https://doi.org/10.30799/jaec.050.18040101 J. Adv. Electrochem. - Volume 4 Issue 1 (2018) 152–157

ISSN: 2455-0205

Share Your Innovations through JACS Directory

Journal of Advanced Electrochemistry

Visit Journal at http://www.jacsdirectory.com/jaec

Electrochemical Study of Candesartan Drug as Corrosion Inhibitor for Carbon Steel in Acid Medium

Adel H. Ali*

Department of Medicinal Chemistry, Faculty of Medical Science, Taiz University, Yemen.

ARTICLE DETAILS

Article history:
Received 07 April 2018
Accepted 21 April 2018
Available online 26 April 2018

Keywords:
Corrosion Inhibition
Carbon Steel
Adsorption

ABSTRACT

Candesartan drug was utilized as an inhibitor for carbon steel (CS) corrosion in 1 M HCl by utilizing many techniques: weight loss (WL), electrochemical frequency modulation (EFM), electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization (PP) techniques. WL is investigated at various temperatures between (25 – 45 °C) but all electrochemical studies at room temperature. The inhibition efficiency (% IE) increment with expanding doses of the Candesartan drug. The activation and the adsorption parameters were investigated and calculated by the effect of temperature on the inhibition of corrosion. The adsorption of the Candesartanon CS surface was found to obey with Langmuir adsorption model. The morphology of inhibited CS was analyzed by the energy dispersive X-ray spectroscope (EDX), atomic force microscopy (AFM) and scanning electron microscope (SEM). All techniques were utilized to examine the corrosion inhibition of the drug and confirm the formation thin film adsorbed on the metal surface and prevent the corrosion process. Polarization data revealed that this drug affect both anodic and cathodic reactions.

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, cheap, friendly to the environment and easily 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 facilitate 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 for the most part concur that medications are inhibitors that can compete favorably with green inhibition of corrosion and that most medications can be synthesized from natural products. 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 [18-22]. A few medications have been discovered to be a great corrosion inhibitors for metals such as: biopolymer gave 86% IE for Cu in NaCl [23], pyromellitic diimide linked to oxadiazole cycle gave 84.6% IE for CS in HCl [24], 2-mercaptobenzimidazole gave 82% IE for CS in HCl [25], antidiabetic drug janumet gave 88.7% IE for MS in HCl [26], januvia gave 79.5% IE for Zn in HCl[27], cefuroxime axetil gave 89.9% IE for Al in HCl [28], phenytoin sodium gave 79% for CS in HCl [29], aspirin gave71% IE for MS in H_2SO_4 [30], septazole gave 84.8% IE for Cu in HCl [31] and chloroquine diphosphate gave 80% IE for MS in HCl [32].

The scope of this paper is to use Candesartan 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 Methods

2.1 Metal Sample

The composition of metal sample is listed in Table 1.

Table 1 The component of the CS under study (wt%)

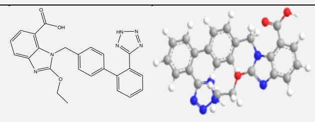
Constituent	C	Mn	P	Si	Iron
Composition %	0.2	0.6	0.04	0.003	Rest

2.2 Chemicals

2.2.1 Inhibitor

Candesartan drug is an organic compound which describing in Table 2. The pharmaceutical drug, which was investigated, is purchased from Sandozinc and Pfizer Inc companies.

Table 2 The Component and molecular structure of the investigated drug

Comp.	Structure	IUPAC name	Mw.	Chemical formula
Candesartan		2-ethoxy-3-[[4-[2-(2H-tetrazol-5-yl) phenyl] phenyl] methyl] benzimidazole -4-carboxylic acid	440.45	$C_{24}H_{20}N_6O_3$

2.2.2 Corrosive Medium

The corrosive medium is 1 M HCl, which prepared by diluted the (37%) HCl with distill water and the different concentrations of inhibitor (50, 100, 150, 200, 250 and 300 ppm) were prepared by dilution.

2.3 Experimental Techniques

2.3.1 Weight Loss (WL) Technique

For WL estimations, coins have the area surface (2 cm x 2 cm) x 2 that presented to the destructive solution that utilized. The coins were scraped with SiC polisher sheet coarseness sizes (400, 800 and 1200) and clean with $(CH_3)_2CO$. At that point, clean a few times with bi-distilled water, lastly dried by soft tissue. The WL estimations were done in a 100 mL glass-measuring beaker put in an indoor regulator thermostat or water path. The coins were then quickly dipped in the test medium in nonexistence and existence dissimilar doses of the examined compound.

