Dorothy Rajendran[1], Thankappan Sasilatha[1], Susai Santhammal Rajendran[2,5]*, Abdulhameed Al-Hashem[3], Caslav Lacnjevac[4],Gurmeet Singh[6]

[1]*AMET University, Department of EEE, East Coast Road, Chennai, India,* [2]*Department of Chemistry, St. Antony's College of Arts and Sciences for Women Thamaraipady, Dindigul–624005,Tamil Nadu, India,* [3]*Petroleum Research Centre, Kuwait Institute for Scientific Research , Kuwait,* [4]*University of Belgrade, Faculty of Agriculture, Belgrade, Serbia,* [5,6] *Pondicherry University, Puducherry, India*

Inhibition of corrosion of mild steel hull plates immersed in natural sea water by sandalwood oil extract of some natural products

ABSTRACT

The hull plates of the ship made of mild steel (MS) are always in contact with sea water are always in contact with aggressive ions such as chloride ions present in sea water.The corrosion resistance of the hull plates of the ship made of mild steel has been investigated by polarization study. Sandalwood oil extract containing 5 g each of Cardamom (disambiguation), Clove (disambiguation), Nutmeg, India Sambrani (loban), Chrysopogon zizanioides, commonly known as vetiver and Camphor was used as corrosion inhibitor along with Trisodium citrate (TSC), sodium dihydrogen phosphate (SDP) and Zn^{2+}. The corrosion resistance was measured in the absence and presence of various inhibitor systems: Trisodium citrate (TSC) 100 ppm+ Zn^{2+} 50ppm system, sodium dihydrogen phosphate (SDP) 100 ppm+ Zn^{2+} 50ppm system, Oil coated (3days) MS, Oil coated (3days) MS +TSC 100 ppm+ Zn^{2+} 50 ppm system and Oil coated (3days) MS +SDP100 ppm+ Zn^{2+} 50 ppm system were used. It is observed that when mild steel is immersed in SW+TSC 100 ppm+ Zn^{2+} 50ppm system , the corrosion resistance of MS increases. When mild steel is immersed in SW+ SDP 100 ppm+ Zn^{2+} 50ppm system , the corrosion resistance of MS increases. When mild steel is immersed in Oil coated (3days) MS in Sea water system , the corrosion resistance of MS increases. When mild steel is immersed in Oil coated (3days) MS in SW+TSC 100 ppm+ Zn^{2+} 50ppm system , the corrosion resistance of MS increases. When mild steel is immersed in Oil coated (3 days) MS in SW+ SDP 100 ppm+ Zn^{2+} 50ppm system , the corrosion resistance of MS increases. This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value. The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly. This implies that these inhibitor systems may be coated on mild steel surface used as hull plates to prevent corrosion of mild steel in sea water.

Keywords: *corrosion inhibition, hull plates, mild steel, sea water, green inhibitors, electrochemical study.*

1. INTRODUCTION

Hull plates made of mild steel are in contact with sea water all the time. So they undergo corrosion easily and severely. It is essential to protect them from corrosion. Several corrosion inhibitors have been used to control corrosion of metals and alloys in sea water [1-10].

Ahmad et al. [1] have reported synthesis, identification, theoretical and experimental studies for carbon steel corrosiron inhibition in sea water for new urea and thiourea derivatives linkage to 5-Nitro Isatin Moiety. Isatin derivative is chosen as the best inhibitor by polarization study [1].

Influence of inhibitors on reinforced bar corrosion of coral aggregate seawater concrete has been investigated [2]. The effect of inhibitors on corrosion behavior of reinforced bar in coral aggregate seawater concrete (CASC) in artificial sea water was studied by means of linear polarization resistance method (LPR) and electrochemical impedance spectroscopy (EIS).

Two inhibitors, calcium nitrite rust inhibitor (CN) and amino-alcohol rust inhibitor (AA) are used. The effect of inhibitors on corrosion behavior of reinforced bar in coral aggregate seawater concrete (CASC) in artificial sea water was studied by means of linear polarization resistance method (LPR) and electrochemical impedance spectroscopy (EIS) [2].Corrosion studies of zinc coated steel parts in sea water have been made by Karthikeyan and Jeeva. The corrosion inhibition of zinc coated steel sheets immersed in 3.5% NaCl with sulfisoxazole (SSZ) has been reported by weight loss, potentiodynamic polarization, electrochemical impedance spectroscopy, hydrogen permeation studies and quantum mechanical studies. Polarization studies confirmed that the inhibition mode follows a mixed type. The adsorption of the compounds onto the zinc coated steel surface obeyed Langmuir adsorption isotherm [3]. Managing corrosion in desalination plants has been discussed by Schorr et al. To protect the desalination plant (DP) materials, industrial paints, polymeric coatings and rubber linings compatible with the DP fluids are applied. Cathodic protection with sacrificial anodic metals or impressed direct electrical current and corrosion inhibitors are supplied [4]. In marine conditions, especially in the Arctic, the problems of reliability and safety of marine corrosion protection systems are relevant. Reliability can be enhanced by corrosion inhibitors. Phosphating compound with anode inhibitors have been used by Plaskeeva and Trusov[5].

Duduna et al. [6] have compared various adsorption isotherm models for allium cepa as corrosion inhibitor on austenitic stainless steel in sea water. The sorption data of the allium cepa extract obeyed Langmuir, Freundlich, Temkin, El-Awady and Adejo Ekwenchi isotherm of which Langmuir Isotherm gave the best model fit [6]. Shen et al. have made a Study of pitting corrosion inhibition effect on aluminum alloy in seawater by biomineralized film. The electrochemical results showed that the radius of the impedance arc of the alloy immersed in seawater with bacteria increased gradually with time. The bacteria promoted the formation of the $CaMg(CO_3)_2$ film, which blocked seawater from the alloy and consequently, inhibited pitting corrosion [7]. Xu et al. have investigated steel rebar corrosion in artificial reef concrete with sulphoaluminate cement. It has been observed that a 2% dosage of corrosion inhibitor can significantly decrease the steel rebar corrosion in a new artificial reef concrete (NARC) to a similar corrosion

degree of ordinary artificial reef concrete (ARC) [8]. Colloidal ZrO_2 nanoparticles have been used for corrosion protection of AA2024 in synthetic sea water by Elbasuney et al. Inhibition efficiency of 93.6% was achieved. It was noted that ZrO_2 could act as cathodic inhibitor by suppressing the dealloying of the intermetallic particles [9]. Corrosion-induced morphological changes and the mechanism of A3003 aluminum alloy in model sea water containing gluconates and zinc ions have been investigated by Otani et al. The XPS results also suggest that zinc ions in the solutions bond to the oxide film of aluminum alloy and zinc ions enhance the corrosion inhibition ability of the protective films of gluconates for aluminum alloy in model sea water [10].

The present work is undertaken to investigate the inhibition of corrosion of mild steel hull plates immersed in natural sea water by sandalwood oil extract of some natural products, namely, Cardamom (dismbiguation), Clove (dismbiguation), Nutmeg, India Sambrani (loban), Chrysopogon zizanioides, commonly known as vetiver and Camphor. Also, Trisodium citrate (TSC), sodium dihydrogen phosphate (SDP) and Zn^{2+} are used as corrosion inhibitors. The inhibition effect has been studied by polarization study. The important parameters involved in this study are linear polarization resistance (LPR) corrosion potential (E_{corr}) and corrosion current (I_{corr}). It is better to understand the meaning of these terms.

