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Egy- dronate drug as promising corrosion inhibitor of C - steel in aqueous medium

ABSTRACT

The effect of Egy – dronate as the corrosion inhibition of Carbon steel (CS) in 1 M HCl was studied by weight loss (WL), hydrogen evaluation (HE), Open circuit potential (E_{OCP}), potentiodynamic polarization (PP), electrochemical impedance spectroscopy (EIS), electron frequency modulation (EFM) and surface examination of the specimens by atomic force microscopy (AFM), energy dispersion spectroscopy (EDS) and scanning electron microscopy (SEM). The results of the inhibition efficiency (IE %) increase with increasing the concentration of inhibitor but decreases with raising the temperature. The adsorption of Egy - dronate on the C - steel surface obeys with Langmuir adsorption isotherm. The adsorption process is spontaneous, endothermic and physical adsorption. The polarization curves show that Egy - dronate is a mixed-type inhibitor tends to anodically more. The results obtained from chemical and electrochemical techniques are a good agreement quality and gives the same behavior of the adsorption of Egy-dronate drug. All techniques have proved the thin film formation adsorbed on the metal surface as a protective coated to prevent the dissolution metal in the corrosive medium, due to electrostatic attraction between unshared electrons of inhibitor molecules and the positive sites on the metal surface.

Keywords: *corrosion inhibition, HCl, CS, adsorption, SEM, EDX, AFM.*

1. INTRODUCTION

The most methods for protection of metals from corrosion are investigated by utilization of inhibitors that especially in acid medium [1-2]. The well-known acidic inhibitors are drugs and organic compounds that contain O, S, N (N-heterocyclic), long carbon chain and aromatic compounds. The organic inhibitors have many advantages such as high % IE, low cost, friendly to the environment and easy to produce [3-5]. Pharmaceutical drugs like heterocyclic compounds are used for to reduced corrosion process of Fe, Cu and Al [6-16] in various aqueous medium. Adsorption of the drug facilitates the protection of the metal surface [17]. A few medications such as tetracycline, cloxcillin, azithromycin, ampiclox, ampicillin and orphenadrine were discovered to have a great inhibition for corrosion of metals and alloys.

Numerous authors generally concur that medications are inhibitors that can compete favorably with green inhibition of corrosion and that most medications can be synthesized from natural products. A few medications have been discovered to be a great corrosion inhibitors for metals such as: Biopolymer gave 86% (IE) for Cu in NaCl [18], pyromellitic diimide linked to oxadiazole cycle gave 84.6% IE for CS in HCl [19], 2-mercapto-benzimidazole gave 82% (IE) for CS in HCl [20], Antidiabetic Drug Janumet gave 88.7% inhibition efficiency for MS in HCl [21], Januvia gave 79.5% (IE) for Zn in HCl [22], Cefuroxime Axetil gave 89.9% (IE) for Al in HCl [23], Phenytoin sodium gave 79% (IE) for CS in HCl [24], Aspirin gave 71% (IE) for MS in H_2SO_4 [25], Septazole gave 84.8% IE for Cu in HCl [26] and Chloroquine diphosphate gave 80% (IE) for MS in HCl [27]. Selection of some medication as corrosion inhibitors due to the followings: (1) drug molecules contain oxygen, sulphur and nitrogen as active sites, (2) it is environmentally friendly furthermore vital in organic responses and (3) drugs can be easily produced and purified [28-32].

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The scope of this paper is to use Egy-dronate drug as save corrosion inhibitor for CS in acid medium by various chemical and electrochemical methods, and to elucidate the mechanism of corrosion inhibition.

2. EXPERIMENTAL TECHNIQUES

2.1. Materials

The CS specimen composition is listed in the following Table 1.

Table 1: The composition of CS specimen

Tabela 1. Sastav uzorka ugljeničnog čelika

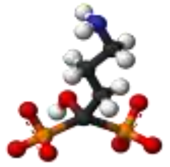
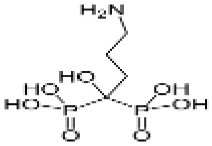
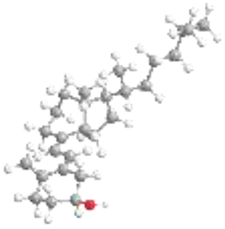
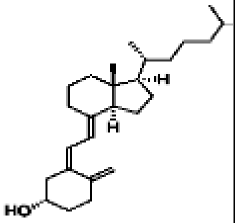
Constituent	C	Mn	P	Si	Iron
Composition %	0.2	0.6	0.04	0.003	Rest

2.2. Inhibitors

Egy - dronate drug is mixed inhibitor which consists of two substances Alendronic acid and Cholecalciferol which describing in Table 2. The pharmaceutical drugs have been investigated purchased from Sandozinc and Pfizer inc companies.

Table 2. The Components and molecular structure of investigated drug

Tabela 2. Komponente i molekularna struktura ispitane droge

<table>
<tr><th>Chemical formula</th><th>Active center</th><th>Molecular weight</th><th>IUPAC Name</th><th colspan="2">Structure</th><th>Inhibitor</th></tr>
<tr><td>$C4H13NO7P2$</td><td>N
7O
2P</td><td>249.097 g/mol</td><td>sodium [4-amino-1-hydroxy-1-(hydroxy-oxido-phosphoryl)-butyl]phosphonic acid trihydrate</td><td></td><td>
Alendronic acid</td><td>(1)</td></tr>
<tr><td>$C27H44O$</td><td>O
2π</td><td>384.64 g/mol</td><td>(3β,5Z,7E)-9, 10-secocholesta-5,7,10(19) trien-3-ol</td><td></td><td>
Cholecalciferol (Vit. D3)</td><td>(2)</td></tr>
</table>

2.3. Solutions

The corrosive solution was prepared by dilution of analytical grade (37 %) HCl with bi-distill water to obtain 1M HCl. The corrosive solution mixed with different concentration range of the Egy –dronate drug that was used between 50 and 300 ppm.

2.4. WL measurements

Seven square CS sheets of 2.0 × 2.0 × 2.0 cm^2 were abraded by emery paper (grade 600, 800, 1000 and 1200) and then washed by bi-distill water and acetone. After accurate weighting, the specimens were immersed in a 100 ml beaker, which contained 100 ml of 1M HCl with and without adding different doses of investigated drug.

All corrosive solutions were opened to air. After three hour, the coins were taken out, washed, dried, and weighed accurately per thirty minutes. The average WL for seven square CS specimens will be obtained.

The % IE and the degree of surface coverage (θ) of Egy - dronate inhibitor for the corrosion of CS were calculated as following [33]:

$$\% IE = \theta \times 100 = [1- (W/W^o)] \times 100 \qquad (1)$$

Where, W^o and W are the WL, without and with adding deferent doses of investigate drug respectively.

2.5. Gasometric measurements

Measurements of HE were estimation at 25°C, and the H_2 volume developed every 15 minutes, the Ɵ and the % IE were calculated by (3) and (4).

$$V = K \times t \qquad (2)$$

Where, (V) is the volume of hydrogen in ml, (K) is rate constant and (t) is time in minute.

$$\Theta = 1 - K/K^o \qquad (3)$$

Where, (K^o) and (K) are the rate of corrosion in absence and presence drug, which calculated by plotting (V) vs. (t) and (K) value is the slope.

$$\% IE = \Theta \times 100 \qquad (4)$$

2. 6. Electrochemical measurements

Electrochemical measurements including E_{OCP}, PP, EIS and EFM were performed in three electrodes at 25^{o}C. The counter electrode is platinum, saturated calomel electrode (SCE) coupled to a fine Lugging capillary as reference electrode and the working electrode was in the form of a square cut from CS fixed with epoxy resin of polytetrafluoroethylene (PTFE) except the flat surface act the working electrode in 1 cm^2 area.

Electrochemical estimation performed for four techniques. Impedance measurements were carried out in frequency range from 100 kHz to 10 mHz with amplitude of 5 mV peak-to-peak using AC signals at open circuit potential. The experimental impedance were analyzed and interpreted on the basis of the equivalent circuit. The main parameters deduced from the analysis of Nyquist diagram are the resistance of charge transfer R_{ct} or R_p (diameter of high frequency loop) and the capacity of double layer C_{dl}.

EFM measurement is the techniques that can directly and fast to determination corrosion current data without knowledge of Tafel slopes with a small signal polarization. The % IE_{EFM} was calculated.

The electrode potential was allowed to stabilize for 30 min before starting the measurements. All the experiments were conducted at 25 ± 1°C. Measurements were performed using Gamry (PCI 300/4) Instrument Potentiostat / Galvanostat/ZRA.

2. 7. Surface Examinations

The CS coins used for analysis of morphology surface were prepared in 1M HCl acid (blank) and with 300 ppm of Egy-dronate drug at room temperature for one day (24 h). The performed specimens examined by using SEM, EDX and AFM techniques.

3. RESULT AND DISCUSSION

3.1. WL technique

The WL curves of CS without and with the addition various doses of Egy – dronate drug as an inhibitor in 1M HCl were shown in Figure 1, that the WL values of CS in 1M HCl solution containing the investigated drug, that clarified the % IE, increasing with increasing the concentration of the drug, but decreases with raising temperatures. The results are appearing in the Table 3.This direction may as a result from the fact that the adsorption of the drug on the CS increases with increasing the concentrations of the drug. These means, the inhibitor make thin film in the surface of the metal which protective it from corrosion process [34].