---

*Corresponding Author:Adelchemst22@gmail.com(Adel H. Ali)

https://doi.org/10.30799/jaec.050.18040101

Cite this Article as: Adel H. Ali, Electrochemical study of candesartan drug as corrosion inhibitor for carbon steel in acid medium, J. Adv. Electrochem. 4(1) (2018) 152–157.

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

The % IE and surface coverage (θ) of Candesartan for the corrosion of CS were determinate from the following equation [33]

$$IE\% = \theta x100 = [1-(W/W^\circ)] \text{ x } 100 \quad (1)$$

where, W° and W are the WLs in the nonexistence and existence of adding various doses of investigate drug respectively.

C-steel used for anodic and cathodic Tafel polarization measurements and AC impedance measurements, a cylindrical rod embedded in araldite with exposed surface area of 1.0 cm^2 was employed. Prior to each experiment the surface of Fe specimens were mechanically polished with different grades of emery paper, degreased with acetone and rinsed by distilled water.

2.3.2 PP Technique

Polarization tests were done in a traditional three-anode cell with a Pt counter electrode terminal and an immersed calomel pool (SCE) as the reference pool. The working electrode, which consists of a square sheet from CS settled in epoxy resin like polytetrafluoroethylene, which don't affect by acid and covered the coin sample until the level surface that have 1.0 cm^2 area. The working terminal was polished with SiC polisher papers. Before estimation, the electrode was submerged in corrosive medium at normal potential for 30 min. until the point when an enduring or steady state was come to.

The potential of open circuit (E_{ocp}) started in the blank -533 mV and the presence different doses of Candesartan drug started from -497 to 470.2 mV. All tests were done in newly arranged or preparing corrosive medium at room temperature and the data were constantly rehashed no less than three times to check the accuracy or valid results. Determination of % IE and the θ as below [34]:

$$\% \, IE \ = \ \theta \ \times 100 \ = \left[1 \ - \ \frac{i_{corr(inh)}}{i_{corr(free)}} \right] \times 100 \quad (2)$$

where, $i_{corr(free)}$ and $i_{corr(inh)}$ are the densities of oxidation current in the nonexistence and existence of Candesartan drug as an inhibitor, in that order.

2.3.3 EIS Technique

All EIS measuring data were performing at open circuit potential E_{ocp} at 25±1 °C more than a broad frequency range of (1x10^5 Hz to x 0.1 Hz). The perturbation potential was 10 mV in abundance peak to peak. The obtain diameters of the capacitive loops raise in occurrence of Candesartan drug, and are indicated of the capacity of the extent of inhibition of oxidation progression, contrary to the diminished of the capacitance of double layers (C_{dl}) which is determination by:

$$C_{dl} \ = \frac{1}{(2\pi f_{max} R_p)} \quad (3)$$

where, f_{max} is the highest frequency.

The % IE and the (θ) acquired from the impedance estimations were characterized by the accompanying connection:

$$\% \, IE \ = \ \theta \ \times 100 \ = \left[1 \ - \ \frac{R_p^o}{R_p} \right] \times 100 \quad (4)$$

where, R°_p and R_p are resistance of the charge move in the nonattendance and nearness of Candesartan, separately.

2.3.4 EFM Technique

The large peaks were utilized for the determination of the corrosion current density (i_{corr}), the Tafel inclines (β_c and β_a) and the causality factors CF_2 and CF_3 [35, 36].

The % IE_{EFM} was calculated as follows:

$$\% \, IE_{EFM} = \left[1 \ - \ \frac{i_{corr}}{i_{corr}^o} \ \right] \times 100 \quad (5)$$

where, i^o_{corr} and i_{corr} are densities of the corrosion current in the nonexistence and existence of Candesartan drug.

All potentiodynamic, open circuit potential, EIS and EFM as electrochemical analysis were investigated by utilizing Gamry tool PCI300/4.

2.3.5 Surface Examinations

The CS specimens utilized for analysis of surface morphology were prepared in 1M HCl acid (blank) and with 300 ppm of Candesartan at room temperature for one day after abraded automatically utilizing various emery sheets up to 1200 gravel size. Then, after this the coins were dipped in corrosive medium at even time, the coins were cleaned quietly with distill water, charily dried and mount into the performed specimens examined by using SEM, EDX and AFM.

3. Results and Discussion

3.1 WL Measurement

The WL of CS relative to the surface area at different times in the nonexistence and existence of various doses (50, 100, 150, 200, 250 and 300 ppm) of the Candesartan. The bends lines or curves acquired within the sight of various doses of drug fall essentially underneath that of free corrosive medium as appeared in Fig. 1.