Linear polarization resistance (LPR)

A linear polarization resistance (LPR) [11] test is a corrosion rate monitoring method and it can give an indication of the corrosion resistance of materials in an aqueous environment. LPR tests are performed both in the static condition and under reciprocating motion.

In LPR tests, potential is shifted from 50mV below E_{corr} (more negative than E_{corr}) to 50 mV more positive than E_{corr}. Current flow between the specimen and the counter electrode is monitored. A linear relationship of potential and current values can be observed. The linear polarization resistance (LPR) can be interpreted as the inverse of the corrosion rate at the time of measurement.

As the polarization curve close to the free corrosion potential can be assumed to be linear, the linear polarization resistance can be determined as the quotient of electrode potential shift and resulting current flow.

For LPR measurements, a three-electrode setup consisting of a working electrode, a counter electrode, and a reference electrode is required.

The linear polarization resistance strongly depends on the geometry of the corrosion system, i.e., the size of the working electrode, the distance between working electrode and reference electrode, and the position of the reference electrode.

Measurements on corroding systems—both corrosion current measurements and linear polarization resistance measurements—allow qualitative or semiquantitative determination on time-dependent changes in corrosion activity.

In a three-electrode probe, one electrode serves as a test specimen, the second as an auxiliary electrode and the third as a reference electrode against which the potential of the specimen is precisely controlled. The current flow is across the test electrode and the auxiliary electrode. Such a probe minimizes errors due to IR drop and is particularly suited for liquids having poor ionic conductivity.

Linear polarisation resistance (LPR) methods

Linear polarisation resistance (LPR) methods can be used to characterise a material medium pair by scanning the current–potential (i–E) domain. The linear polarisation resistance method consists of applying to the metal very small voltage variations (typically less than 30 mV) above and below its corrosion potential. Over this narrow range in the vicinity of the corrosion potential the current response obtained is linear. The polarisation resistance (Rp), defined as the slope of this current–potential curve, is therefore constant. According to the Stern– Geary equation (Stern and Geary, 1957), Rp is inversely proportional to the instantaneous corrosion rate, at least under certain conditions

$$Rp = B/i_{cor} \boxtimes when\ B = (\beta a \beta c / 2.3 (\beta a + \beta c))$$

where i_{cor} is the corrosion current and βa and βc the Tafel coefficients

Corrosion potential and corrosion current

The driving force for the flow of electrons is the difference in potential between the anode and the cathode. This process is most evident in the corrosion between two dissimilar metals (also known as bimetallic corrosion).

When a metal is immersed in a liquid (electrolyte), it adopts an electrode potential (also known as corrosion potential). The variance in potentials between the two metals results in a potential difference, which is responsible for the movement of electrons from the anode to the cathode.

The magnitude of the corrosion current in the system is proportional to the potential difference. That is, the greater the potential difference, the greater the corrosion current generated, and therefore the more severe the rate of corrosion at the anode.

In simple terms, corrosion potential is the characteristic or property of metal and nonmetal surfaces to lose electrons in the presence of an electrolyte. During the process of corrosion, two electrodes are formed spontaneously, a cathode and an anode.

Corrosion current and corrosion potential

The terms Eoc (Open Circuit Potential) and Ecorr (Corrosion Potential) are usually interchangeable, but Eoc is preferred. The value of either the anodic or cathodic current at Eoc is called the Corrosion Current, Icorr. If we could measure Icorr, we could use it to calculate the corrosion rate of the metal.

The corrosion rate

Corrosion rate is the speed at which any metal in a specific environment deteriorates. It also can be defined as the amount of corrosion loss per year in thickness. The speed or rate of deterioration depends on the environmental conditions and the type and condition of the metal under reference.

Corrosion potential is a mixed potential (also an open-circuit potential or rest potential) at which the rate of anodic dissolution of the electrode equals the rate of cathodic reactions and there is no net current flowing in or out of the electrode. Corrosion current is the dissolution current at the corrosion potential.

2. EXPERIMENTAL

Composition of mild steel

The composition of mild steel used in this study is given in Table 1 (Done in steel company at Dindigul, Tamil Nadu , India). This mild steel is used in the construction of hull plates. The hull plates are in contact with sea water.

Table 1. Composition of mild steel

Tabela 1. Sastav mekog čelika

Element	Average, %	Abs. Std. Dev.	Ref. Std. Dev.	1	2
C	0.101	0.0014	1.4	0.102	0.1
Si	0.055	0.0021	3.89	0.053	0.056
Mn	1.629	0.0057	0.35	1.633	1.625
P	0.0087	0.0003	3.25	0.0085	0.0089
S	0.0028	0.0003	10.1	0.0026	0.003
Cr	0.036	0.0014	3.93	0.037	0.035
Mo	0.0086	0.00007	0.83	0.0086	0.0085
Ni	0.033	0.0007	2.18	0.033	0.32
Cu	0.0063	0.00007	1.13	0.0062	0.0063
Al	0.044	0.0014	3.21	0.043	0.045
As	0.0011	0	0	0.0011	0.011
B	0.0027	0.0005	18.68	<0.00010	<0.00010
Bi	<0.00010	0.00002	84.85	<0.0025	0.003
Ce	0.0032	0.0013	42.65	0.0041	0.0022
Co	0.011	0	0	0.011	0.011
Mg	0.0003	0	0	0.0003	0.0003
Nb	0.03	0.0007	2.4	0.029	0.03
Pb	0.0081	0.0013	15.71	0.0072	0.009
Sb	0.004	0.0004	8.95	0.0037	0.0042
Sn	0.0034	0	0	0.0034	0.0034
Ta	0.03	0.0071	23.57	0.025	0.035
La	0.0071	0	0	0.0071	0.0071
Ti	0.0035	0	0	0.0035	0.0035
V	0.138	0.0014	1.02	0.137	0.139
W	0.071	0,0078	11.03	0.076	0.065
Zn	0.0024	0	0	0.0024	0.0024
Zr	0.0051	0.0002	0.2	0.0052	0.0049
Se	<0.0005	0.0001	4.42	<0.0005	<0.0005
N	0.0093	0.00007	0.76	0.0092	0.0093
Ca	0.0014	0.0001	10.1	0.0013	0.0015
Te	0.0026	0.0025	97.91	<0.0010	0.0044
Fe	97.74	0	0	97.74	97.74

Sea water

The corrosion resistance of mild steel in sea water was investigated, before oil coating and after oil coating. The composition of sea water used in this study is given in Table 2. Sea water was collected in Bay of Bengal, located at Kanampadi, East Coast Road, Chennai, India (near AMET University, Kanampadi, East Coast Road, Chennai, India).

Table 2. Composition of sea water used in this study

Tabela 2. Sastav morske vode korišćene u ovoj studiji

S. No.	Physical Examination	Acceptable Limit	Permissible limit	Sample Value
1	Colour	–	–	Unobjectionable
2	Odour	Unobjectionable		Unobjectionable
3	Turbidity NT Units	1	5	0.2
4	Total Dissolved Solids mg/1	500	2000	29400
5	Electrical Conductivity micro mho/cm	–	–	42000
6	pH	6.5–8.5	6.5–8.5	7.46
7	pH Alkalinity as $CaCO_3$	–	0	0
8	Total Alkalinity as $CaCO_3$	200	600	140
9	Total Hardness as $CaCO_3$	200	600	4000
10	Calcium as Ca	75	200	1200
11	Manganese as Mn	30	100	240
12	Iron as Fe	0.1	1	0
13	Magnesium as Mg	0.1	0.3	NT
14	Free Ammonia as NH_3	0.5	0.5	0.48
15	Nitrite as NO_2	0.5	0.5	0.104
16	Nitrate as NO_3	45	45	25
17	Chloride as Cl	250	1000	15000
18	Fluoride as F	1	1.5	1.8
19	Sulphate as SO_4	200	400	1170
20	Phosphate as PO_4	0.5	0.5	1.47
21	Tids Test 4hrs as O_2	–	–	NT

Preparation of inhibitor (Oil containing extracts of plant materials)

5 g Each of Cardamom (disambiguation), Clove (disambiguation), Nutmeg, India Sambrani (loban), Chrysopogon zizanioides, commonly known as vetiver and Camphor were boiled along with sandalwood oil for 15 minutes in an iron vessel. The suspended impurities were removed by filtration. The total volume of the oil extract of the above ingredients was 100 ml. This oil extract of the plant materials was used in the present study as corrosion inhibitor.

