typical of the anode ionization of iron in weakly acidic chloride media in the absence of passivation. E_{corr} increases to –0.38 V in the presence of a film of fresh I-20A oil, and the i_{corr} decreases to 5.015 A/m^2, the Tafel slope coefficient of the anodic polarization curve is 68 mV, which is also close to the value of 2.3 RT/F. But the protective efficiency of such a coating (Z) is small, only 29% (Table 3). Application of a film of fresh motor oil $M10G_{2(k)}$ increases the

E_{corr} almost like I-20A, the WMO film promotes a shift of the E_{corr} to –0.29 V (Figures 3 and 4, Table 3). The Tafel slope coefficients of the anodic polarization curves are almost the same for all three types of the oil coatings. The protective efficiency of the $M10G_{2(k)}$ and WMO oil films is 55 and 84%, respectively (Table 3).

Table 3. Electrochemical characteristics of St3 steel, covered with the oil compositions with M-531, and their protective efficiency in a 0.5 M NaCl solution.

Coating composition	**$-E_{corr}$, V**	**i_{corr}, A/m^2**	**b_a, V**	**b_c, V**	**Z, %**
Without coating	0.554	7.080	0.055	0.042	–
M-531	0.200	0.035	0.087	0.160	99
I-20A	0.380	5.015	0.068	0.125	29
I-20A + 3 wt.% M-531	0.400	0.398	0.075	0.142	94
I-20A + 5 wt.% M-531	0.158	0.200	0.069	0.100	97
I-20A + 7 wt.% M-531	-0.010	0.032	0.085	0.175	99
I-20A + 10 wt.% M-531	0.033	0.035	0.080	0.128	99
$M10G_{2(k)}$	0.390	3.162	0.069	0.077	55
$M10G_{2k}$ + 3 wt.% M-531	0.294	0.501	0.080	0.100	93
$M10G_{2k}$ + 5 wt.% M-531	0.300	0.501	0.080	0.100	93
$M10G_{2k}$ + 7 wt.% M-531	0.526	0.251	0.085	0.100	96
$M10G_{2k}$ + 10 wt.% M-531	0.333	0.774	0.070	0.143	89
WMO	0.290	1.122	0.069	0.100	84
WMO + 3 wt.% M-531	0.350	0.501	0.070	0.090	93
WMO + 5 wt.% M-531	0.238	0.158	0.065	0.080	98
WMO + 7 wt.% M-531	0.242	0.050	0.065	0.090	99
WMO + 10 wt.% M-531	0.263	0.060	0.065	0.080	99

The introduction of M-531 additives into the oils under study significantly reduces corrosion currents and, accordingly, increases a protective efficiency of the oil films (Table 3). Already at the concentration of M-531 equal to 3 wt.%, it is possible to achieve $Z = 93–94\%$. The protective effect increases with the further growth of a concentration of M-531 and reaches 99% at 7–10 wt.% of the inhibitor in the I-20A and WMO oils. The same protective effectiveness is provided by the coating of an individual M-531. For composition based on $M10G_{2(k)}$, the maximum protective efficiency equal to 96% is observed with the concentration of M-531, equal to 7 wt.% (Table 3).

From the analysis of the polarization curves it follows that in the presence of oil compositions with M-531, inhibition of both electrode processes on the steel electrode is observed. However, a displacement of the corrosion potential in a positive direction indicates a predominant slowdown of the anode reaction.