The % IE is recorded in Table 3. In all cases, the IE of the drug increment with expanding doses of drug but the rate of corrosion were decreased. These results indicated that, the Candesartan under study are good substance that prevent CS oxidation in corrosive medium.

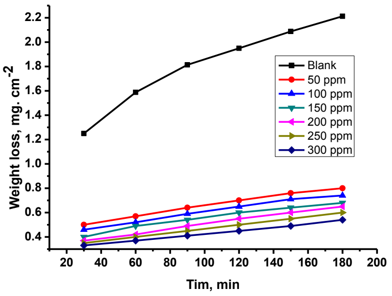


Fig. 1 W L-time bending curves for the oxidation of CS in the nonexistence and existence of various doses of Candesartan at 25 °C

Table 3 Variation of % IE of Candesartan with various doses at 25 °C from WL testing at 120 min dipping in 1 M hydrochloric acid

Compound	Conc. ppm	K_{corr} x 10^{-3} mgcm^{-2} min^{-1}	% IE
Blank	-----	16.25	-----
Candesartan	50	5.42	66.7
	100	5.00	69.2
	150	4.58	71.8
	200	4.25	73.9
	250	4.00	75.4
	300	3.83	76.4

3.1.1 Temperature Effect

Study the effect of temperature by applied Arrhenius equation and the rate of corrosion (k_{corr}.) can be determined:

$$\log k_{corr} \ = \ A - \left[\frac{E_a}{2.303 \, RT} \right] \quad (6)$$

where, E_a is the activation of inhibition for the oxidation of CS in corrosive medium in nonexistence and existence of Candesartan inhibitor, R is universal gases constant, T is absolute temperature and A is Arrhenius pre-exponential consistent relies upon the metal sort and electrolyte. Arrhenius plots of log k_{corr}. versus (1/T) for CS in 1 M hydrochloric acid in the nonexistence and existence of various doses of Candesartan drug is shown graphically in Fig. 2. The variety of log k_{corr} versus (1/T) is straight lines and the estimation of E_a got are recorded in Table 4. These outcomes propose that the drug is comparative in the system of activity. The expansion in E^*_a with the expansion of various doses of inhibitor, demonstrating that, the energy limit for the oxidation-reduction expanded. After additionally shown that the entire procedure is controlled by the relative of surface corroded occurs, since the actuation energy of the consumption oxidation process is more than 20 kJ mol^{-1} [37].

The (ΔS^*, ΔH^*) of activation are determinate from the theory of transition state by applied the following relation [38].

$$k_{corr} \ = \left[\frac{RT}{Nh} \right] \exp(\frac{\Delta S^*}{R}) \ \exp\left(\frac{\Delta H^*}{RT}\right) \quad (7)$$

where, N is Avogadro's number, h is Planck's constant. A plot of log (k_{corr}/T) versus (1/T) likewise gave straight lines as appeared in Fig. 3, for CS dissolution in one molar hydrochloric acid in the absence and presence of changed doses of Candesartan. The slopes of these lines equal -ΔH^*/2.303R and the intercept rise to log [RT/Nh] + (ΔS^*/2.303R), that the estimation of ΔH^o and ΔS^* were determination and recorded in Table 4.

https://doi.org/10.30799/jaec.050.18040101

Cite this Article as: Adel H. Ali, Electrochemical study of candesartan drug as corrosion inhibitor for carbon steel in acid medium, J. Adv. Electrochem. 4(1) (2018) 152–157.

These outcomes demonstrate that they the used compound acts as inhibitor. The estimations of ΔH^* are reflected the strength of the adsorption of this drug on CS surface. The estimations of ΔS^* without and with the used compound is large and negative; this demonstrates that the rate-deciding step is association rather than dissolution [39].

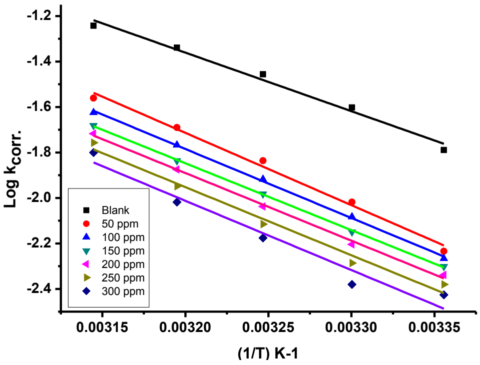


Fig. 2 Diagram (log k_{corr} vs 1/ T) for oxidation of CS in HCl acid in the nonexistence and existence of various doses of Candesartan