The main active ingredients of the above materials[12] are given in Table 3, and their structures are shown in Figure 1.

Table 3. Ingredients of natural products

Tabela 3. Sastojci prirodnih proizvoda

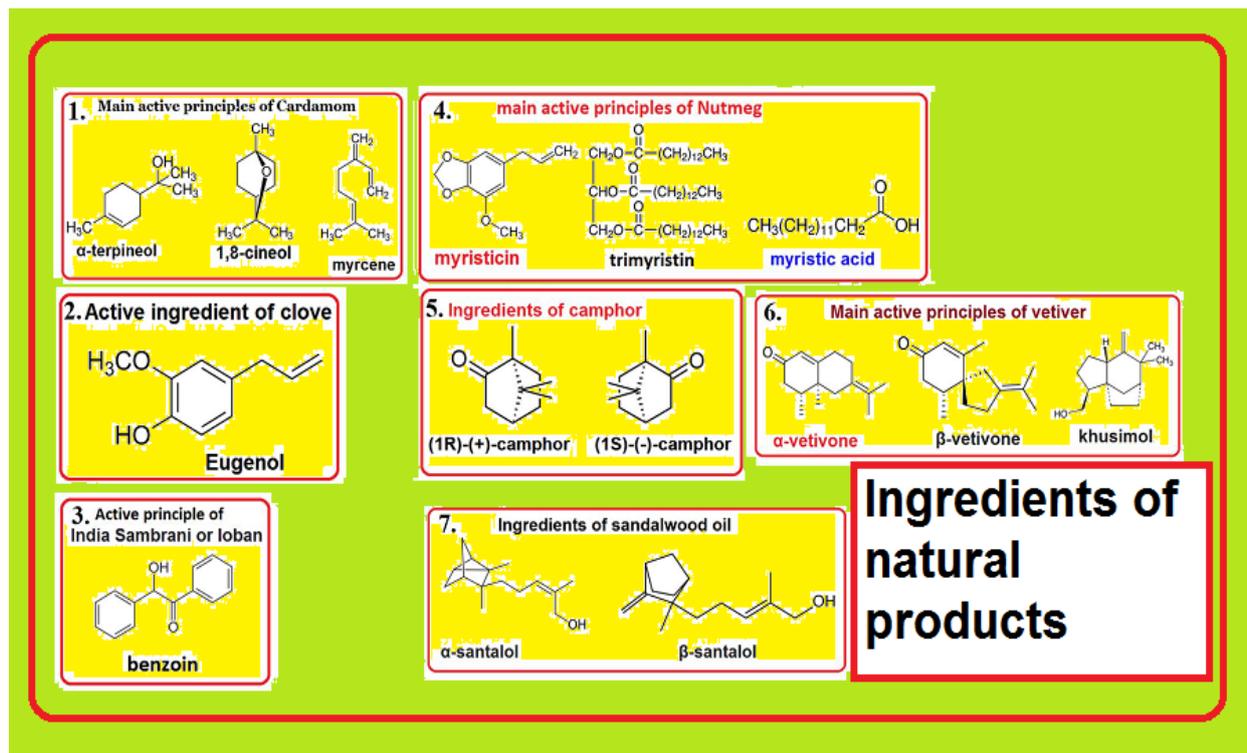| S. No	Natural products	Ingredients
1	Cardamom	α-terpineol, myrcene, 1,8-cineol
2	Clove	Eugenol
3	Nutmeg	Myristicin, tremyristicin, myristic acid
4	India Sambrani (loban)	Benzoin
5	Vetiver	α-vetivone, β-vetivone, khusimol
6	Camphor	(+)-Camphor, (–)-Camphor
7	sandalwood oil	α-santalol, β-santalol

Figure 1. Ingredients of natural products: 1 – active principles of cardamom; 2 – active principles of clove;
3 – active principles of loban; 4 – active principles of nutmeg; 5 – active principles of camphor;
6 – active principles of vetiver; 7 – active principles of sandalwood oil.

Slika 1. Sastojci prirodnih proizvoda: 1 – aktivni delovi kardamoma; 2 – aktivni delovi karanfilića;
3 – aktivni delovi lobana; 4 – aktivni delovi muskatnog oraščića; 5 – aktivni delovi kamfora;
6 – aktivni delovi vetivera; 7 – aktivni delovi ulja sandalovine.

Electrochemical study

In the present work the corrosion resistance of mild steel specimens immersed in various test solutions was measured by Polarization study.

Polarization study

Polarization studies were carried out in a CHI Electrochemical work station model 660A. It was provided with automatic iR compensation facility. A three electrode cell assembly was used (Figure 2). The working electrode was mild steel. A SCE was the reference electrode. Platinum was the counter electrode. From polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Tafel slopes anodic = b_a and cathodic = b_c and LPR (linear polarisation resistance) values were derived. The scan rate (V/S) was 0.01. Hold time at (E_{fcs}) was zero and quiet time (s) was 2.
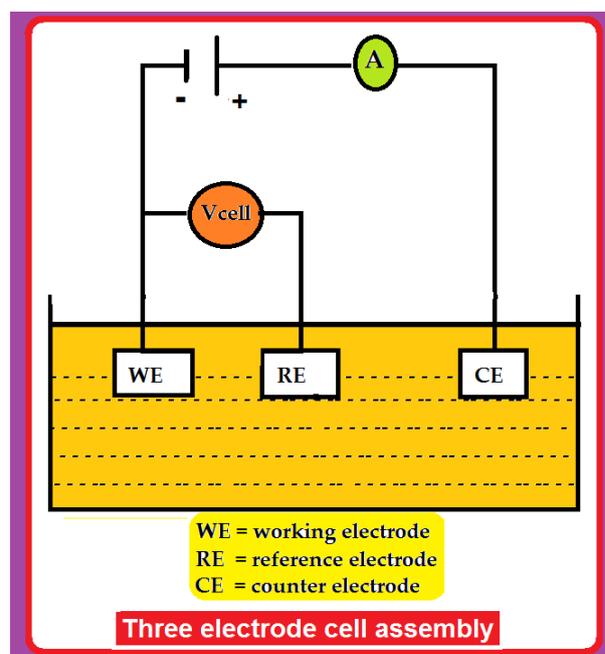

Figure 2. Three electrode cell assembly

Slika 2. Sklop ćelije sa tri elektrode

3. RESULTS AND DISCUSSION

Electrochemical study

The hull plates of the ship made of mild steel are always in contact with sea water, which contains aggressive ions such as chloride ions. Consequently the hull plates undergo corrosion. To prevent this kind of corrosion the hull plates were coated with an oil extract of natural products. The hull plate specimens were made of mild steel as mentioned in experimental section. The preparation of the oil extract has also been given in experimental section. The corrosion resistance of mild steel (hull plate) in sea water before and after oil coating has been evaluated by electrochemical study, namely, polarization study[13–37].