Table 3. The rate of corrosion and % IE for WL measurements without and with various concentrations of Egy-dronate drug that was immersion for 120 min in 1M HCl at 25^{o}C

Tabela 3. Stopa korozije i % IE za VL merenja bez i sa različitim koncentracijama leka Egi-dronate koji je uronjen 120 minuta u 1M HCl na 25°C

% IE	Kcorr. mg. cm-2. min-1	Conc. Ppm	Compound
----	16.25	---	Blank
64.1	5.83	50	Egy – dronate
66.7	5.42	100	
69.2	5.00	150	
71.8	4.58	200	
74.4	4.17	250	
76.9	3.75	300	

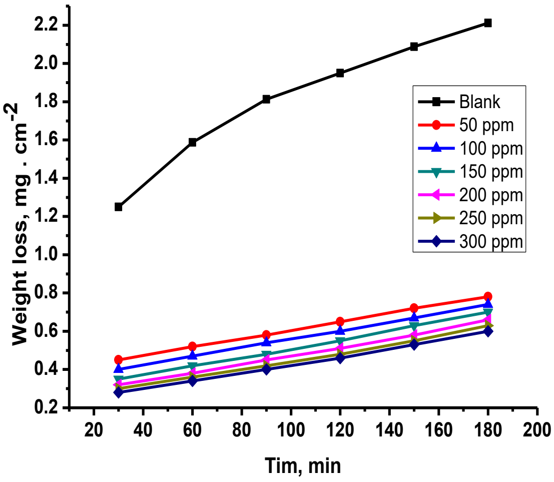


Figure 1. Weight loss – time curves for the corrosion of CS in 1M HCl in the absence and presence of different doses of Egy-dronate drug at 25^{o}C

Slika 1. Krive gubitak težine - vreme za koroziju ugljeničnog čelika u M HCl u odsustvu i prisustvu različitih doza leka Egi-dronate na 25^{o}C

3.2. Effect of temperature

The effect of temperature of the rate of corrosion for CS in acid medium with various concentrations from Egy – dronate drug was tested by WL measurements over the temperature range from 25 to 45^{o}C. The effect of increasing temperatures on the rate of corrosion and the % IE, calculated. The results of the rate of corrosion were increased as the temperatures increases and decreasing both θ and % IE, Figure 2.

The activation energy (E^{*}_{a}) of the corrosion process was calculated by using Arrhenius equation (5):

$$K_{corr.} = A \exp(-E_a^*/RT) \quad (5)$$

Where, (k) is the rate of corrosion and (A) is the Arrhenius constant or frequency factor, (R) is general gas constant and (T) is absolute temperature. Figure 3, represents the Arrhenius plot in the presence and absence of drug. E^*_a values determined from the slopes of these linear plots are shown in Table 4. The linear regression (R^2) is close to 1 which indicates that the corrosion of CS in 1 M HCl solution can be obvious that using the kinetic model. Table 4 showed that the value of E^*_a for the inhibited solution is higher than that for uninhibited solution, suggesting that dissolution of CS is slow in the presence of inhibitor and can be sure due to physical adsorption. It is known from equation (8), that the higher E^*_a values lead to the lower of the rate of corrosion. This is due to the formation of a film on the CS surface serving as an energy barrier for the CS corrosion [35].

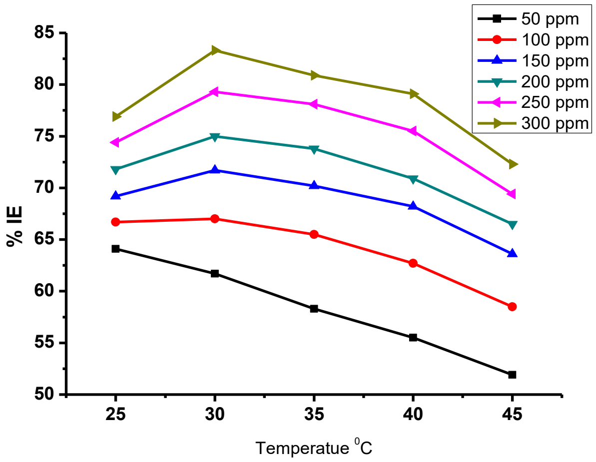


Figure 2. The effect of Egy - dronate % IE at various temperatures

Slika 2. Uticaj Egi - dronate na % IE na različitim temperaturama

Table 4. Activation parameters for CS corrosion in the nonexistence and existence of various doses of Egy-dronate drug in 1M HCl

Tabela 4. Parametri aktivacije za koroziju ugljeničnog čelika u prisustvu i odsustvu različitih doza leka Egi-dronate u 1M HCl

Conc. ppm	Activation parameters		
	E*a kJ mol-1	ΔH* kJ mol-1	-ΔS* J mol-1 K-1
Blank	47.3	45.5	125.6
50	55.5	53.9	106.8
100	56.8	55.2	103.4
150	57.7	56.3	100.9
200	61.8	57.3	98.2
250	62.5	61.0	86.9
300	62.9	61.5	85.8

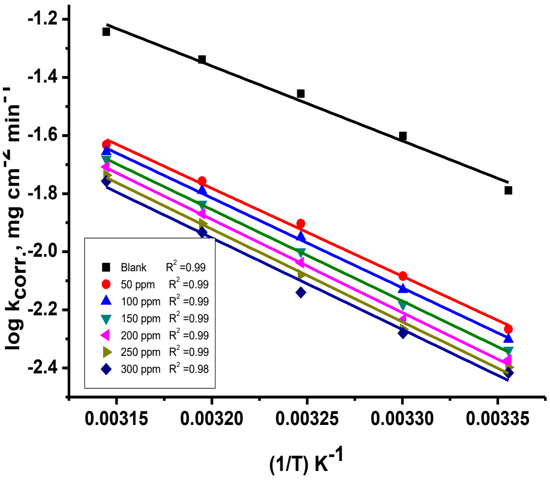


Figure 3. Arrhenius curves for CS dissolution in 1 M HCl in the nonexistence and existence Egy – dronate drug

Slika 3. Arreniusove krive za ugljenični čelik u 1M HCl u odsustvu i prisustvu Egi-dronate droge

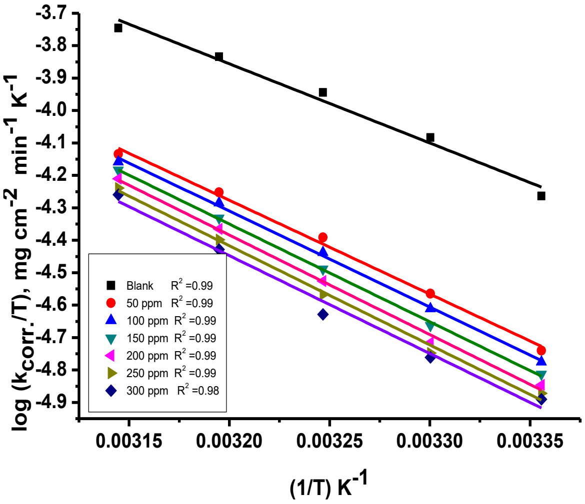


Figure 4. Log (kcorr. /T) vs. (1/T) for metal in M HCl in existence and nonexistence Egy - dronate drug at various temperatures

Slika 4. Log (kcorr. / T) vs. (1 / T) za metal u M HCl u prisustvu i odsustvu Egi-dronat leka na različitim temperaturama

Enthalpy and entropy of activation (ΔH^*, ΔS^*) of the corrosion process was calculated from the transition state equation (6) which listed in the Table 4:

$$K_{corr}/T = (RT/Nh) \exp(\Delta S^*/R) \exp(-\Delta H^*/RT) \quad (6)$$

Where, (h) is Planck's constant and (N) is Avogadro's number.

A plot of log ($k_{corr.}$/T) vs. (1/ T) for CS in 1 M HCl at different concentrations from investigated drug, gives straight lines as shown in Figure 4. The positive signs of (ΔH^*) refer to the endothermic nature of the CS dissolution process. Large and negative values of ΔS^* imply that the activated complex in the rate-determining step represents an association rather than dissociation step, meaning that decrease in disordering takes place on going from reactants to the activated complex [36].

3.3. Adsorption isotherm

Inhibitions of corrosion are found to protect of CS from corrosion in acid solution by adsorption on the surface of the CS. Moreover, the adsorption process depends on the chemical composition of the drug molecule, the temperature and the electrochemical potential at the metal and solution interface. The adsorption process involving two types:

1- Physisorption - which involves electrostatic force between ionic charges at the metal and the solution containing inhibitor interface? The heat of adsorption is low and therefore this type of adsorption is stable only at relatively low temperatures.
2- Chemisorption - which involves charge sharing or charge transfer from the inhibitor molecules to the metal surface form a coordinate type bond [37]. Chemisorption is typically by much stronger adsorption energy than physical adsorption. Such bond is therefore more stable at higher temperatures. Various adsorption isotherms including Frumkin, Langmuir, Temkin and Freundlich isotherms were tested to find the best suitable adsorption isotherm for adsorption of the studied inhibitors on the CS surface. Langmuir adsorption isotherm was found to fit the experimental data. The mathematical expression of Langmuir is given as following [38]:

$$C/\Theta = 1/k_{ads.} + C \qquad (7)$$

where, $k_{ads.}$ is the adsorption equilibrium constant.