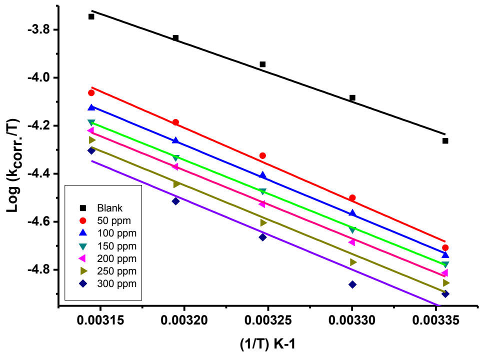


Fig. 3 Diagram (log k_{corr} / T) vs (1/ T) for oxidation of CS in 1 M HCl in the nonexistence and existence of variant doses of Candesartan at 25 °C

Table 4 E^*_a, ΔH^* and ΔS^*variables for the oxidation of CS in 1 M hydrochloric acid in the nonexistence and existence of variant doses of tested drug

Conc. Ppm	Activation parameters E^*_a kJmol^{-1}	 ΔH^* kJmol^{-1}	 $-\Delta S^*$ Jmol^{-1}K^{-1}
Blank	42.3	40.4	142.2
50	53.8	52.1	111.5
100	54.1	52.5	111.4
150	54.9	53.4	109.9
200	57.5	55.9	102.5
250	62.1	60.9	87.9
300	67.0	65.9	72.8

3.1.2 Adsorption Isotherms

Candesartan adsorbed on the metal and the values of (θ) for various doses of drug in one molar hydrochloric acid was determinate from WL data utilizing the follows relation:

$$\theta = \left[\frac{weight\ loss_{(pure)} - weight\ loss_{(inh)}}{weight\ loss_{(pure)}}\right] \qquad (8)$$

From the Θ values, it is obvious that increment with raising the doses of Candesartan. By utilizing these values and for applying various adsorption isotherms Langmuir adsorption was found the best one and to follow the next relation [40].

$$C/\theta = 1/K_{ads} + C \qquad (9)$$

where K_{ads} is the equilibrium constant of adsorption. Plotting (C/Θ) against (C) of Candesartan at various temperatures is shown in Fig. 4. The linear relationship is given with intercept equal to ($1/K_{asd.}$) and slope similar the unity, the adsorption constant being result to the standard free energy of ΔG^o_{ads} by follows:

$$\Delta G^o_{ads} = -RTln\,(55.5\ K_{ads}) \qquad (10)$$

where, R is the general gas constant, T is the absolute temperature and 55.5 is the doses of water in the solution in M/L. The ΔG^o_{ads} values at all studied at different temperatures, which determined by above equation (13) and recorded in Table 5. The ($\Delta H^o_{ads.}$) was determined according to the Van't Hoff equation [41].

$$\log k_{ads} = \left(\frac{-\Delta H^{\circ}_{ads}}{2.303RT}\right) + constant \qquad (11)$$

Plotting (log $K_{ads.}$) against (1/T) give straight lines as shown in Fig. 5, the straight lines give slope equal ($\Delta H^o_{ads.}$/2.303R), from this slope; the ΔH^o_{ads} values were calculated and are listed in Table 5. Then by applying the following equation:

$$\Delta G^o_{ads} = \Delta H^o_{ads.} - T\Delta S^o_{ads.} \qquad (12)$$

From introducing the values of ΔG^o_{ads} and $\Delta H^o_{ads.}$, the ΔS^o_{ads} was calculated at all studied temperatures from the above Eq.(12). All thermodynamic adsorption parameters for Candesartan inhibitor on CS from 1M HCl medium can be concluded that:

1. The correlation coefficients between (0.99 - 0.98) reflected that the experimental data give good curves fitting for the adsorption isotherm, and K_{ads} values increase with increasing temperatures from 25 to 45 °C
2. The negative values of ΔG^o_{ads} reflect that the adsorption of Candesartan on CS surface in 1 M hydrochloric acid solution is spontaneous process.
3. The ΔG^o_{ads} values are around -19 kJmol^{-1} or less lead to the Van Der Waal's forces or electro-static attraction between positive charged of metal surface or vacant space in valance orbital's of the metal surface and the negative charge of Candesartan molecules in the bulk of the medium i.e. physical adsorption.
4. The negative sign of ΔH^o_{ads} refer to the adsorption of inhibitor molecules is an exothermic process, indicating that the adsorption is physical adsorption. The unshared pairs electron from investigate molecule may attractive with positive center on the surface of CS by electrostatic attraction to provide a protective film prevent corrosion process [42].
5. The ΔS^o_{ads} values, in the existence of the investigate drug are negative and large that is accompanied with exothermic adsorption process [43].