Analysis of polarisation curves

Polarisation study has been used to notice the formation of protective film on the metal surface. When a protective film is formed on the metal surface, the linear polarisation resistance (LPR) increases and the corrosion current (I_{corr}) decreases (Figure 3).
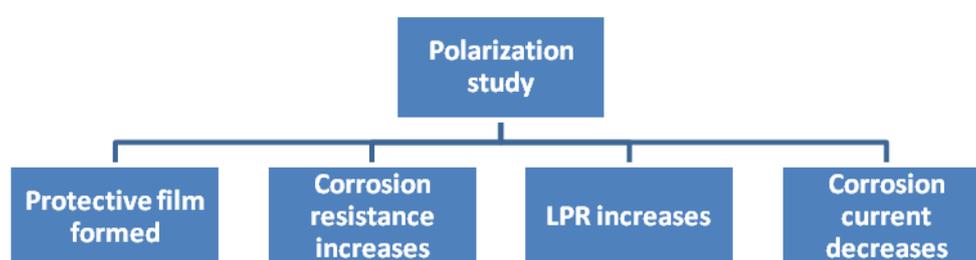

Figure 3. Correlation among corrosion parameters in polarization study

Slika 3. Korelacija između parametara korozije u proučavanju polarizacije

Corrosion parameters derived from polarisation study, namely corrosion potential (E_{corr}), Tafel slopes (b_c, b_a), Linear Polarisation Resistance (LPR) values and Corrosion Current (I_{corr}) values are given in Table 4. The polarisation curves (Tafel plots) of mild steel (hull plate) immersed in sea water in the absence and presence of oil coating containing plant extract are shown in Figures 4-9.

Table 4. Corrosion parameters of mild steel (hull plate) immersed in sea water (SW) in the absence and presence of oil containing plant extracts, obtained by Polarization study

Tabela 4. Parametri korozije mekog čelika (ploča trupa) potopljenog u morsku vodu (SV) u odsustvu i prisustvu biljnih ekstrakata koji sadrže ulje, dobijeni polarizacionom studijom

| System	E_{corr} mV vs SCE	b_c mV/decade	b_a mV/decade	LPR Ohm.cm^2	I_{corr} A/cm^2
MS in Sea water	-875	106	223	1630	1.918×10^{-5}
MS in SW+TSC 100 ppm+ Zn^{2+} 50ppm	-801	126	219	3045	1.140×10^{-5}
MS in SW+SDP 100 ppm+ Zn^{2+} 50ppm	-755	160	164	2498	1.408×10^{-5}
Oil coated (3days) MS in Sea water	-668	196	093	3486	0.7835×10^{-5}
Oil coated (3days) MS in SW+TSC 100 ppm+ Zn^{2+} 50ppm	-518	179	234	10026	0.4403×10^{-5}
Oil coated (3days) MS in SW+SDP100 ppm+ Zn^{2+} 50 ppm	-576	151	172	10664	0.3283×10^{-5}
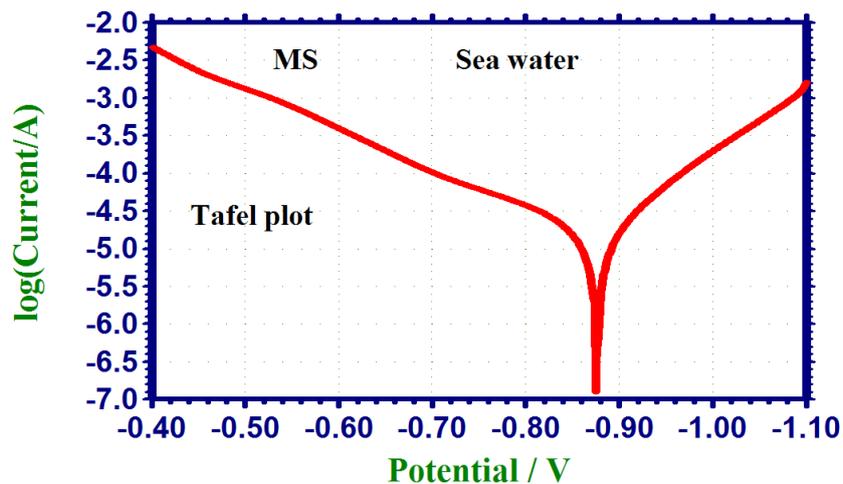
Figure 4. Tafel plot of mild steel immersed in sea water

Slika 4. Tafel kriva za meki čelik uronjen u morsku vodu

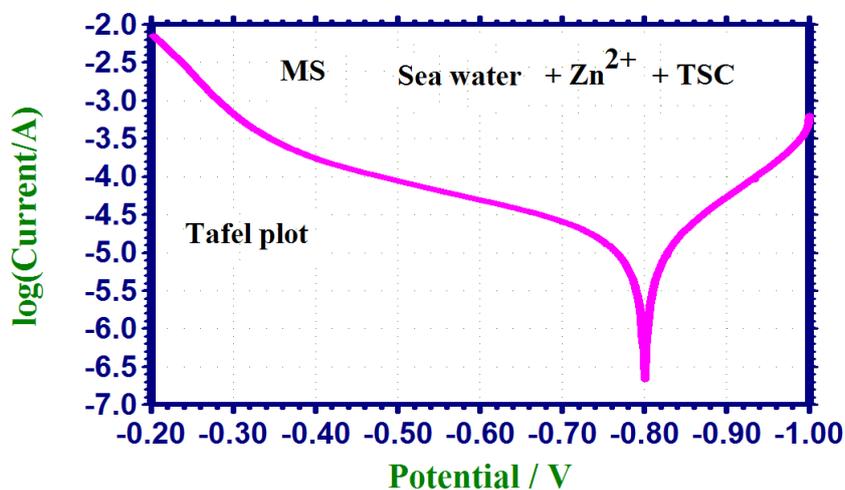*Figure 5. Tafel plot of mild steel immersed in sea water + TSC + Zn [2+]*

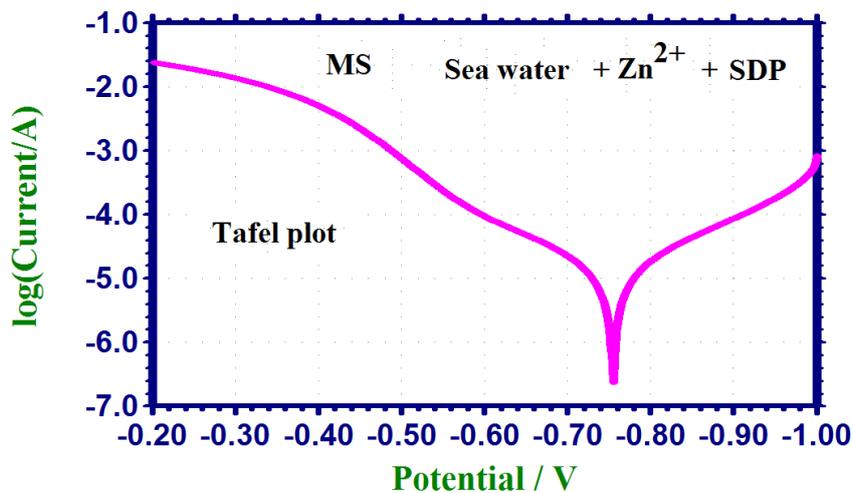*Slika 5. Tafel-ova kriva za meki čelik uronjen u morsku vodu + TSC + Zn^{2+}*