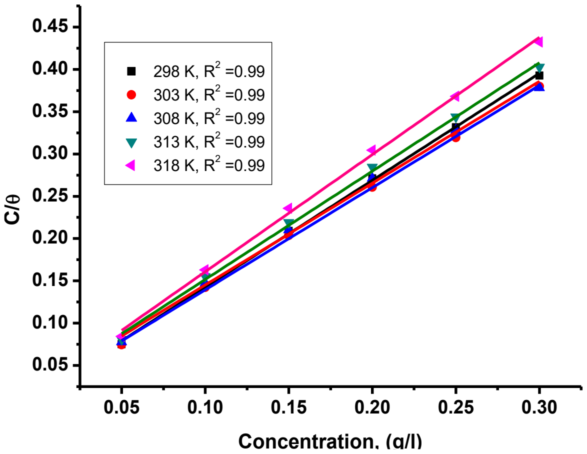


Figure 5. Langmiur adsorption isotherm of Egy - dronate drug on CS surface in 1M HCl at various temperatures

Slika 5: Lengmirova adsorpciona izotermna leka Egi-dronata na površini ugljeničnog čelika u 1M HCl na različitim temperaturama

Plotting (C/Θ) versus (C) of Egy – dronate drug at various temperatures is introduced in Figure 5 recommends that no forces of attraction between the atoms adsorbed on the metal surface. The relationship is linearly with unity slope and intercept equal ($1/k_{asd.}$), the adsorption constant being result to the standard free energy of adsorption ΔG^o_{ads} by the relation (8):

$$\Delta G^o_{ads.} = - RT \ln (55.5 K_{ads.} \qquad (8)$$

Where, R is the universal gas constant, T is the absolute temperature and 55.5 is the concentration of water in the solution in M/L.

The ΔG^o_{ads} values at all studied temperatures which calculated by above equation (8) and recorded in Table 5. The heat of adsorption ($\Delta H^o_{ads.}$) was calculated according to the Van't Hoff equation [39]:

$$\text{Log } k_{ads.} = (-\Delta H^o_{ads.} /2.303RT) + constant \qquad (9)$$

Plotting (log $K_{ads.}$) against (1/T) give straight line that shown in Figure 6, the straight line gives slope equal ($-\Delta H^o_{ads.}/2.303R$), from this slope, the $\Delta H^o_{ads.}$ value was calculated and listed in Table 5. Then in accordance with the basic equation (10):

$$\Delta G^o_{ads} = \Delta H^o_{ads.} - T\Delta S^o_{ads.} \qquad (10)$$

Table 5. Thermodynamic parameters for the adsorption of Egy – dronate drug on CS surface in 1M HCl at various temperatures

Tabela 5. Termodinamički parametri za adsorpciju leka Egi-dronata na površini ugljeničnog čelika u 1M HCl na raznim temperaturama

Temp. oC m	Kads M-1	-ΔGoads kJ mol-1	ΔHoads kJ mol-1	ΔSoads J mol-1K-1
25	62.5	20.12	14.34	96.7
30	53.76	20.16		95.0
35	44.84	19.76		92.2
40	42.55	20.22		92.2
45	40.32	20.66		92.2

The values of ΔG^o_{ads} and $\Delta H^o_{ads.}$, the ΔS^o_{ads} were calculated at all studied temperatures by the above equation (10). For all thermodynamic adsorption parameters for Egy - dronate drug on CS from 1M HCl solution, can be concluded that:

1- The experimental data give good curves fitting for the applied adsorption isotherms as the correlation coefficients were in the range (0.99 - 0.98).
2- $K_{ads.}$ values decrease with increasing temperatures from 25 to 45°C

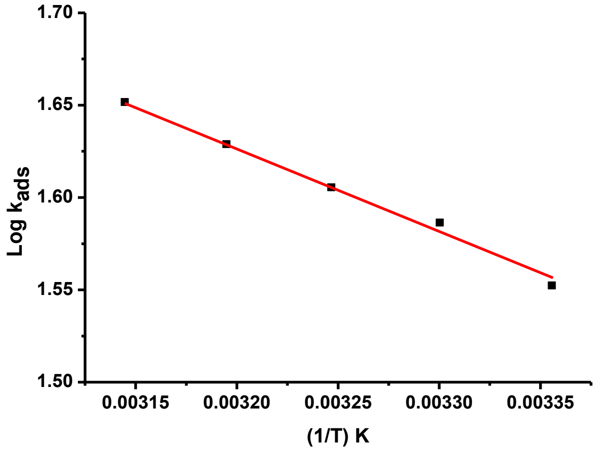


Figure 6. Curve (log kads.) vs. (1/T) for the corrosion of CS in 1M HCl in the presence of Egy - dronate drug at various temperatures

Slika 6. Kriva (log kads.) vs. (1/T) za koroziju ugljeničnog čelika u 1M HCl u prisustvu leka Egi-dronate na različitim temperaturama

3- The negative values of ΔG^o_{ads} reflected that the adsorption of Egy – dronate drug on CS surface in 1 M HCl solution is spontaneous process.

4- ΔG^o_{ads} slightly increases (becomes less negative) with increasing temperatures which indicated that the occurrence of endothermic process and the adsorption was unfavorable with increasing reaction temperature as a result of the inhibitor desorption from the CS surface [40].

5- The value of ΔG^o_{ads} around -20 kJ mol^{-1} or lower indicates the electrostatic attraction between charged metal surface and charge drug molecules in the bulk of the solution i.e. physisorption.

6- The positive sign of ΔH^o_{ads} refers to the adsorption of inhibitor molecules is an endothermic process, indicate that the adsorption is physical adsorption. The unshared electron pairs in investigate molecule may attractive with positive center on the surface of CS by electrostatic attraction to produce a protective film which prevent the dissolution process [41].

7- The values of ΔS^o_{ads} in the presence of investigate drug as an inhibitor are large and positive that is accompanied with endothermic adsorption process [42].

3.4. HE technique

Plotting the volume of hydrogen against time at various doses between 50 to 300 ppm of Egy – dronate drug gives straight lines in Figure 7. The slope of line equals the rate of corrosion. The great straight lines show vicinity of insoluble film adsorbed on the metal surface. The rate of corrosion (k_{corr}), θ and IE % obtained from hydrogen evolution at various doses are listed in Table 6. As shown, the rate of corrosion reduced with increasing of Egy – dronate drug doses, appearing diminishes conduct for the metal disintegration. The reaction is presented by chemical equation (11) and pointed out that Fe dissociation in acid arrangements relies on hydrogen ion more than the chloride ion [43], this means the Fe^{2+} boded with Cl^- and formed $FeCl_2$.

$$Fe_{(S)} + 2H^{+} == Fe^{+}_{2} + H_{2\,(g)} \qquad (11)$$

Table 6. The rate of corrosion for metal nonexistence and existence various doses of Egy - dronate drug

Tabela 6. Procenat korozije metala u odsustvu i prisustvu različitih doza leka Egy-dronata

Conc. ppm m	kcorr ml cm-2 min-1	Ө	% IE
Blank	0.158	----	----
50	0.062	0.608	60.8
100	0.060	0.620	62.0
150	0.055	0.652	65.2
200	0.052	0.671	67.1
250	0.049	0.689	68.9
300	0.047	0.703	70.3

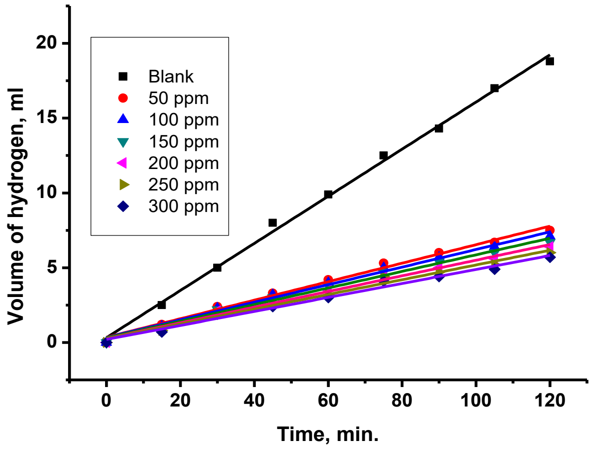


Figure 7. Hydrogen volume produced versus time arrangements with distinctive centralization of inhibitor at 25°C

Slika 7: Zapremina vodonika proizvedena u odnosu na vremenske aranžmane sa prepoznatljivom centralizacijom inhibitora na 25°C

3.5. Open circuit potential (E_{ocp})

From the Figure 8 is shown several interesting points:

1. The E_{OPC} in the blank solution began from -533 mV then shifted anodically and reached the steady state after 300 second indicating that the initial dissolution process and formation oxide film on the metal surface.

2. The E_{OCP} is started in the existence of Egy-dronate drug, at less negatively potential compared with that in the nonexistence of the drug and then shifted anodically, according to the increasing the doses 50, 100, 150, 200, 250 and 300 respectively, that shown in Table 7. The steady state is attained rapidly, with increasing the doses of the drug comparing with the blank, then it shifted in the potential of E_{OCP} increment in the positive direction position and the drug might certainly act as an anodic inhibitor [44]. However, from Figure (8), the shift in E_{OCP} on addition Egy-dronate drug is about 57.5 mV revealing that the present drug acts as anodically drug.