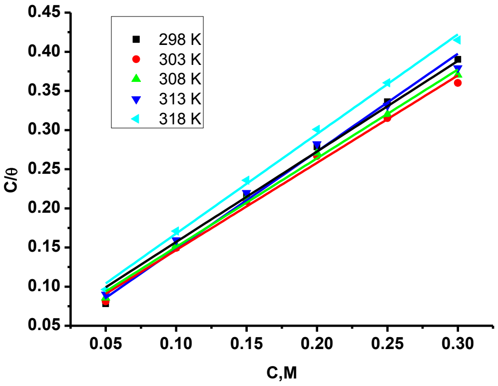


Fig. 4 Diagram illustrate the Langmuir adsorption that plotted (log C) against (C/θ) of the Candesartan drug for corrosion of CS in 1 M HCl from WL technique at 25 °C

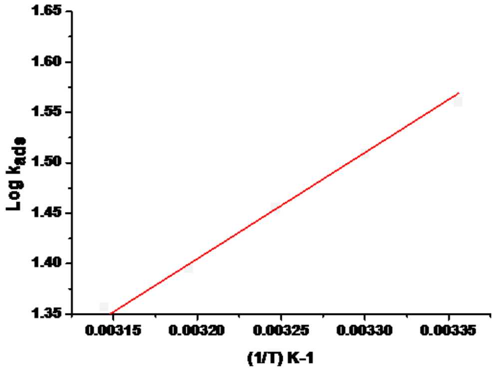


Fig. 5 (log K_{ads}) vs (1/T) for the corrosion of CS in 1 M HCl in the existence of Candesartan at various temperatures

Table 5 K_{ads} and adsorption free energy (ΔG°_{ads}) for the adsorption of Candesartan on CS in 1 M hydrochloric acid from WL method at 25 °C

Temp. °C	K_{ads} M^{-1}	$-\Delta G^{o}_{ads}$ kJ mol^{-1}	$-\Delta H^{o}_{ads}$ kJ mol^{-1}	$-\Delta S^{o}_{ads}$ J mol^{-1}K^{-1}
25	42.55	19.25		3.06
30	28.44	18.55		5.30
35	26.79	18.71	20.16	4.72
40	24.17	18.74		4.52
45	24.63	19.09		3.36

3.4 Potentiodynamic Polarization Technique (PP)

PP is carrying out in 1 M HCl acid medium in the nonexistence and existence of different doses of Candesartan at 25 °C. The results are drowning in Fig. 6. The PP variables are recorded in Table 6. These outcomes information showing that the cathodic and anodic bends lines gotten by Tafel-type behavior. The type of the bends lines is fundamentally the same, which shows the dissolution of the mechanism of CS and hydrogen evolution, obviously stay without changing. Expansion of Candesartan reduces the corrosion current. The small change of the E_{corr} revealed that the drug acts as mixed one [45]. The information data additionally demonstrate that the inclines of the anodic and the cathodic Tafel slants (β_a and β_c) were slightly changed on expanding the doses of the used compound. This demonstrates that there is no change of mechanism but % IE increment with expanding doses of Candesartan.

The way of the approximations of β_c are somewhat higher than the approximations of β_a. This is attributed to the cathodic activity of the drug. The steadiness and the cathodic incline gotten from the electrochemical estimations demonstrate that the hydrogen evolution reaction was activation controlled [46] when the adding of the Candesartan did not alter the mechanism of this process.

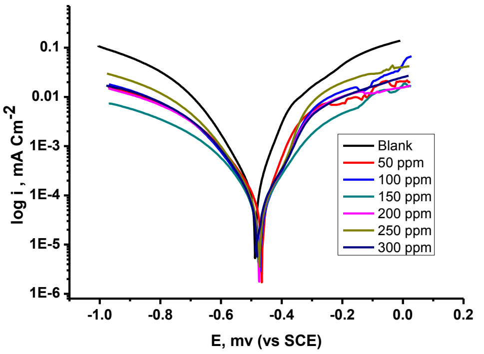


Fig. 6 The PP curves for the oxidation of CS in 1M HCl in the nonexistence and existence of varied doses of Candesartan at 25 °C

Table 6 The effect of doses of Candesartan on the E_{corr}, i_{corr}, Tafel slopes (β_a and β_c), % IE, and ϴ for the oxidation of CS in 1M HCl at 25 °C

Conc. ppm	$I_{corr.}$ mA/cm^{-2}	$-E_{corr.}$ mV(SCE)	β_a mV dec^{-1}	β_c mV dec^{-1}	C. R. Mpy	ϴ	% IE
0.0	147	480	166	208	67.3	----	----
50	63.8	476	118	118	29.14	0.578	57.8
100	63.4	468	79.9	129	28.97	0.580	58.0
150	59.4	476	112	109	27.14	0.607	60.7
200	58.2	462	63.3	114	26.58	0.615	61.5
250	42.6	482	88.5	94.9	19.45	0.718	71.8
300	30.5	464	40.1	70.9	13.96	0.798	79.8