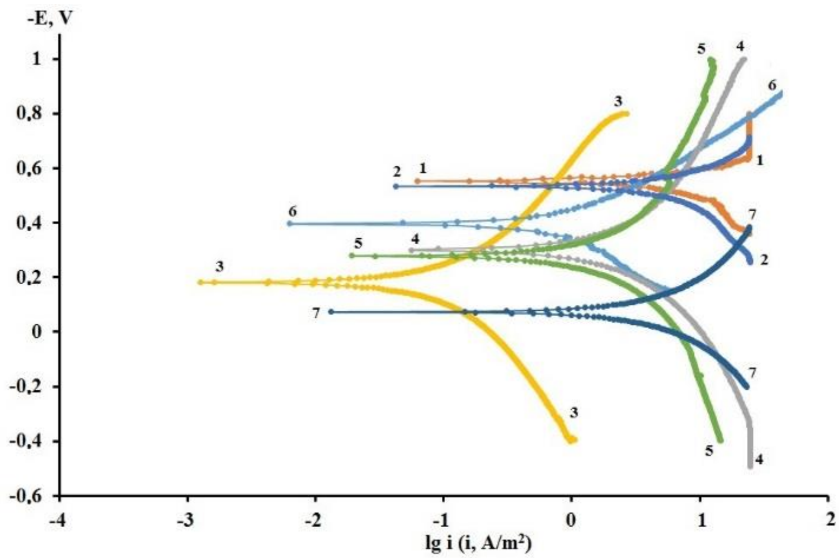

Figure 3. Polarization curves measured on a steel electrode covered with the compositions based on $M10G_{2(k)}$ in a 0.5 M NaCl solution: 1 – no coating; 2 – $M10G_{2(k)}$; (3–7) $M10G_{2(k)}$ with M-531, wt.%: 3 – 100, 4 – 3, 5 – 5, 6 – 7, 7 – 10.

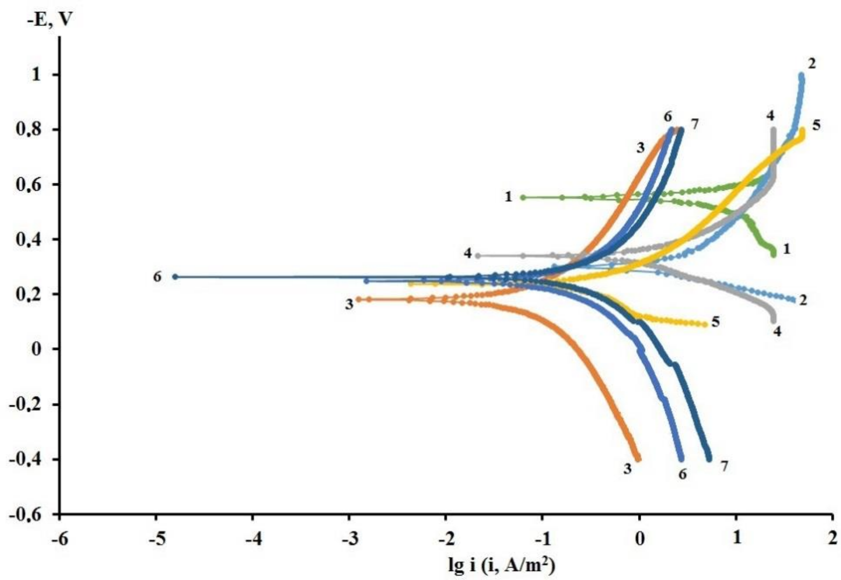

Figure 4. Polarization curves measured on a steel electrode coated the compositions based on WMO in a 0.5 M NaCl solution: 1 – no coating; 2 – WMO; (3 – 7) WMO with M-531, wt.%: 3 – 100, 4 – 3, 5 – 5, 6 – 7, 7 – 10.

The results of accelerated corrosion tests in the thermal moisture chamber G-4 for 960 hours showed (Table 4) that all the oil compositions inhibited by M-531 (3–10 wt.%) demonstrate a very high protective effect (97–100%). The increase in the value of *Z* with an increase in the concentration of M-531 in the compositions is consistent with the corresponding increase in their work of adhesion. The smallest work of adhesion is typical for the compositions based on $M10G_{2(k)}$, which is reflected in a higher concentration of the additive, corresponding to the same *Z* value as in the rest of the compositions.

Table 4. Experimental results of corrosion tests of the steel samples with the coatings studied in the thermal moisture chamber G-4. Exposure time is 960 hours.

C_{M-531}, wt.%	Protective effect of the oil compositions					
	I-20A		$M10G_{2(k)}$		WMO	
	K, g/(m²·h)	*Z*, %	*K*, g/(m²·h)	*Z*, %	*K*, g/(m²·h)	*Z*, %
Control	0.0409	–	0.0409	–	0.0409	–
0	0.0188	54	0.0294	28	0.0010	97
3	0.0005	98	0.0011	97	0.0006	98
5	0.0004	99	0.0004	99	0.0001	~100
7	0.0003	~100	0.0004	99	0.0001	~100
10	0.0003	~100	0.0003	~100	0.0001	~100
15	0.0003	~100	~100	~100	0.0001	~100
20	0.0002	~100	~100	~100	0.0001	~100

According to the results of gravimetric corrosion tests of steel samples protected by the coatings in a 0.5 M NaCl solution for a duration of 336 hours (Table 5), the protective effectiveness of the oil compositions is lower than in the G-4 thermal moisture chamber and in a chloride solution during short-term exposure (according to the polarization curves).

Table 5. The results of gravimetric corrosion tests in a 0.5 M NaCl solution at an exposure of 336 hours.