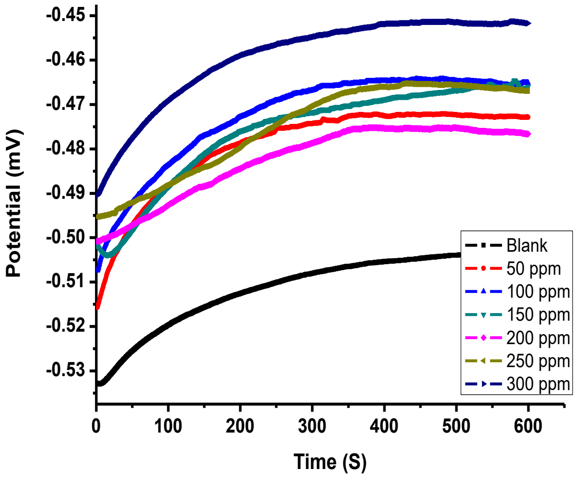


Figure 8. Open circuit potential, EOCP vs. time relations for CS immersed in 1M HCl in the nonexistence and existence of Egy-dronate drug at 25°C

Slika 8. Potencijal otvorenog kola, EOCP vs. vremenu za ugljenični čelik uronjeni u M HCl u odsustvu i prisustvu droge Egi-dronate na 25°C

Table 7. Open circuit potential of CS for without and with various doses of Egy - dronate drug at 25°C

Tabela 7. Potencijal otvorenog kola ugljeničnog čelika bez prisustva i u prisustvu različitim dozama leka Egi-dronate na 25°C

Conc. ppm	-EMin (mV)	-EMax (mV)
Blank	533.0	502.0
50	515.7	472.1
100	507.4	464.3
150	503.9	464.5
200	500.8	475.2
250	495.3	465.2
300	490.5	451.3

3.6. PP technique

Polarization measurement was carried out to obtain Tafel plots in the nonexistence and existence of various doses of Egy - dronate drug at 25 °C. The current and potential relationship for CS electrode in different test solutions of Egy-dronate drug is shown in Figure 9. The numerical values of the variation of the corrosion current density (icorr.), the corrosion potential (Ecorr.), the anodic Tafel slope (βa), the cathodic Tafel slope (βc), θ and % IE are listed in Table (8). The results in this table indicate [u7] that:

1. The icorr diminish in the existence of drug compared to the blank solution and also diminish [u7] with raising doses of drug.
2. Addition of Egy – dronate drug causes diminish in the rate of corrosion that shifted both anodic and cathodic curves to lower values of icorr. This suggests that both the hydrogen evolution at cathodic and at the anodic dissolution reactions of CS electrode are inhibited by adsorption of Egy – dronate drug on the metal surface [45].
3. The anodic and cathodic slopes of Tafel lines (βa and βc) were slightly changed by increasing the doses of the tested compound. This indicates that there is no change of mechanism of inhibition in existence and nonexistence of Egy-dronate drug and effects of both anodic and cathodic reaction [46] i.e. mixed type.

Calculation IE % and θ according to equation (12) [47]:

$$IE\ \% = \theta \times 100 = [1- (icorr(inh)/icorr(free))] \times 100 \quad (12)$$

Where, icorr(free) and icorr(inh) are the corrosion current densities in the nonexistence and existence of drug, respectively.

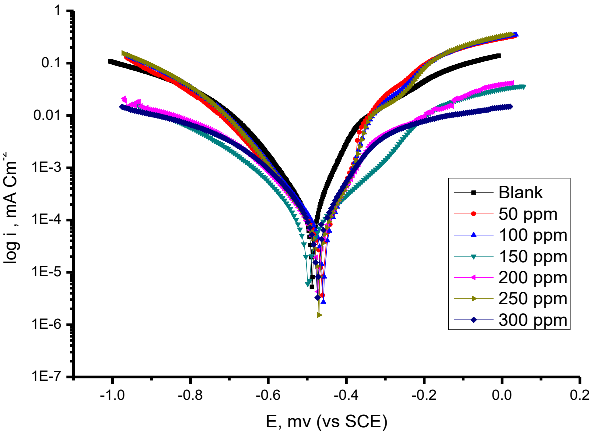


Figure 9. PP curves for corrosion of CS in 1M HCl in the nonexistence and existence of various doses of Egy-dronate drug at 25°C

Slika 9. PP krive za koroziju ugljeničnog čelika u 1M HCl u odsustvu i posustvu različitih doza leka Egi-dronate na 25°C

Table 8. PP parameters for the corrosion of CS in 1M HCl in the nonexistence and existence of various doses of Egy – dronate drug at 25°C

Tabela 8. PP parametri za koroziju ugljeničnog čelika u 1M HCl u odsustvu i posustvu različitih doza leka Egi-dronata na 25°C

Conc. ppm	Icorr. mA/cm-2	-Ecorr. mV(SCE)	βa mV dec-1	βc mV dec-1	C. R. Mpy	Θ	% IE
0.0	147	480	166	208	67.3	----	----
50	65.7	470	85.3	107	30.02	0.565	56.5
100	61.6	459	65.1	108	28.16	0.592	59.2
150	54.9	467	84.5	132	25.08	0.636	63.6
200	48.5	459	63.3	128	22.15	0.679	67.9
250	45	462	53.3	84.0	20.56	0.702	70.2
300	31.8	459	36.7	72.6	14.51	0.789	78.9

3.7. EIS technique

The EIS collection data was carried out at room temperature in corrosive medium in existence and nonexistence of Egy – dronate drug. The equivalent circuit which used to fit EIS data is shown in Figure 10. Where, Rs, Rct and CPE refer to solution resistance, the change transfer resistance and constant phase element representing the double layer capacitance (Cdl) of the in interface, respectively.

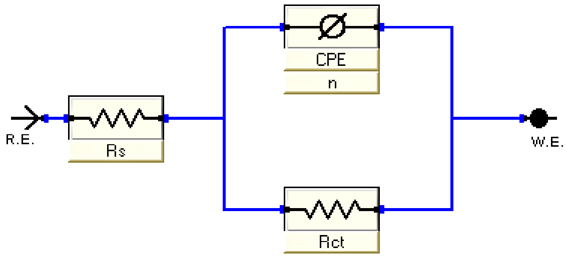


Figure 10. Equivalent circuit model used to fit the impedance spectra

Slika 10. Model ekvivalentnog kola koji se koristi za ispitivanje impedance

A typical example of EIS data obtained for Egy - dronate drug is represented as Nyquist and Bode plots in Figure 11- a, b. The diagram of impedance is characterized by a single full semicircular loop appearance indicating that a charge transfer process controls the corrosion of CS [48]. Small distortion was observed in the diagrams; this distortion has been attributed to frequency dispersion [49]. The obtained diameters of the capacitive loops increase in existence of Egy-dronate drug. The % IE, of corrosion process, contrary to the RDUCES of the capacity of double layer (Cdl) which is defined as:

$$C_{dl} = 1/(2\pi f_{max} R_p) \tag{13}$$

Where, fmax is the maximum frequency.

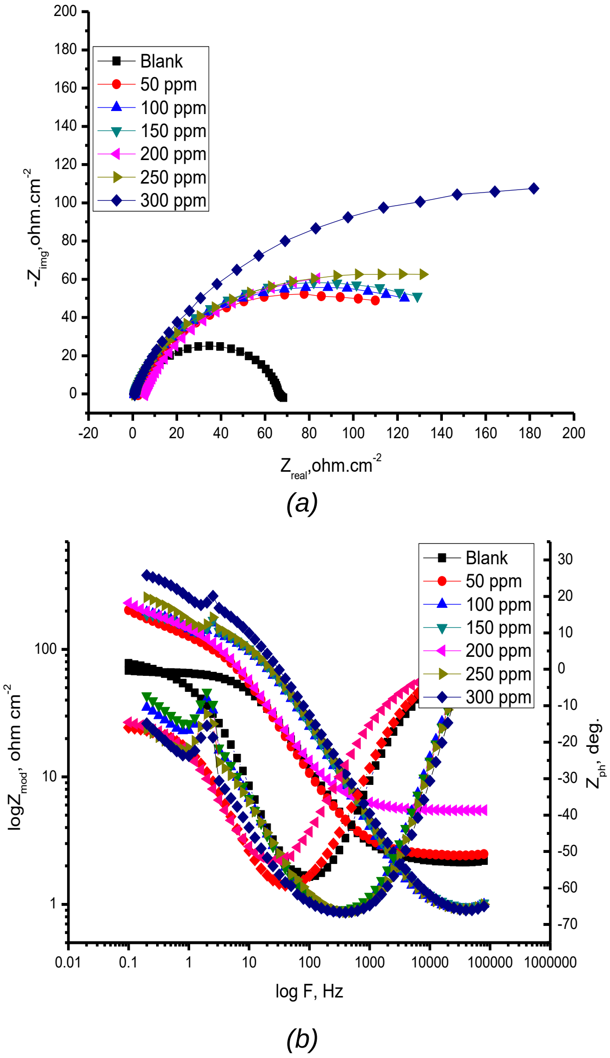


Figure 11. The Nyquist (a) and Bode (b) plots for corrosion of CS in 1M HCl in the nonexistence and existence of various doses of Egy - dronate at 25°C

Slika 11. Nyquist (a) i Bode (b) krive za koroziju ugljeničnog čelika u 1M HCl u odsustvu i prisustvu različitih doza leka Egi-dronata na 25°C

The % IE and θ obtained from the impedance measurements were defined by the following relation:

$$IE\ \% = \theta \times 100 = [1- (R^{\circ}p/Rp)] \times 100 \qquad (14)$$

Where, Rop and Rp are the charge transfer resistance in the absence and presence of Egy-dronate drug, respectively. The analysis of EIS parameters were shown, that the Rp increases with increasing doses of Egy-dronate drug and provides consequently the reduction of the corrosion rate. It is important to emphasize that the values of Cdl decrease with increasing the doses of Egy-dronate.