Figure 6. Tafel plot of mild steel immersed in sea water + SDP + Zn [2+]

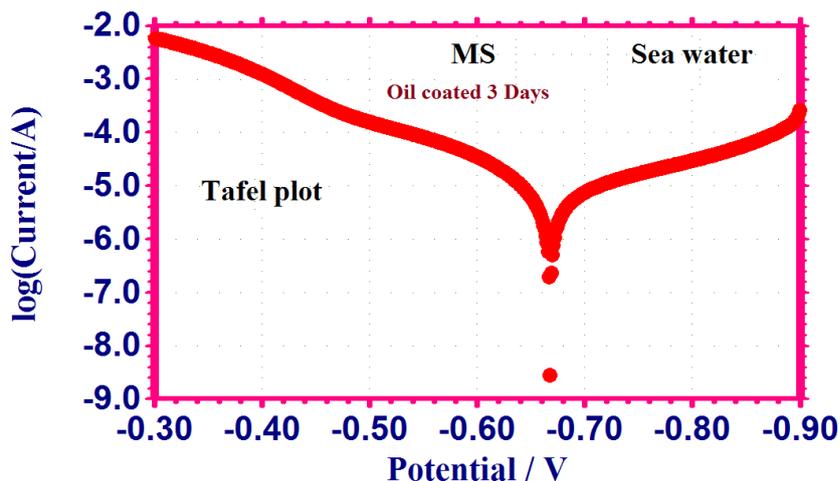*Slika 6. Tafelova kriva za meki čelik uronjen u morsku vodu + SDP + Zn [2+]*

Figure 7. Tafel plot of oil coated (3 Days) mild steel immersed in sea water

Slika 7. Tafelova kriva za meki čelik obloženog uljem (3 dana) uronjen u morsku vodu
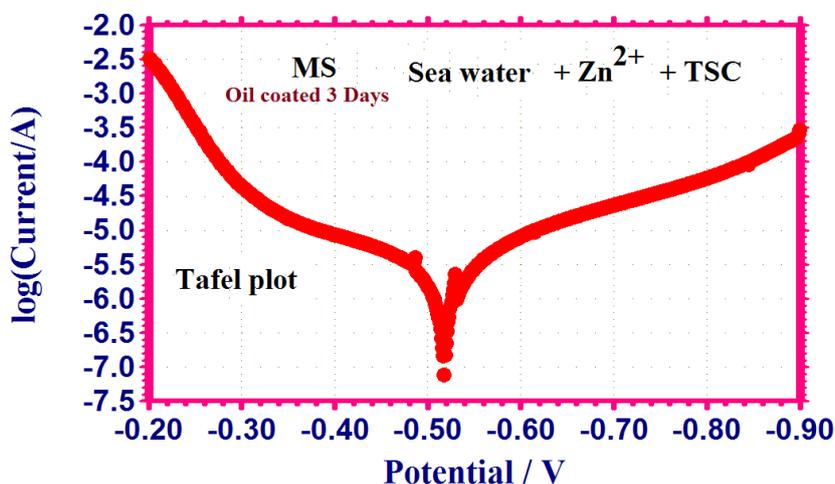

Figure 8 . Tafel plot of oil coated (3 Days) mild steel immersed in sea water + TSC + Zn $^{2+}$

Slika 8. Tafel-ova kriva za meki čelik obloženog uljem (3 dana) uronjenog u morsku vodu + TSC + Zn^{2+}
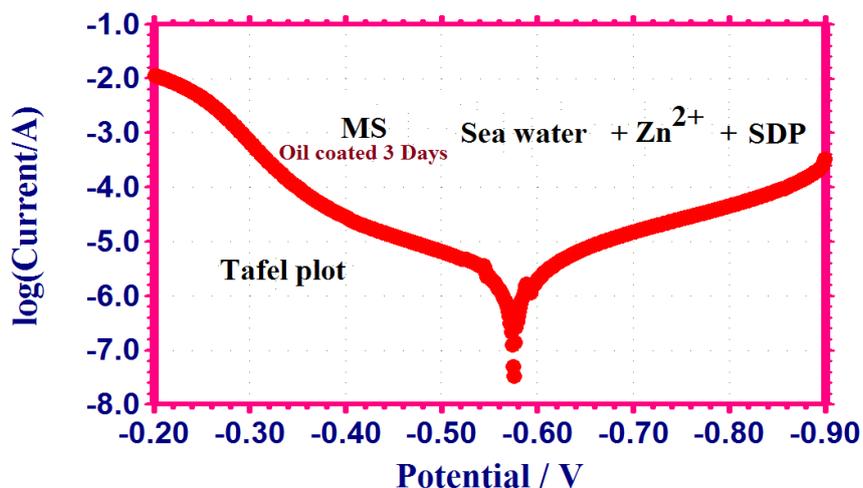

Figure 9. Tafel plot of oil coated (3 Days) mild steel immersed in sea water + SDP + Zn^{2+}

Slika 9. Tafel-ova kriva za meki čelik obloženog uljem (3 dana) uronjenog u morsku vodu + SDP + Zn^{2+}

It is observed from Table 4, that when mild steel is immersed in sea water the corrosion potential is -875 mV vs SCE. The LPR value is 1630 Ohm.cm^2. The corrosion current is 1.918x10^{-5} A/cm^2

MS in SW+TSC 100 ppm + Zn^{2+} 50 ppm system

When mild steel is immersed in SW+TSC 100 ppm+ Zn^{2+} 50 ppm system, the corrosion resistance of MS increases. This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value. The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly.

MS in SW+ SDP 100 ppm + Zn^{2+} 50 ppm system

When mild steel is immersed in SW+ SDP 100 ppm+ Zn^{2+} 50 ppm system, the corrosion resistance of MS increases. This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value. The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly.

Oil coated (3days) MS in Sea water

When mild steel is immersed in Oil coated (3days) MS in Sea water system , the corrosion resistance of MS increases. This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value. The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly.

Oil coated (3 days) MS in SW + TSC 100 ppm + +Zn^{2+} 50ppm

When mild steel is immersed in Oil coated (3days) MS in SW+TSC 100 ppm+ Zn^{2+} 50ppm system , the corrosion resistance of MS increases. This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value. The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly.

Oil coated (3days) MS in SW + SDP100 ppm + +Zn^{2+} 50ppm

When mild steel is immersed in Oil coated (3days) MS in SW+ SDP 100 ppm+ Zn^{2+} 50ppm system , the corrosion resistance of MS increases. This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value. The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly.

The corrosion potential values, the LPR values and corrosion current values of mild steel immersed in various test solutions are compared in Figures 10-12 respectively.