C_{M-531}, wt.%	Protective effect of the oil compositions					
	I-20A		$M10G_{2(k)}$		VMO	
	K, g/(m²·h)	*Z*, %	*K*, g/(m²·h)	*Z*, %	*K*, g/(m²·h)	*Z*, %
Control	0.0414	–	0.0414	–	0.0414	–
0	0.0422	20	0.0256	38	0.0240	42
3	0.0311	25	0.0240	42	0.0224	46
5	0.0224	46	0.0136	67	0.0145	65
7	0.0202	51	0.0103	75	0.0091	78
10	0.0149	64	0.0058	86	0.0016	96
15	0.0128	69	0.0050	88	0.0012	97
20	0.0952	77	0.0033	92	0.0012	97
100	0.0041	90	0.0041	90	0.0041	90

The reason, obviously, is the aggressive action of Cl^- ions, which are absent during tests in the G-4 thermal moisture chamber and do not fully manifest themselves when the samples are in the solution for a short time, as it was also observed in the presence of conservation materials of a different composition [7].

An increase in the concentration of M-531 in all the oils studied, as follows from Table 5, contributes to an increase in the protective effectiveness of the compositions, the lowest one for compositions based on I-20A and the highest one for compositions based on WMO. Coatings with 20 wt.% M-531 in $M10G_{2(k)}$, 10–20 wt.% M-531 in WMO provide values of protective effectiveness exceeding the *Z* values of the coatings with individual (100%) M-531. This is confirmed by the appearance of the samples after corrosion tests (Figure 5). The best results correspond to the coatings based on WMO.