Table 9. EIS data of CS in 2M HCl and in the nonexistence and existence of various doses of test drug at 25ºC

Tabela 9. EIS podaci ugljeničnog čelika u 2M HCl u odsustvu i prisustvu različitih doza lekova za testiranje na 25ºC

Conc. ppm	R_p Ω cm^2	C_{dl} µF cm^2	Θ	% IE
0.0	64.73	594.2	-----	-----
50	158.4	126.3	0.591	59.1
100	162.2	112.1	0.601	60.1
150	170.6	97.69	0.621	62.1
200	186.4	82.54	0.653	65.3
250	205.3	72.7	0.685	68.5
300	301.6	33.16	0.785	78.5

This is due to the gradual replacement of water molecules in the metal interface by the adsorbed drug molecules as an adherent film form on the metal surface as a result of reduces of the local dielectric constant and increases in the thickness of the electrical double layer of the metal solution interface [50]. The obtained Bodes plot for Egy -dronate is shown in Figure 11. The high frequency limits corresponds to (Rp + Rs). The low frequency contribution shows the kinetic response or charge transfer reaction [51]. EIS data are listed in Table 9.

3.8. EFM technique

EFM is a nondestructive corrosion measurement technique that can directly and quickly determine the corrosion current value without prior knowledge of Tafel slopes, and with only a small polarizing signal. These advantages of EFM technique make it an ideal candidate for online corrosion monitoring [52].

The high validly of EFM collection data are seen that have the causality factors similar or equal the hypothetical values of causality factors.

The causality factors CF-2 and CF-3 were calculated from the frequency spectrum of the current responses.

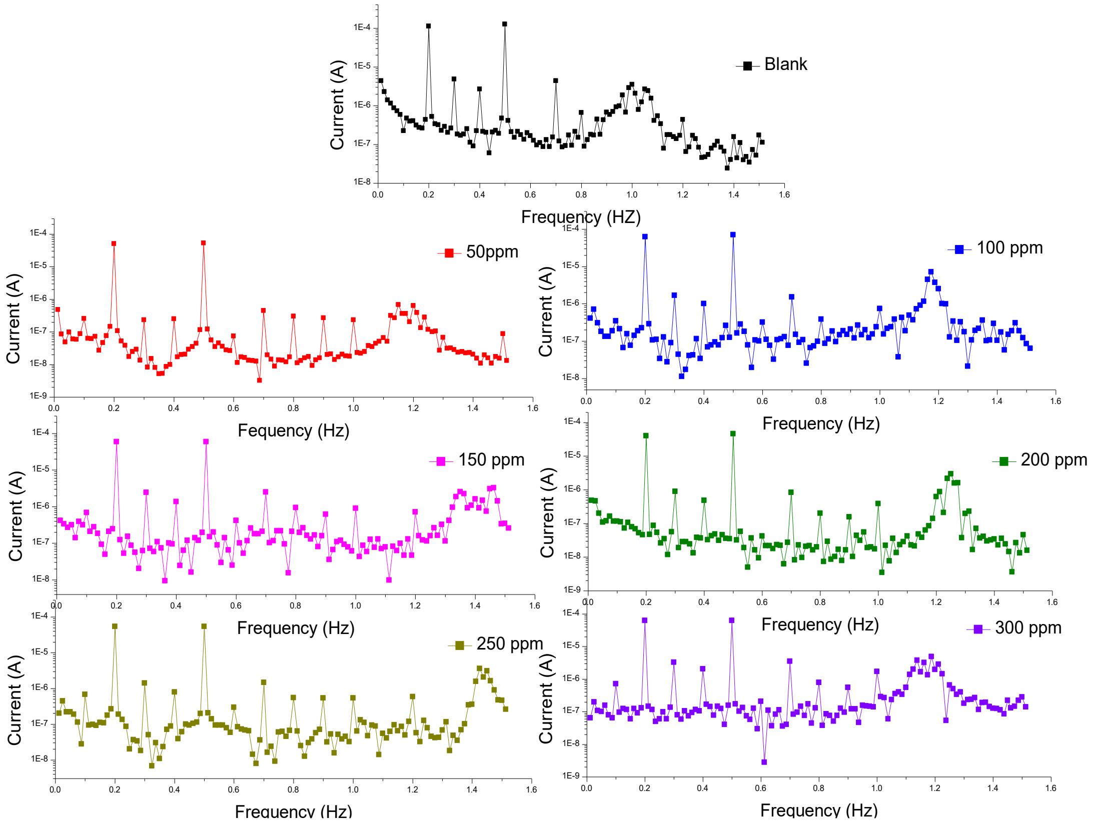


Figure 12. EFM for CS in 1M HCl with and without various doses of the used Egy-dronate drug

Slika 12. EFM za ugljenični čelik u 1M HCl sa i bez različitih doza korišćenog leka Egi-dronate

Figure (12), shows the frequency spectrum (current vs. frequency) of the current response of pure CS in 1M HCl, contains not only the input frequencies, but also contains frequency components which are the sum, difference, and multiples of the two input frequencies. The EFM Intermodulation spectrums of CS in 1 M HCl acid solution containing (50, 100, 150, 200, 250 and 300 ppm) of the Egy – dronate drug as inhibitor is shown in Figure 12. The harmonic and Inter-modulation peaks are clearly visible and are much larger than the background noise. The experimental EFM–data were treated using two different models: complete diffusion control of the cathodic reaction and the "activation" model. The latter, a set of three non-linear equations had been solved, assuming that the corrosion potential does not change due to the polarization of the working electrode [53]. The large peaks were utilized to calculate the corrosion current density (j_{corr}), the Tafel slopes (β_a and β_c) and the causality factors (CF-2 and CF-3).These electrochemical parameters were listed in Table 10. The addition of Egy - dronate drug at a given doses in the acidic solution reduces the corrosion current density, indicating that these compounds inhibit the corrosion of CS in 1 M HCl through adsorption. The causality factors obtained under different experimental conditions are approximately equal to the theoretical values (2 and 3) indicating that the measured data are validity and of good quality [54]. The inhibition efficiencies % IE $_{EFM}$ increases by increasing the drug doses and were calculated as follows:

$$\% IE = [(1- i_{corr.} / i^{o}_{corr.}) \times 100 \qquad (15)$$

Where, $i^{o}_{corr.}$ and $i_{corr.}$ are corrosion current densities without and with deferent doses of drug respectively.

Table 10. Electrochemical kinetic variables occur by EFM method for CS in 1 M HCl nonexistence and existence different doses of Egy-dronate at 25^{o}C

Tabela 10. Elektrokemijske kinetičke varijable dobijene metodom EFM za ugljenični čelik u 1M HCl u odsustvu i prisustvu različitih doza leka Egi-dronata na 25°C

Comp.	Conc. M	$I_{corr.}$ µAcm^{-2}	B_a x 10^{-3} mVdec^{-1}	B_c x 10^{-3} mVdec^{-1}	CF (2)	CF (3)	CR mpy	Ө	%IE
Blank	0.0	350.3	156.4	247.9	1.5	2.9	160.1	----	----
Egy – dronate	50	110.3	134.0	141.6	1.4	4.5	50.4	0.685	68.5
	100	103.1	94.1	109.4	1.8	4	47.1	0.706	70.6
	150	96.6	93.4	122.7	2.2	1.9	44.2	0.724	72.4
	200	95.4	133.5	160.0	2	6	43.6	0.728	72.8
	250	93.2	102.5	123.1	2.2	1.6	42.6	0.734	73.4
	300	89.2	81.0	111.3	1.8	4	40.8	0.745	74.5

3.9. EDX spectra

The EDX spectra were used to determine the elements existence on the surface of CS after one day to exposure of the uninhibited and inhibited specimens in 1M HCl. Figure (13), shows the EDX analysis result on the composition of CS only without acid, with acid and with inhibitor treatment. The EDS analysis indicates that only Fe and oxygen were detected, which shows that the passive film contained only Fe_2O_3. The EDS analysis diagram of CS in 1 M HCl only and in the presence of 300 ppm of pharmaceutical compound. The spectra views additional lines, appearing the existence of C (owing to the carbon atoms of Egy - dronate). These data show that is the carbon, oxygen and the electrons density of π bonding formation thin layer that cover the specimen surface. This layer is entirely owing to the inhibitor, because the carbon, iron and oxygen signals are absent on the specimen surface exposed to uninhibited HCl.