3.5 EIS Tests

The (EIS) charts (Nyquist and bode) at frequencies extending range between 0.1 Hz to 105 Hz with 10 mV plenitude position at OCP for CS in one molar hydrochloric acid in the nonexistence and existence of varied measurements of Candesartan doses are acquired. The identical circuit that describe for (CS) and electrolyte are found in Fig. 7, EIS variables and % IE were determined and recorded in Table 7. The obtained Nyquist and Bode that are plotting in curves for Candesartan are shown in Fig. 8. Nyquist spectra are described by a semicircle. These demonstrate that a charge transfer process [47] restricts the oxidation of CS. The diameter of the capacitive circle acquired increments within the sight of Candesartan were demonstrated that the expanding the level of inhibition of the consumption oxidation process [48].

From the results of (EIS) that obtained R_p rises and C_{dl} reducing with increasing of Candesartan drug doses. The increase in Rp values improve the increase of the %IE because of the progressive substituent of water particles by the adsorption of the medication particles on the metal surface by an adherence film form on the metal surface. The formation film on the metal surface reduced the double layer thickness. Also, the decreasing of C_{dl} with rises the drug doses as result from reduce in local dielectric constant which indicating that, the drug was adsorbed on anodic sites and covered the cathodic sites on the surface of the metal [49].

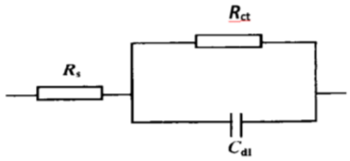


Fig. 7 Circuit model used to fit the experimental data, R_s refer to solution resistance and R_p or R_{ct} charge transfer resistance, respectively

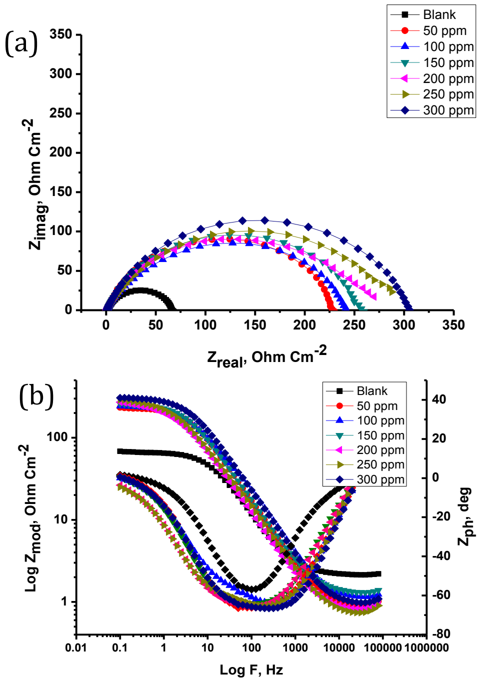


Fig. 8 The Nyquist (a) and Bode (b) plots for oxidation of CS in one 1M HCl in the nonexistence and existence of various doses of Candesartan at 25 °C

Table 7 Electrochemical kinetic variables occur by EIS technique for oxidation of CS in 1 M HCl nonexistence and existence various doses of Candesartan at 25 °C

Conc. ppm	R_p Ω cm^2	C_{dl} µF cm^2	ϴ	% IE
0.0	64.7	594	-----	-----
50	170.6	69	0.621	62.1
100	205.5	55.9	0.685	68.5
150	225.5	49.3	0.713	71.3
200	258.1	36.9	0.749	74.9
250	278.7	29.9	0.768	76.8
300	280.9	27.4	0.769	76.9

3.6 EFM Tests

EFM is regarded a very good technique to determination corrosion information directly and quickly because EFM is nondestructive technique to determination corrosion [50]. The measurements data of EFM are become a valid data when the practical causality factors (CF2 and CF3) are equals or near the hypothetical values (2 and 3) which determination from the frequency spectrum of the current reaction. Fig. 9, illustrated the EFM inter-modulation spectrum of CS in 1 M hydrochloric acid in nonexistence and existence deferent doses of Candesartan drug. It clearly that the treatment EFM data utilizing two various models: (1) the activation model by solved three nonlinear equation and assuming no change of the corrosion potential due to the polarization of the working electrode (2) cathodic reaction controlled by complete diffusion [51].