Implication

These inhibitor systems may be coated on mild steel surface used as hull plates to prevent corrosion of mild steel in sea water.
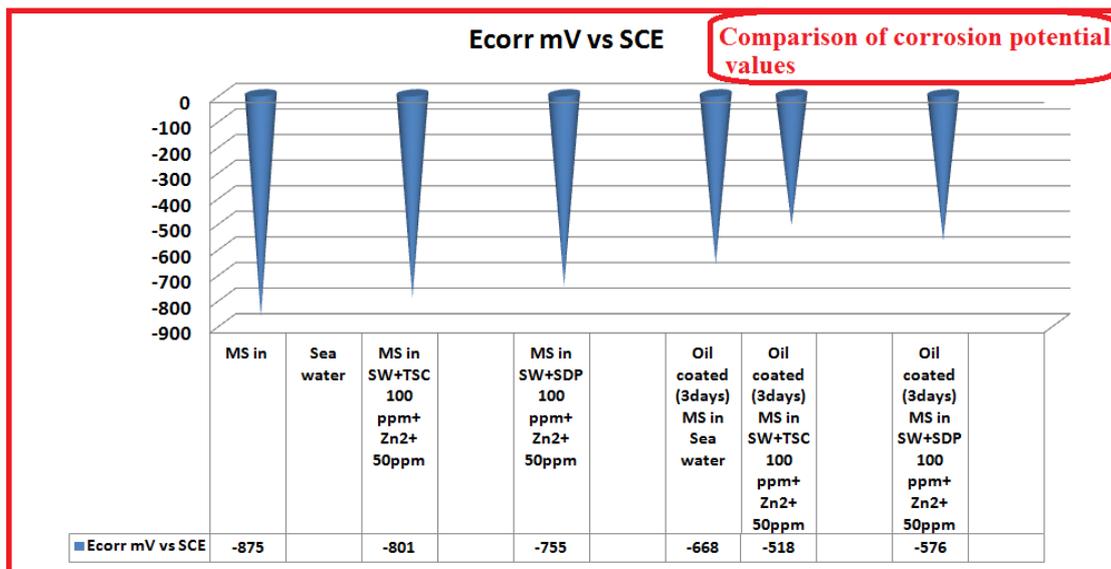

Figure 10. Comparison of corrosion potentials of mild steel immersed in various test solutions

Slika 10. Poređenje potencijala korozije mekog čelika uronjenog u različita ispitivana rastvora
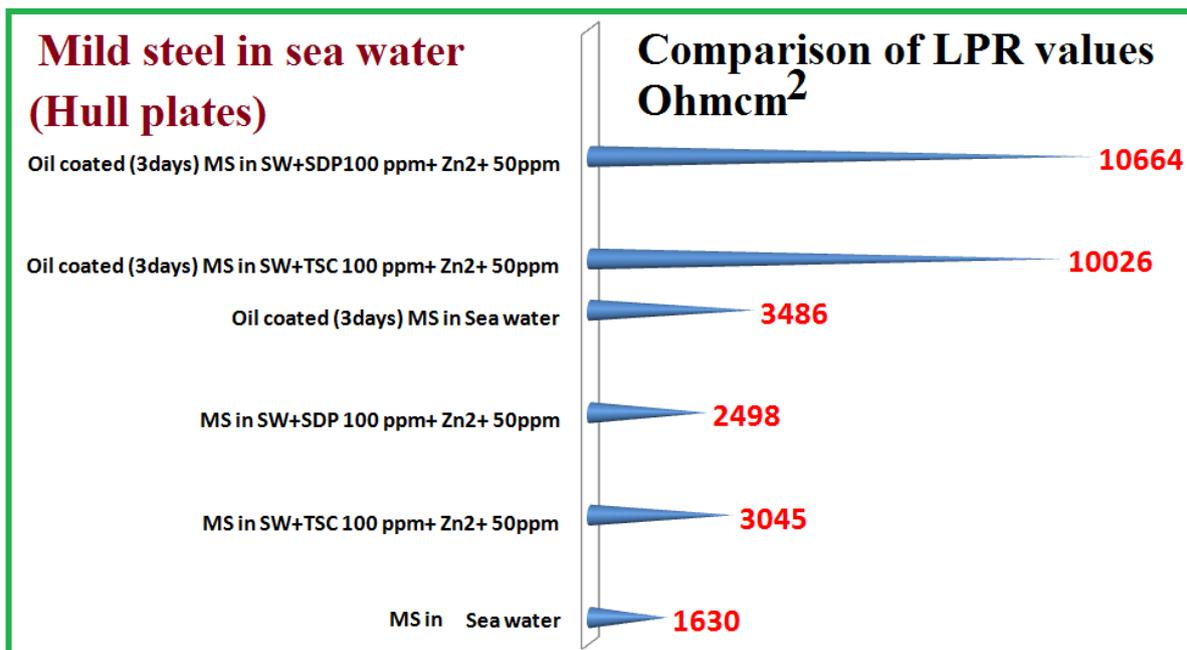
Figure11 . Comparison of LPR values

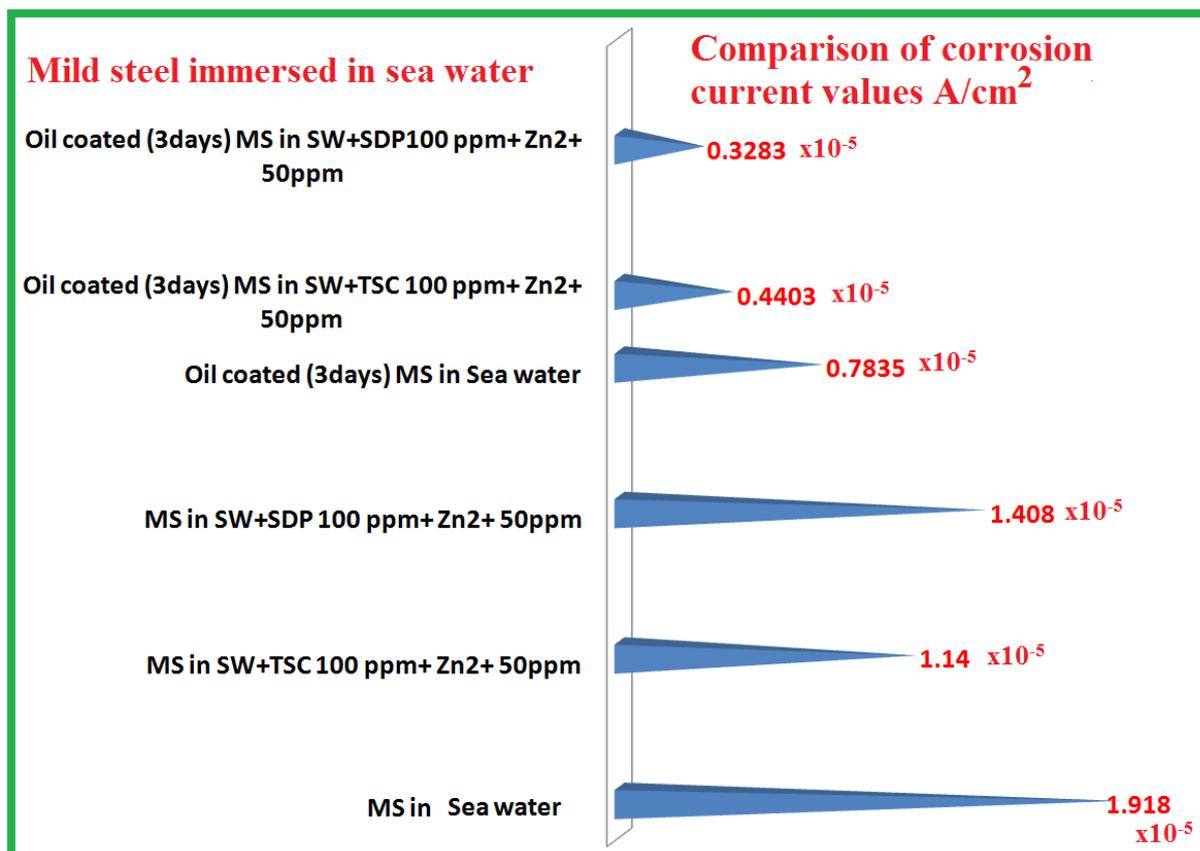*Slika 11. Poređenje vrednosti LPR*

Figure12 . Comparison of corrosion current values

Slika 12. Poređenje vrednosti struja korozije

4. CONCLUSIONS

The hull plates of the ship made of mild steel (MS) are always in contact with sea water are always in contact with aggressive ions such as chloride ions present in sea water. The corrosion resistance of the hull plates of the ship made of mild steel has been investigated by polarization study. Sandalwood oil extract containing 5 g each of Cardamom (disambiguation), Clove (disambiguation), Nutmeg, India Sambrani (loban), Chrysopogon zizanioides, commonly known as vetiver and Camphor was used as corrosion inhibitor along with Trisodium citrate **(**TSC), sodium dihydrogen phosphate (SDP) and Zn^{2+}. The corrosion resistance was measured in the absence and presence of various inhibitor systems.