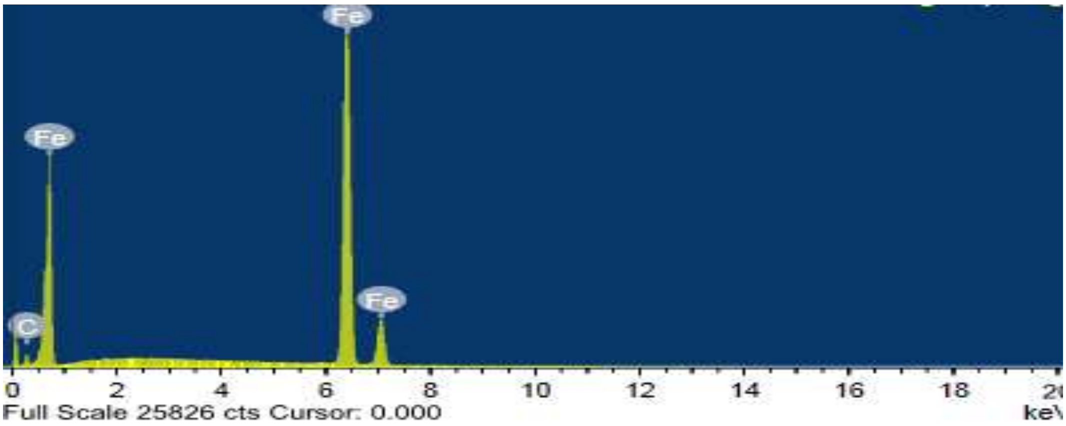
It is shown that, in addition of Egy dronate drug gives the signals of C, O and Fe were present in the spectra. A comparable elemental distribution is shown in Table (11).

Table 11. Surface composition (weight %) of the CS after immersion 24 h in 1M HCl with 300 ppm of the studied inhibitor

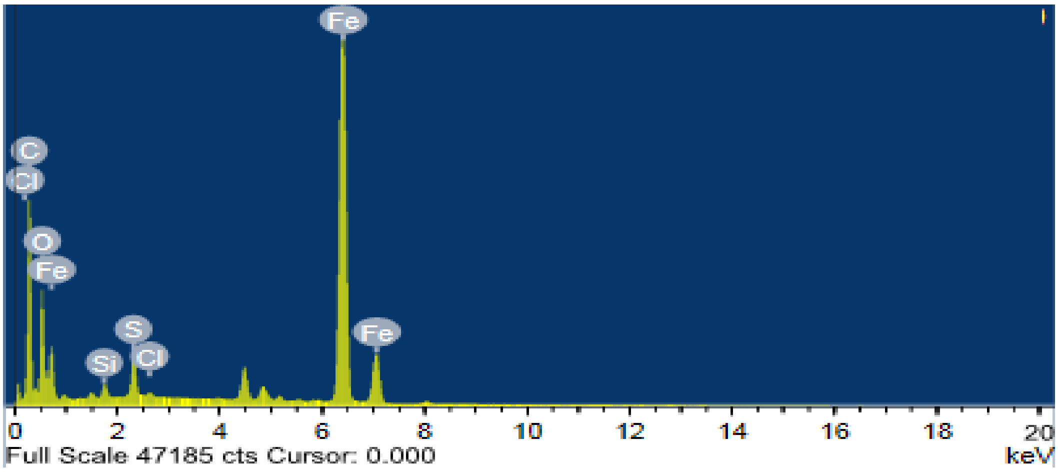
Tabela 11. Sastav površine (težina%) ugljeničnog čelika posle potapanja 24 h u 1M HCl sa 300 ppm ispitanog inhibitora

(Mass %)	Fe	C	O	Cl
Pure	98.28	0.78	--	--
Blank	72.1	9.23	17	0.35
Egy - dronate	75.97	2.08	20.68	--

CS free - čist uzorak



Blank - prazan uzorak



In presence 300 ppm of Egy-dronat drug

U prisustvu 300 ppm leka Egi-dronat

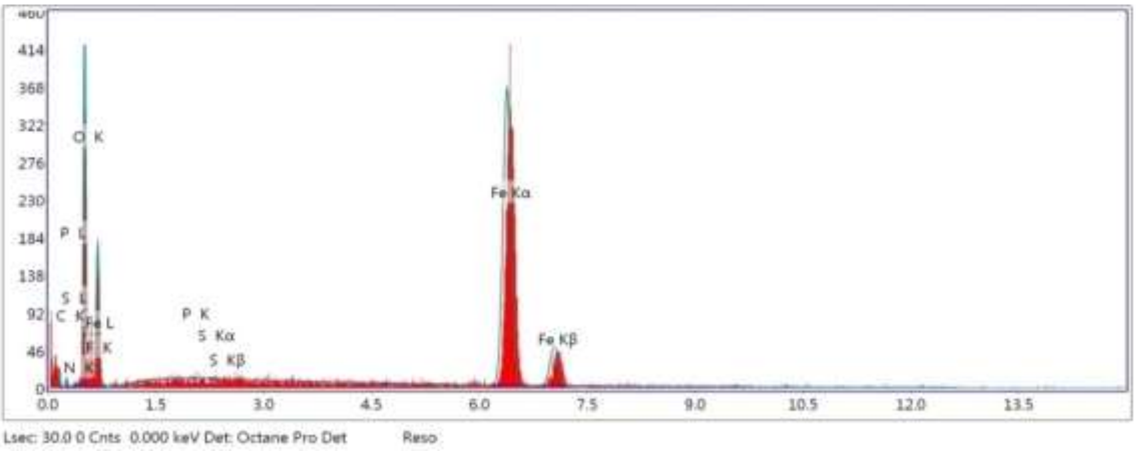


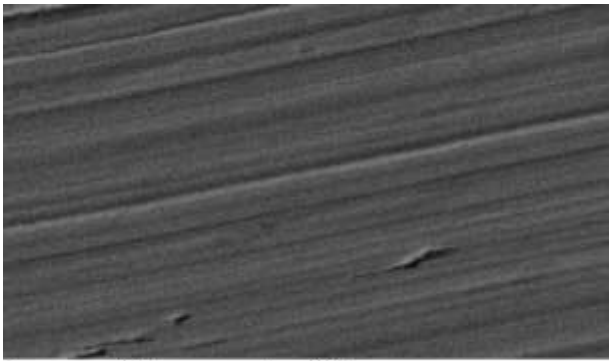
Figure 13. EDS analysis on CS in nonexistence and existence of Egy - dronate drug that immersion one days

Slika 13. EDS analiza ugljeničnog čelika u odsustvu i prisustvu leka Egi-dronate koji se potapaju jedan dan

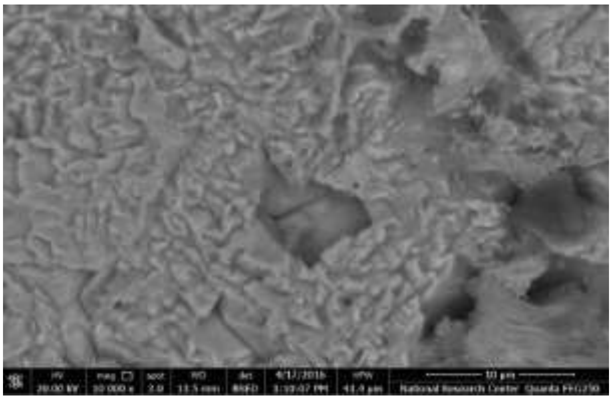
3.10. SEM microscopy

Figure 14, represents the micrograph is obtained of CS samples after exposure to 1M HCl only and 1MHCl containing 300 ppm Egy-dronate for one day immersion.

Pure sample - čist uzorak



Blank - prazan uzorak



In 300 ppm of Egy - dronate

U prisustvu 300 ppm leka Egi-dronat

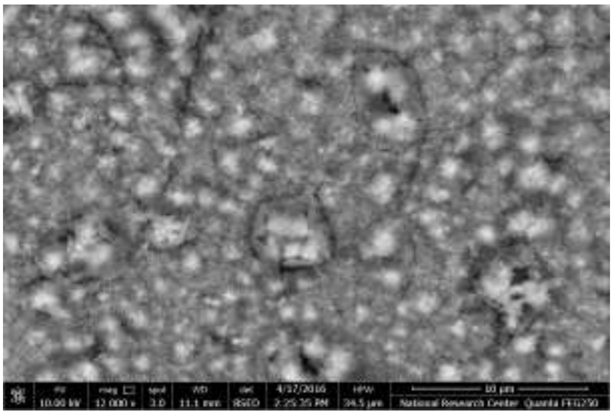


Figure 14. SEM micrographs for CS in nonexistence and existence of 300 ppm of Egy - dronate inhibitor

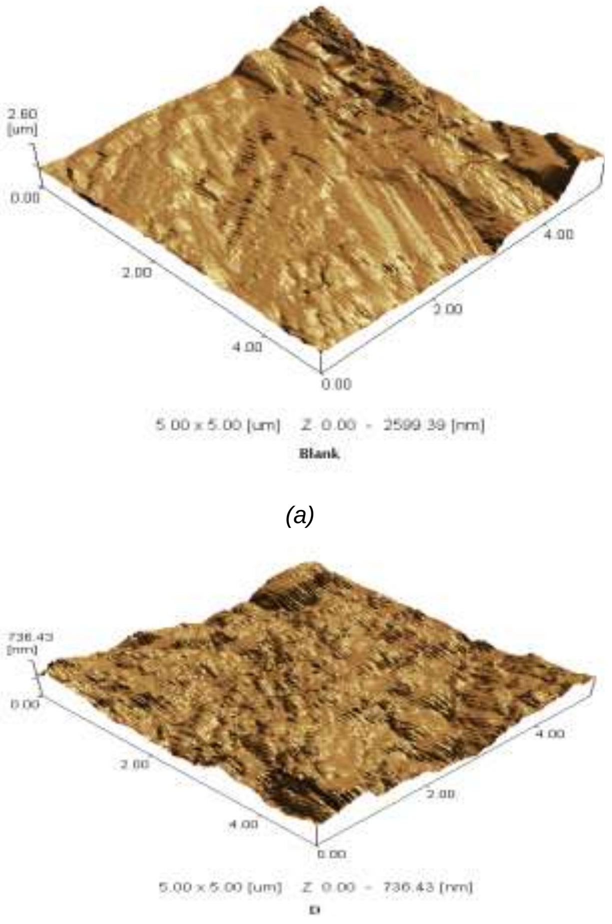
Slika 14. SEM mikrografija za ugljenični čelik u odsustvu i prisustvu 300 ppm inhibitora Egi-dronata

It is important to stress out that when the compound is exists in the solution, the morphology of CS alloy surfaces are quite different from the previous one, the specimen surfaces were very smooth. We observed the formation of a film which is distributed in a random way on the whole surface of the CS alloy. This may be interpreted as due to the adsorption of the Egy – dronate drug on the CS alloy surface incorporating into the passive film in order to block the active site present on the CS alloy surfaces. Or due to the involvement of drug molecules in the interaction with the active sites of CS alloy surface, resulting in a decrease in the contact between CS alloy and the corrosive medium and sequentially exhibited excellent inhibition effect [56-57].