The density of corrosion current (i_{corr}), the (β_a and β_c) and (CF2 and CF3) are calculated from the two large peaks of inter-modulation spectrum, and then recorded in Table 8. It is obviously, that the addition of tested Candesartan at given doses to the corrosive medium reducing the (i_{corr}), indicating that the Candesartan inhibits the corrosion of CS by the adsorption process. The (CF2 and CF3) are equal to the hypothetical values (2 and 3) indicative of that the estimation information are valid and good value [52]. The % IE $_{EFM}$ values are increments by expanding the doses of Candesartan which determination and recorded in Table 8.

https://doi.org/10.30799/jaec.050.18040101

Cite this Article as: Adel H. Ali, Electrochemical study of candesartan drug as corrosion inhibitor for carbon steel in acid medium, J. Adv. Electrochem. 4(1) (2018) 152–157.

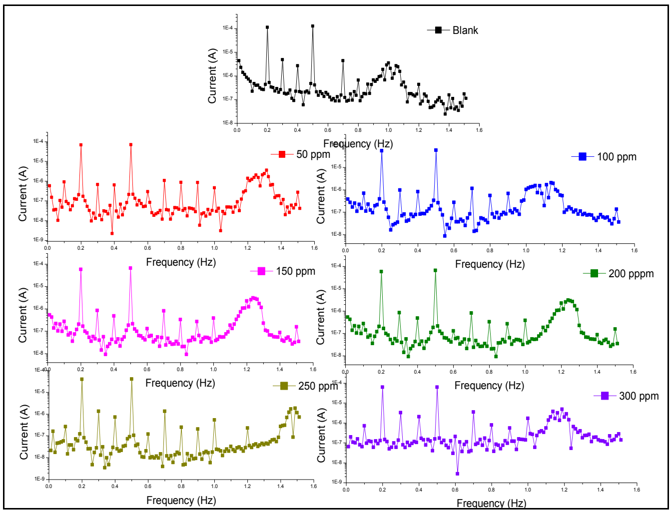


Fig. 9 EFM for CS in 1M HCl with and without various doses of the used Candesartan drug as inhibitor

Table 8 Electrochemical kinetic variables occur by EFM method for CS in 1 M HCl nonexistence and existence different doses of Candesartan at 25 °C

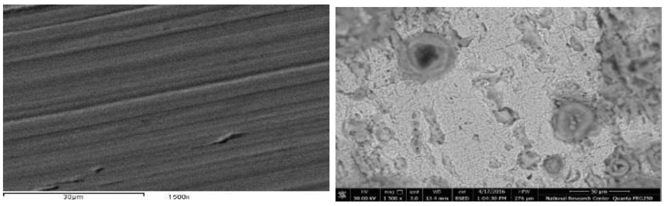
Comp.	Conc. M	$i_{corr.}$ µAcm^{-2}	β_a x 10^{-3} mVdec^{-1}	β_c x 10^{-3} mVdec^{-1}	CF (2)	CF (3)	CR Mpy	θ	%IE
Blank	0.0	350.3	156.4	247.9	1.5	2.9	160.1	----	----
Candesartan	50	100.9	92.3	99.4	1.6	3.5	46.1	0.712	71.2
	100	98.3	104.7	119.0	1.2	3	44.9	0.719	71.9
	150	96.5	98.3	107.1	1.9	5.4	44.1	0.724	72.4
	200	94.2	104.6	115.8	2	3.3	43.0	0.731	73.1
	250	92.7	132.7	183.3	2	5	42.4	0.735	73.5
	300	89.2	81.0	111.3	1.8	4	40.8	0.745	74.5

3.7 SEM Analysis

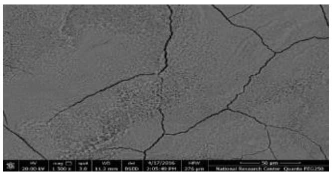
Fig. 10, refer the micro-graph obtain for CS coins in existence and in nonexistence of 300 ppm of Candesartan after contact for 1 day submersion. It is obvious that CS surfaces help and enhance corrosion aggression in corrosive medium by inter-granule corrosion.

The coin morphology of CS surface is smooth before immersion in the corrosive medium with 300 ppm of Candesartan drug that adsorbed on surface of metal and formation thin film.

We are clear that the development of a film which is dispersed in a request route in general or in the whole surface of the CS. This might be because of the adsorption of the Candesartan on the CS surface and make the passive film keeping in mind the end goal to obstruct the dynamic site introduce on the CS surface. The inhibitor particle association with dynamic locales of CS surface, resulting in a reduction in the contact between CS and the destructive medium and consecutively displayed superb restraint impact [53,54].