- Trisodium citrate **(**TSC) 100 ppm + Zn^{2+} 50ppm system, sodium dihydrogen phosphate (SDP) 100 ppm + Zn^{2+} 50ppm system, Oil coated (3days) MS, Oil coated (3days) MS +TSC 100 ppm + Zn^{2+} 50 ppm system and Oil coated (3days) MS +SDP100 ppm + Zn^{2+} 50 ppm system were used.

- It is observed that when mild steel is immersed in SW+TSC 100 ppm + Zn^{2+} 50ppm system , the corrosion resistance of MS increases.

- When mild steel is immersed in SW+ SDP 100 ppm + Zn^{2+} 50ppm system , the corrosion resistance of MS increases.

- When mild steel is immersed in Oil coated (3days) MS in Sea water system , the corrosion resistance of MS increases.

- When mild steel is immersed in Oil coated (3days) MS in SW+TSC 100 ppm + Zn^{2+} 50ppm system , the corrosion resistance of MS increases.

- When mild steel is immersed in Oil coated (3days) MS in SW+ SDP 100 ppm + Zn^{2+} 50ppm system , the corrosion resistance of MS increases.

- This is revealed by the fact that there is increase in LPR value and decrease in corrosion current value.

- The corrosion potential is shifted to anodic side. This indicates that in this inhibitor system, the anodic reaction of metal dissolution is controlled predominantly.

- This implies that these inhibitor systems may be coated on mild steel surface used as hull plates to prevent corrosion of mild steel in sea water.

5. REFERENCES

[1] A.H.Ahmad, R.M.Kubba, S.M.Hussain Al-Majidi (2019) Synthesis, identification, theoretical and experimental studies for carbon steel corrosion inhibition in sea water for new urea and thiourea derivatives linkage to 5-Nitro, Isatin Moiety Journal of Global Pharma Technology, 11(7), 117-132

[2] B.Da, H.Yu, H.Ma, Z.Wu (2019) Z Influence of inhibitors on reinforced bar corrosion of coral aggregate seawater concrete, Journal of the Chinese Society of Corrosion and Protection, 39(2), 152-159

[3] S.Karthikeyan, P.A.Jeeva (2019) Corrosion studies of zinc coated steel parts in sea water, Portugaliae Electrochimica Acta, 37(5), 307-315

[4] M.Schorr, B.Valdez, A.Eliezer, R.Salinas, C.Lora (2019) Managing corrosion in desalination plants, Corrosion Reviews, 37(2), 103-113

[5] E.Plaskeeva, V.Trusov (2019) Inhibited composition for work in marine conditions, E3S Web of Conferences, 121, 02011

[6] W.E.Duduna, O.N.Akeme, T.M.Zinipere (2019)Comparison of various adsorption isotherm models for allium cepa as corrosion inhibitor on austenitic stainless steel in sea water, International Journal of Scientific and Technology Research, 8(8), 961-964

[7] Y.Shen, Y.Dong, Y.Yang, L.Dong, Y.Yin (2020) Study of pitting corrosion inhibition effect on aluminum alloy in seawater by biomineralized film Bioelectrochemistry, 132, 107408

[8] Q.Xu, T.Ji, Z.Yang, Y.Ye [2019] Steel rebar corrosion in artificial reef concrete with sulphoaluminate cement, Construction and Building Materials,227,116685

[9] S. Elbasuney, M.Gobara, M.Zoriany, A.Maraden, I. Naeem (2019) Colloidal ZrO_2 nanoparticles for corrosion protection of AA2024, Environmental Nanotechnology, Monitoring and Management, 12, 100242.

[10] K.Otani, M.Sakairi, A.Kaneko, D.Nagasawa (2018) Corrosion - induced morphological changes and the mechanism of A3003 aluminum alloy in model sea water containing gluconates and zinc ions, Keikinzoku/ Journal of Japan Institute of Light Metals , 68(1), 16-21

[11] https://www.sciencedirect.com/topics/engineering/linear-polarisation-resistance

[12] https://www.fs.fed.us/wildflowers/ethnobotany/medicinal/ingredients.shtml.

[13] S.Rajendran, M.Agasta, R.B.Devi, B.S.Devi, K. Rajam, J.Jeyasundari (2009) Corrosion inhibition by an aqueous extract of Henna leaves (*Lawsonia Inermis L*), Zast. Mater*.,* 50(1), 77–84.

[14] A.C.C.Mary, S.Rajendran, J.Jeyasundari (2017) Influence of Coffee on the corrosion resistance of SS 316L, Ni-Ti alloy and thermoactive alloy in artificial saliva, Eur. Chem. Bull., 6, 232–237.

[15] V.Sribharathy, S.Rajendran, P.Rengan, R. Nagalakshmi (2013) Corrosion inhibition by an aqueous extract of Aloe vera (L) Burm F. (Liliaceae), Eur. Chem. Bull., 2, 471–476.

[16] R.Epshiba, A.P.P.Regis, S.Rajendran (2014) Inhibition of corrosion of carbon steel in a well water by sodium molybdate – Zn2+ system, Int. J. Nano Corros. Sci. Eng., 1, 1–11.

[17] N.Kavitha, P.Manjula (2014) Corrosion inhibition of water Hyacinth Leaves, Zn2+ and TSC on mild steel in neutral aqueous medium, Int. J. Nano Corros. Sci. Eng., 1, 31–38.

[18] R.Nagalakshmi, L.Nagarajan, R.J.Rathish, S.S. Prabha, N.Vijaya, J.Jeyasundari, S.Rajendran (2014) Corrosion resistance of SS316l in artificial urine in the presence of D-glucose, Int. J. Nano Corros. Sci. Eng., 1, 39–49.

[19] J.A.Thangakani, S.Rajendran, J.Sathiabama, R.M. Joany, R.J.Rathis, S.S.Prabha (2014) Inhibition of corrosion of carbon steel in aqueous solution containing low chloride ion by glycine – Zn^{2+} system, Int. J. Nano Corros. Sci. Eng., 1, 50–62.

[20] S.Gowri, J.Sathiyabama, S.Rajendran, J.A. Thangakani (2012) Typtophane as corrosion inhibitor for carbon steel in sea water, J. Chem., Biol. Phys. Sci., 4(2), 2223–2231.

[21] A.Nithya, P.Shanthy, N.Vijaya, R.J.Rathish, S.S. Prabha, R.M.Joany, S.Rajendran (2015) Inhibition of Corrosion of Aluminium by an aqueous extract of beetroot (Betanin), Int. J. Nano Corr. Sci. Eng., 2(1), 1–11.