3. 11. AFM Microscopy

AFM is a powerful tool to investigate the surface morphology of various samples at nano-micro scale that is currently used to study the influence of corrosion inhibitor on metal solution interface. From the analysis, it can be gained regarding the roughness (Ra) on the surface. The roughness profile values play an important role in identifying and report the efficiency of the drug under study. Among the Ra take a role in explanation about the nature of the adsorbed film on the surface [45-46].

Figure (15), shows the 3D images as well as elevation profiles of polished CS in absence and present Egy - dronate drug as an inhibitor. It was observed in Figure (15), that the surface of CS specimen which exposed to corroded solution (a) affects CS surface with large and deep crack but the surface in specimen (b) was covered by thin film. The conclusion, that the adsorption film can protects the surface of the metal from corrosion process. Analysis of the values indicated higher values of roughness parameter reached. The mean roughness (Ra) was found to be (2.60 µm) for the specimen placed in 1M HCl for one day. The observation of the metal surface which immersed in 1M HCl in presence of 300 ppm of Egy - dronate drug possess Ra (738.34 nm) which is very small compared to the blank value. The decrease in the Ra value reflected the adsorption of drug molecules on metal surface thereby reducing the rate of corrosion.



(a)

(b)

Figure 15. The 3D of optical images of AFM in nonexistence (a) and existence (b) of Egy - dronate drug

Slika 15. 3D optičke slike AFM u odsustvu (a) i prisustvu (b) leka Egi-dronat

4. CONCLUSIONS

1. The tested Egy – dronate drug establish a very good inhibition for CS corrosion in HCl solution.
2. Egy - dronate inhibit the CS corrosion by adsorption on its surface and make layer film.
3. The inhibition efficiencies of the tested compound increase with increasing of their concentrations.
4. Double layer capacitances decrease with respect to blank solution when the inhibitor added. This fact may explained by adsorption of the inhibitor molecule on the CS surface.
5. The adsorption of Egy - dronate compound on CS surface in HCl solution applied by Langmuir adsorption isotherm.
6. The values of inhibition efficiencies obtained from the different independent techniques used showed the validity of the obtained results.

5. REFERENCES

[1] G.Trabanelli (1991) Inhibitors - an old remedy for a new challenge Corrosion, 47, 410-419.

[2] D.N.Singh, A.K. Dey (1993) Synergistic Effects of Inorganic and Organic Cations on Inhibitive Performance of Propargyl Alcohol on Steel Dissolution in Boiling Hydrochloric Acid Solution Corrosion, 49, 594-600.

[3] G.Banerjee, S.N.Malhotra (1992) Contribution to the adsorption of aromatic amines on mild steel surfaces from HCl solutions by impedance, UV and Raman spectroscopy Corrosion-NACE, 48, 10-15.

[4] S.T.Arab, E.A.Noor (1993) Inhibition of Acid Corrosion of Steel by Some S-Alkylisothiouronium Iodides, Corrosion, 49, 122-129.

[5] I.A.Raspini (1993) Influence of Sodium Salts of Organic Acids as Additives on Localized Corrosion of Aluminum and Its Alloys, Corrosion, 49, 821-828.

[6] N.Hajjaji, I.Ricco, A.Srhiri, A. Lattes, M.Soufiaoui, A.Benbachir (1993) Effect of N-Alkylbetaines on the Corrosion of Iron in one molar hydrochloric acid Solution, Corrosion, 49, 326-334.

[7] M.Elachouri, M.S.Hajji, M.Salem, S.Kertit, R Coudert, E.M. Essassi (1995) Some surfactants in the series of 2-(alkyldimethylammonio) alkanol bromides as inhibitors of the corrosion of iron in acid chloride solution, Corros.Sci., 37,381-389.

[8] H. Luo, Y.C.Guan, K.N.Han (1998) Inhibition of mild steel corrosion by sodium dodecyl benzene sulfonate ... and Sodium Oleate in Acidic Solutions, Corrosion, 54, 619-627.

[9] M.A.Migahed, E.M.S.Azzam, A.M.Al-Sabagh (2004) Corrosion inhibition of mild steel in 1 M sulfuric acid solution using anionic surfactant, Mater.Chem.Phys., 85, 273-279.

[10] M.M.Osman, A.M.Omar, A.M. Al-Sabagh (1997) Corrosion inhibition of benzyl triethanol ammonium chloride and its ethoxylate on steel in sulphuric acid solution, Mater.Chem.Phys., 50, 271- 274.

[11] F.Zucchi, G.Trabanelli, G.Brunoro (1992) The influence of the chromium content on the inhibitive efficiency of some organic compounds, Corros. Sci., 33,1135-1139.

[12] R.F.V Villamil, P.Corio, J.C.Rubim, M.L.Siliva Agostinho (1999) Effect of sodium dodecylsulfate on copper corrosion in sulfuric acid media in the absence and presence of benzotriazole, J.Electroanal.Chem., 472, 112-119.

[13] T.P.Zhao, G.N.Mu (1999) the adsorption and corrosion inhibition of anion surfactants on aluminium surface in hydrochloric acid, Corros. Sci., 41, 1937-1944.

[14] S.S.Abd El Rehim, H.Hassan, M.A.Amin (2001) Corrosion inhibition of aluminum by 1,1(lauryl amido) propyl ammonium chloride in HCl solution, Mater. Chem. Phys., 70, 64-72.

[15] S.S.Abd El Rehim, H.Hassan, M.A. Amin (2003) The corrosion inhibition study of sodium dodecyl benzene sulphonate to aluminium and its alloys in 1.0 M HCl solution, Mater. Chem. Phys., 78, 337-348.

[16] R.Guo, T.Liu, X.Wei (2002) Effects of SDS and some alcohols on the inhibition efficiency of corrosion for nickel, Colloids Surf., A, 209, 37-45.

[17] V.Branzoi, F.Golgovici, F.Branzoi (2002) Aluminium corrosion in hydrochloric acid solutions and the effect of some organic inhibitors, Mater. Chem. Phys., 78, 122-131.

[18] R.Oukhrib, B. El Ibrahimi, H. Bourzi, K. El Mouaden, A.Jmiai, S.E.Issami, L.Bammou, L.Bazzi (2017) Quantum chemical calculations and corrosion inhibition efficiency of biopolymer “chitosan” on copper surface in 3% NaCl, JMES, 8 (1), 195-208.

[19] A.M.Al-Azzawi, K.K.Hammud (2016) Newly antibacterial / anti-rusting oxadiazoleporomellitic di-imids of CS / hydrochloric acid interface: Temkin isother model, IJRPC, 6(3), 391-402.

[20] L. E.Ouasif, I.Merimi, H.Zarrok, M.El Ghoul, R. Achour, M.Guenbour, H.Oudda, F.El-Hajjaji, B. Hammouti (2016) Synthesis and inhibition study of CS corrosion in hydrochloric acid of a new surfactant derived from 2-mercaptobenzimidazole , J. Mater. Environ. Sci., 7 (8), 2718-2730.

[21] U.M.Sani, U.Usman (2016) Electrochemical Corrosion Inhibition of Mild Steel in Hydrochloric Acid Medium Using the Antidiabetic Drug Janumet as Drug, International Journal of Novel Research in Physics Chemistry & Mathematics, 3(3), 30-37.

[22] A.M. Kolo, U.M. Sani, U. Kutama, U.Usman (2016) Adsorption and Inhibitive Properties of Januvia for the Corrosion of Zn in 0.1 M HCl,Pharmaceutical and Chemical Journal, 3 (1),109-119.

[23] P.O.Ameh, U.M.Sani (2015) Cefuroxime Axetil: A Commercially Available Pro-Drug as Corrosion Drug for Aluminum in Hydrochloric Acid Solution, Journal of Heterocyclics, 1(1), 2 – 6.

[24] H.I. Al-Shafey, R.S.Abdel Hameed, F.A.Ali, A.S. Aboul-Magd, M.Salah (2014) Effect of Expired Drugs as Corrosion Drugs for CS in 1M HCL Solution, Int. J. Pharm. Sci. Rev. Res., 27(1), 146-152.

[25] R.Kushwah, R.K.Pathak (2014) Inhibition of Mild Steel Corrosion in 0.5 M Sulphuric Acid Solution by Aspirin Drug, International Journal of Emerging Technology and Advanced Engineering, 4(7), 880-884.

[26] A.S.Fouda, M.N. EL-Haddad, Y.M. Abdallah (2013) Septazole: Antibacterial Drug as a Green Corrosion Drug for Copper in Hydrochloric Acid Solutions, IJIRSET, 2 (12), 7073-7085.