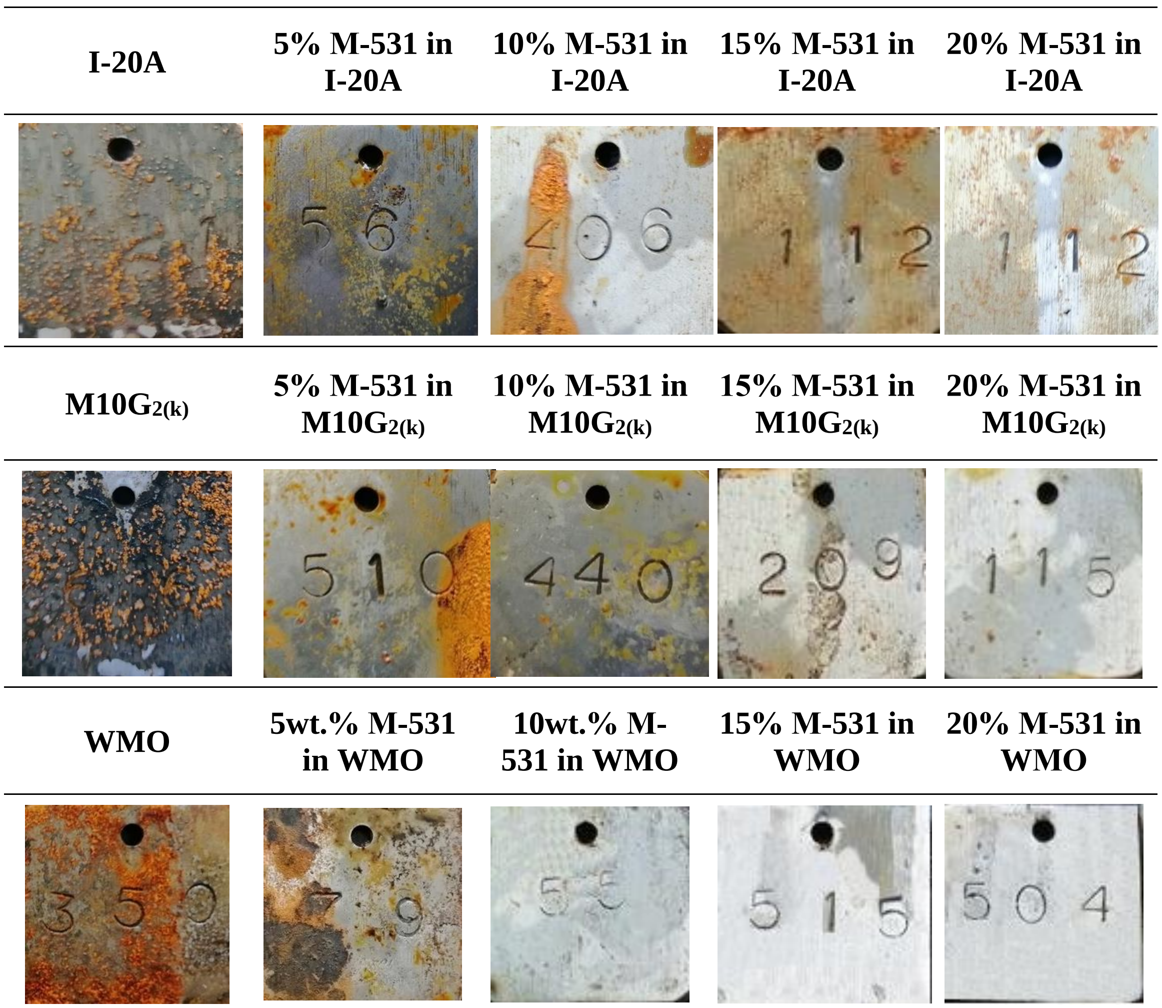

Figure 5. Appearance of the St3 steel samples, coated with the oil compositions, after testing in a 0.5 M NaCl solution for 336 hours.

The appearance of steel samples coated with the oil compositions containing 20 wt.% M-531 after testing in a salt spray chamber (SSC) is presented in Table 6. An uncoated sample was completely susceptible to corrosion after 8 hours. The first signs of corrosion appeared on the samples coated with the composition based on I-20A oil after 8 hours of exposure, and on the samples with coatings based on the MMO and $M10G_{2(k)}$ oils after 16 hours.

Table 6. Appearance of the St3 steel samples, coated with the oil compositions, after exposure to a salt fog chamber.

Exposure time, hour	**Coating**			
	Without coating	**20 wt. % M-531 in WMO**	**20 wt. % M-531 in I-20A**	**20 wt.% M-531 in $M10G_{2(k)}$**
8				
16				
24				
32				
40				
48				

With further exposure to SSC, the area susceptible to corrosion increases on all the coated specimens. This is especially noticeable on the samples coated with a composition based on I-20A oil, the entire area of which turns out to be rusted by 48 hours of exposure. The greatest protective efficiency during tests in the SSC is provided by the compositions based on WMO.

The compositions based on I-20A oil are better wetted by water than others, are characterized by the highest values of σ and $\sigma \cdot \cos\theta_1$, which indicate the highest driving force *P* of the process of penetration of the aqueous medium through the oil film to the metal surface (formula (4)), have the lowest viscosity. Obviously, this determines their lowest protective effectiveness compared to other compounds.

Conservation materials based on WMO oil containing 10–20 wt.% M-531 additive were used in the tests of steel samples in an open site from January to September. The results are shown in Figure 6 and Table 7.