[22] A.C.C.Mary, S.Rajendran, H.Al-Hashem, R.J. Rathish, T.Umasankareswari, J.Jeyasundari (2015) Corrosion Resistance Of Mild Steel In Simulated Produced Water In Presence Of Sodium Potassium Tartrate, Int. J. Nano Corr. Sci. Eng., 2(1), 42–50.

[23] A.Anandan, S.Rajendran, J.Sathiyabama, D. Sathiyaraj (2017) Influence of some tablets on corrosion resistance of orthodontic wire made of SS 316L alloy in artificial saliva, Int. J. Corros. Scale Inhib., 6(2), 132–141.

[24] C.O.Akalezi, C.E.Ogukwe, E.A.Ejele, E.E.Oguzie (2016) Mild steel protection in acidic media using

Mucuna pruriens seed extract, Int. J. Corros. Scale Inhib., 5(2),132–146.

[25] T.A.Onat, D.Yiğit, H.Nazır, M.Güllü, G.Dönmez (2016) Biocorrosion inhibition effect of 2-aminopyrimidine derivativeson SRB, Int. J. Corros. Scale Inhib., 5(3), 273–281.

[26] A.S.Fouda, M.A.El-Morsy, A.A.El-Barbary, L.E. Lamloum (2016) Study on corrosion inhibition efficiency of some quinazoline derivatives on stainless steel 304 in hydrochloric acid solutions, Int. J. Corros. Scale Inhib., 5(2), 112–131.

[27] V.I.Vigdorovich, L.E.Tsygankova, E.D.Tanygina, A.Yu.Tanygin, N.V.Shel (2016) Preservative materials based on vegetable oils for steel protection against atmospheric corrosion. I. Colza oil, Int. J. Corros. Scale Inhib., 5(1), 59–65.

[28] P.N.Devi, J.Sathiyabama, S.Rajendran (2017) Study of surface morphology and inhibition efficiency of mild steel in simulated concrete pore solution by lactic acid – Zn^{2+} system, Int. J. Corros. Scale Inhib., 6(1), 18–31.

[29] I.M.Zin, S.A.Korniy, A.R.Kytsya, L.Kwiatkowski, P.Ya.Lyutyy, Ya.I.Zin (2021) Aluminium alloy corrosion inhibition by pigments based on ion exchanged zeolite, Int. J. Corros. Scale Inhib., 10(2), 541–550.

[30] L.G.Knyazeva, L.E.Tsygankova, A.V Dorokhov, N.A.Kur'yato (2021) Protective efficiency of oil compositions with Cortec VpCI-368D, Int. J. Corros. Scale Inhib., 10(2), 551–561.

[31] S.Rajendran, M.K.Devi, A.P.P.Regis, A.J.Amalraj, J. Jeyasundari, M.Manivannan (2009) Electroplating using environmental friendly garlic extract: a case study, Zast. Mater., 50(2), 131–140.

[32] S.Rajendran, P.Chitradevi, S.Johnmary, A. Krishnaveni, S.Kanchana, L.Christy, R. Nagalakshmi, B.Narayanasamy (2010) Corrosion behaviour of SS 316L in artificial saliva in the presence of electral, Zast. Mater., 51(2), 149–158.

[33] M.Cenoui, I.Himer, R.Touir, M.Ebn Touhami, A.Dermaj, N.Hajjaji, H.El Kafssaoui (2010) Synergistic influence of molybdate ions on the inhibition of corrosion and scale of ordinary steel in cooling water system by new organic compound, Zast. Mater*.,* 51(1), 3-10

[34] N.Antony, H.Benita Sherine, S.Susai Rajendran, (2010) Investigation of the inhibiting effect of nano film by sodium meta silicate- Zn^{2+} system on the corrosion of carbon steel in neutral chloride solution, Zast. Mater*.,* 51(1), 11-18

[35] S.S.Rajendran, T.S.Muthumegala, M.Pandiarajan, P.Nithya Devi, A.Krishnaveni, J.Jeyasundari, B.

Narayana Samy, N.Hajara Beevi (2011) Corrosion resistance of SS316L in simulated concrete pore solution in presence of trisodium citrate, Zast. Mater., 52(2), 85-89.

[36] A.S.Fouda, G.Y.Elewady, A.EL-Askalany, K. Shalabi (2010) Inhibition of aluminum corrosion in hydrochloric acid media by three Schiff base compounds, Zast. Mater., 51(4), 205-219.

[37] S.Rajendran, V.Sribharathy, A.Krishnaveni, J. Jeyasundari, J.Sathiyabama, TS.Muthumegala, M. manivannan (2011) Inhibition effect of self assembled films formed by adipic acid molecules on carbon steel surface, Zast. Mater., 52(3), 163-172.

IZVOD

Sprečavanje korozije ploča od mekog čelika potopljenih u morsku vodu ekstraktom ulja nekih prirodnih proizvoda

Ploče trupa broda od mekog čelika (MČ) su uvek u kontaktu sa morskom vodom i uvek su u kontaktu sa agresivnim jonima, kao što su hloridni joni prisutni u morskoj vodi. Otpornost na koroziju ploča trupa broda od mekog čelika je istražen proučavanjem polarizacije. Ekstrakt ulja sandalovine, koji sadrži po 5 g kardamoma, karanfilića, muskatnog oraščića, Indija Sambrani (loban), Chrysopogon zizanioides, poznatijeg kao vetiver i kamfor, korišćen je kao inhibitor korozije zajedno sa trinatrijum citratom, natrijum dihidrogenom fosfat i Zn^{2+}. Otpornost na koroziju je merena u odsustvu i prisustvu različitih inhibitornih sistema: Trinatrijum citrat (TSC) 100 ppm+ Zn^{2+} 50 ppm sistem, natrijum dihidrogen fosfat (SDP) 100 ppm+ Zn^{2+} 50 ppm sistem, obložen uljem (3 dana) MČ, uljem premazan (3 dana) MČ +TSC 100 ppm+ sistem obložen ZN^{2+} 5 ppm+ sistem MS +SDP100 ppm+ Zn^{2+} 50 ppm. Primećeno je da kada je meki čelik uronjen u sistem SV+TSC 100 ppm + Zn^{2+} 50ppm, otpornost MČ na koroziju se povećava. Kada je meki čelik uronjen u sistem SV+ SDP 100 ppm + Zn^{2+} 50 ppm, otpornost MČ na koroziju se povećava. Kada se meki čelik uroni u MS obložen uljem (3 dana) u sistem morske vode, otpornost MČ na koroziju se povećava. Kada se meki čelik uroni u MS obložen uljem (3 dana) u sistem SV+TSC 100 ppm + Zn^{2+} 50ppm, otpornost MČ na koroziju se povećava. Kada se meki čelik uroni u MS obložen uljem (3 dana) u sistem SV+ SDP 100 ppm + Zn^{2+} 50 ppm, otpornost MČ na koroziju se povećava. Ovo se objašnjava činjenicom da dolazi do povećanja vrednosti LPR i smanjenja vrednosti struje korozije. Potencijal korozije se pomera na anodnu stranu. Ovo ukazuje da se u ovom sistemu inhibitora pretežno kontroliše anodna reakcija rastvaranja metala. Ovo implicira da se ovi sistemi inhibitora mogu obložiti na površinu od mekog čelika koji se koristi kao ploče trupa da bi se sprečila korozija mekog čelika u morskoj vodi.

Ključne reči: *inhibicija korozije, ploče trupa, meki čelik, morska voda, zeleni inhibitori, elektrohemijska studija.*