[27] S.U.Ofoegbu, P.U.Ofoegbu (2012) Corrosion inhibition of mild steel in 0.1 M hydrochloric acid media by chloroquine diphosphate , ARPN Journal of Engineering and Applied Sciences, 7(3), 272-276.

[28] F.Bentiss Traisnel, M.Lagrenee (2000)The substituted 1,3,4-oxadiazoles: a new class of corrosion inhibitors of mild steel in acidic media, Corros.Sci., 42, 127-146.

[29] M.A.B. Christopher, A.R.G. Isabel Jenny (1994) the electrochemical behavior and corrosion of aluminum in chloride media. The effect of inhibitor anions, Corros. Sci., 36, 915-923.

[30] M. Elachouri, M.S.Hajji, M.Salem, S.Kertit, J. Aride, R.,Coudert, E.Essassi (1996) Some Nonionic Surfactants as Inhibitors of the Corrosion of Iron in Acid Chloride Solutions, Corrosion, 52, 103-108.

[31] A.S.Algaber, E.M. El-Nemma, M.M. Saleh (2004) Effect of octylphenol polyethylene oxide on the corrosion inhibition of steel in 0.5 M H_2SO_4, Mater. Chem. Phys., 86, 26-32.

[32] V.Branzoi, F.Golgovici, F.Branzoi (2002) Aluminum corrosion in hydrochloric acid solutions and the effect of some organic drugs, Mater. Chem. Phys., 78, 122-131.

[33] G.N.Mu, T.P.Zhao, M.Liu, T.Gu (1996) Effect of Metallic Cations on Corrosion Inhibition of an Anionic Surfactant for Mild Steel , Corrosion, 52, 853-856.

[34] J. Lipkowski, P.N. Ross (Eds.) (1992) Adsorption of Molecules at Metal Electrodes, VCH, New York.

[35] S. L. F. A., Da Costa and S. M. L. Agostinho (1989) Electrochemical studies of cu-Al Alloys in Sulphate – SciELO, Corrosion, 45, 472 – 477.

[36] J.Aljourani, K.Raeissi, M.A.Golozar (2009) Benzimidazole and its derivatives as corrosion inhibitors for mild steel in 1M HCl solution, Corros. Sci., 51, 1836-1843.

[37] H.Amar, A.Tounsi, A.Makayssi, A.Derja, J. Benzakour, A.Outzourhit (2007) Corrosion inhibition of Armco iron by 2-mercaptobenzimidazole in sodium chloride 3% media, Corros. Sci., 49, 2936-2945.

[38] M.A.Migahed, E.M.S. Azzam, S.M.I. Morsy (2009) Electrochemical behaviour of carbon steel in acid chloride solution in the presence of dodecyl cysteine hydrochloride self-assembled on gold nanoparticles, Corros.Sci., 51, 1636-1644.

[39] S.Bllglc, N.Caliskan (2001) An investigation of some Schiff bases as corrosion inhibitors for austenitic chromium-nickel steel in H_2SO_4, Applied Electrochemistry, 31, 79-83.

[40] H.Ashassi-Sorkhabi, N.Ghalebsaz-Jeddi (2005) Inhibition effect of polyethylene glycol on the corrosion of carbon steel in sulphuric acid, Mater. Chem. Phys., 92, 480-486.

[41] B.B.Damaskin, O.A.Petrii, V.V.Batrakov (1971) Adsorption of Organic compounds on Electrodes, Plenum Press, New York.

[42] I.Al-shafey, M.A..Abass, A. A.Hassan, S. A. Sadeek (2014) Corrosion inhibition of carbon steel in 1M HCl Solution by Schiff base compound obtained from 1,3-Diaminopropane, IJABC, 3, 1004-1015.

[43] A.S.Fouda, A.M.El-Wakeel, KShalabi, A.El-Hossiany (2015) Corrosion inhibition for carbon Steel by Levofloxacin Drug in Acidic Medium, Elixir Corrosion &Day, 83, 33086-33094.

[44] O. A. Hazazi, A. Fawzy, M.Awad (2014) Synergistic Effect of Halides on the Corrosion Inhibition of Mild Steel in H_2SO_4 by a Triazole Derivative: Kinetics and Thermodynamic Studies, Int. J. Electrochem. Sci., 9, 4086 – 4103.

[45] A.S.Fouda, M.M.Gouda, S.I.Abd El-Rahman (2000) Benzaldehyde, 2-Hydroxybenzoyl Hydrazone Derivatives as Inhibitors of the corrosion of Aluminum in hydrochloric Acid, Chem. Pharm. Bull., 48 (5), 636- 640.

[46] A.S.Fouda, G.El-Ewady, A.H.Ali (2017) Corrosion Protection of Carbon Steel by using Simvastatin Drug in HCl Medium, Journal of Applicable Chemistry, 6 (5), 701-718.

[47] A.S. Fouda, A.M.El- Defrawy, M.W.El-Sherbeni (2012) Pharmaceutical compounds as save corrosion inhibitors for carbon steel in 1M H_2SO_4 solution, Reprint form the Mansoura, J.Chemistry, 39 (2), 1-27.

[48] A.S.Fouda, A.A. Al-Sarawy, E.E.El-Katori (2006) Pyrazolone derivatives as corrosion inhibitors for Mild steel HCl solution, Desalination, 201,1-13.

[49] E.Bayol, K.Kayakirilmaz, M.Erbil (2007) the inhibitive effect of hexamethylenetetramine on the acid corrosion of steel, Mater. Chem. Phys., 104, 74-82.

[50] O.Benalli, L.Larabi, M.Traisnel, L. Gengembra, Y. Harek (2007) Electrochemical, theoretical and XPS studies of 2-mercapto-1-methylimidazole adsorption on mild steelin 1 M $HClO_4$, Appl. Surf. Sci., 253, 6130-6139.

[51] I.Epelboin, M. Keddam, H.Takenouti (1972) Use of impedance measurements for the determination of the instant rate of metal corrosion, J. Appl. Electrochem., 2, 71-79.

[52] E.Kus, F.Mansfeld (2006) Evaluation of the Electrochemical Frequency Modulation (EFM) Technique, Corros. Sci., 48, 965-979.

[53] G.A.Caigman, S.K.Metcalf, E.M.Holt (2000) Thiophene substituted dihydropyridines, J.Chem. Cryst., 30, 415-422.

[54] R.W. J. Bosch Hubrecht, W.F. Bogaerts, B.C. Syrett (2001) Electrochemical Frequency Modulation: A New Electrochemical Technique for Online Corrosion Monitoring, Corros. Sci., 57, 60-70.

[55] A.S.Fouda, Y.M. Abdallah, D. Nabil (2014) Dimethyl pyrimidine Derivative as Corrosion inhibitors for Carbon Steel in Hydrochloric Acid solutions, IJIRSET, 3,12965-12982.

[56] Y.Yelri Enriadi, N.Jamarun Gunawarman (2014) Corrosion Inhibition Efficiency of mild Steel in Hydrochloric Acid by Adding theobroma Cacao Feel Extract, BCES, 14, 15-19.

[57] H.Otmocic Curkovic, K.Marusic, E. Stupnisek-Lisac, J. Telegdi (2009) Electrchemical and AFM study of Corrosion Iinhibition with Respect to Application Method, Chem. Biochem. Eng. Q., 23 (1), 61- 66.

[58] S.B.Pralhibha, P.Kotteeswaran, V.Bheema Raju (2012) Study on the inhibition of MU steel Corrosion by Cationic Surfactant in HCl Medium, IOSR Journal of Applied Chemistry (IOSRJAC), 2, 45-53.

IZVOD

EGIDRONAT KAO PERSPEKTIVNI INHIBITOR KOROZIJE UGLENIČNOG ČELIKA U VODENIM RASTVORIMA

Uticaj Egi-dronata kao inhibitora korozije ugljeničnog čelika u 1M HCl proučavan je gubitkom težine, procenom vodonika, potencijalom otvorenog kola, potentiodinamičkom polarizacijom, elektrohemijskom spektroskopskom impedancijom, modulacijom elektronske frekvencije i ispitivanjem površina uzoraka atomskom mikroskopijom (AFM), spektroskopijom disperzije energije (EDS) i skenirajućom elektronskom mikroskopijom (SEM). Rezultati efikasnosti inhibicije (IE%) povećavaju se s povećanjem koncentracije inhibitora, ali se smanjuju sa podizanjem temperature. Adsorpcija Egi-dronata na ugljeničnoj - čeličnoj površini podudara se sa Langmuirovom adsorpcionom izotermom. Proces adsorpcije je spontana, endotermna i fizička adsorpcija. Polarizacijske krive pokazuju da je Egi-dronat mešoviti inhibitor koji ima tendenciju anodnom tipu. Rezultati dobijeni hemijskim i elektrohemijskim tehnikama su dobar kvalitet odogovora i daju isto ponašanje adsorpcije Egi-dronata. Sve tehnike su dokazale formiranje tankog filma na površini metala kao zaštitnu oblogu, kako bi se sprečio metal da se razlaže u korozivnom medijumu, zbog elektrostatičke privlačnosti između nerastvornih elektrona molekula inhibitora i pozitivnih mesta na površini metala.

Ključne reči: *inhibicija korozije, HCl, ugljenični čelik, adsorpcija, SEM, EDKS, AFM.*

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