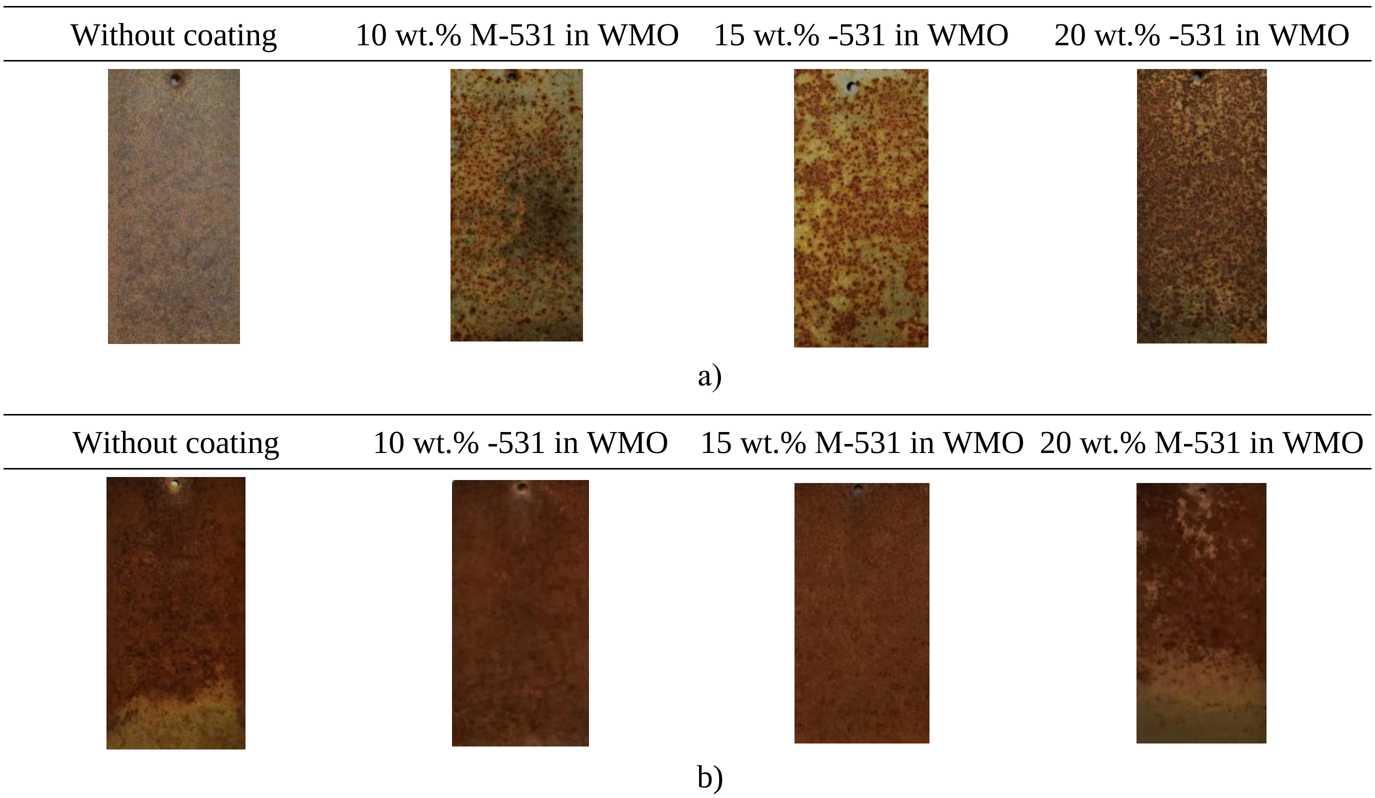

Figure 6. Appearance of St3 steel samples after three months (a) and nine-months (b) tests in an open site with coatings based on WMO with 10–20 wt.% M-531 additive.

Active corrosion processes began on steel samples in an open atmosphere, as follows from the data presented, and after 3 months all the samples were covered with corrosion products. Obviously, the compositions based on the M-531 additive containing a volatile inhibitor are not effective under conditions of prolonged exposure of the samples protected by them in the open atmosphere. They can be used for short-term inter-operational storage of metal products.

Table 7. Results of the tests of St3 samples coated with the WMO oil compositions, containing M-531 additive, in an open site.

No.	$C_{M\text{-}531}$**, wt.%**	**Test duration, months**			
		3		**9**	
		***K*, g/(m²·h)**	***Z*, %**	***K*, g/(m²·h)**	***Z*, %**
1	Without coating	0.0060	–	0.0050	–
2	10	0.0023	62	0.0021	58
3	15	0.0017	71	0.0016	68
4	20	0.0023	62	0.0015	70

Protective efficacy was 68–70% after 9 months, as well as after 3 months for the formulations based on WMO oil with 15–20 wt.% M-531. This closeness of the *Z* values may be due to the fact that the formed corrosion products protect the metal from further destruction.

Conclusion

The protective effectiveness of steel St3 coatings with conservation materials based on petroleum oils and M-531 additive, which is an oil composition with volatile corrosion inhibitors, has been studied. The compositions studied well wet a steel surface with a contact angle $\theta<30°$, themselves are wetted by water with $\theta<48°$ and are characterized by low surface tension with $\sigma<27$ mN/m.

A temperature dependence of the kinematic viscosity of the oil compositions studied in the range of 20–60°C is described by the Reynolds–Filonov formula.

A protective effect *Z* of the coatings studied upon short-term exposure to a 0.5 M NaCl solution, calculated on the basis of polarization curves, is 99% at 7–10 wt.% M-531 in the I-20A and WMO oils. The same high value of *Z* was also obtained during the corrosion tests in a thermal moisture chamber for 960 hours.

Long-term corrosion tests (336 hours) in a 0.5 M NaCl solution make it possible to achieve a protective effect above 90% only for coatings based on WMO with 10–20 wt.% M-531 additive. A coating of the steel samples with the M-531 individual composition is characterized by a *Z* value of 90%.

Tests in a salt spray chamber of steel samples with the oil coatings containing 20 wt.% M-531 additive showed that the best protection is characteristic of the composition based on WMO: the first signs of corrosion appeared after 16 hours. The same composition under natural conditions turned out to be ineffective: already after 3 months, the samples protected by it were completely covered with corrosion products, indicating the inexpediency of using an additive with volatile inhibitors in an open atmosphere. They can be used for short-term inter-operational storage of metal products.

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