(a) Free sample (b) Blank (in 1M HCl only)



(c) In 1M HCl with existence 300 ppm of Candesartan

Fig. 10 SEM micrographs for CS in the nonexistence and existence of 300 ppm of Candesartan after immersion for 1 day

3.8 EDX Analysis

To determination of existence elements which adsorbed on CS surface by EDX spectrum after I day immersion in one molar hydrochloric acid with optimum doses of Candesartan drug.

Fig. 11 gives the EDX examination of CS in one molar hydrochloric acid with within the sight of 300ppm of Candesartan. The spectrum demonstrates extra lines, showing the presence of C (inferable from the carbon atoms of some Candesartan). This information demonstrates that the C and O atoms secured the coins surface.

The elements carbon and oxygen was determination by EDX analysis and shown that passivation film contained the chemical formula of Candesartan drug adsorbed on the surface of CS.

It is seen that, the percent weight of adsorb elements C and O were present in the spectra and recorded in Table 9.

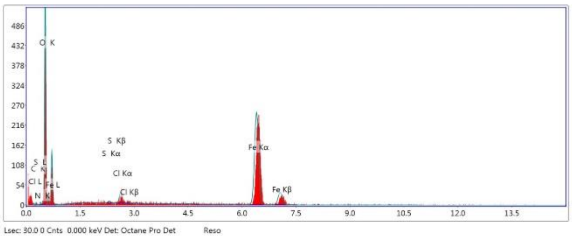


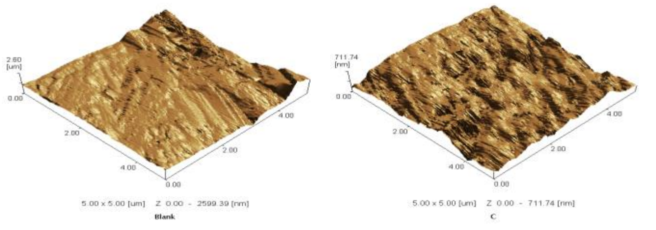
Fig. 11 EDX examination on CS in the existence and nonexistence of Candesartan for one day submersion

Table 9 Surface composition (% wt) of CS after one day of submersion in 1 M HCl nonexistence and existence the 300 ppm of Candesartan

(Mass %)	Fe	C	O	N	S	Cl
Pure metal	98.28	0.78	--	--	--	--
Blank	72.1	9.23	17	--	--	0.35
Candesartan	62.16	1.32	33.54	1.14	--	1.63

3.9 AFM Analysis

From the analysis, it can be gained regarding the roughness on the surface. The roughness profile values play an important role in identifying and report the efficiency of the inhibitor under study. Among the roughness, take a role in explanation about the nature of the adsorbed film on the surface [55, 56]. Fig. 12, shows the 3D images as well as elevation profiles of polished of CS in absence and existence Candesartan as an inhibitor. It observed in Fig. 12, the surface of CS specimen (a) exposed to corroded solution affected vales structure with large and deep crack but the surface (b) reveal that is covering film adsorbed on the metal surface. The conclusion, that the adsorption film can protect the surface of the metal from corrosion process. Analysis of the values indicated higher the values of roughness parameter reached. The mean roughness is found to be (2.60 µm) for the blank in acid solution which placed in 1M HCl one day and analyzed. The observation of the metal surface which submersion in 1M HCl in existence of 300 ppm of Candesartan inhibitor possesses roughness (711.74 nm) compared to the blank solution. It can be noted that the value is less than that of the blank value. The diminish in the roughness value reflected the adsorption of Candesartan drug molecule on metal surface thereby reducing the rate of oxidation.



(a) (b)

Fig. 12 The 3D of optical images of AFM in nonexistence (a) and existence (b) of Candesartan drug

4. Conclusion

WL, potentiodynamic estimations, EIS, EFM, SEM, EDX and AFM examinations dictate the inhibition of the consumption oxidation of CS in 1 M HCl as a corrosive medium by Candesartan.

- The tried Candesartan inhibitor set up a decent restraint for CS corrosion in HCl as the corrosive medium
- Candesartan inhibit the CS by adsorption on its surface and make thin film layer adsorbed on the surface of metal.
- The % IE of the inhibitor increments with expanding of their doses.
- Capacitances of double layer are diminish with respect the blank corrosive medium when the Candesartan included. This reality may clarified by adsorption of the Candesartan particle on the CS surface.

- Adsorption of Candesartan compound on CS surface in HCl solution applicable by Langmuir adsorption model.
- The estimations of % IE acquired from the diverse free procedures utilized demonstrated the valid of the occur results.

References

[1] G. Trabanelli, Inhibitors - An old remedy for a new challenge, Corrosion 47 (1991) 410-419.
[2] D.N. Singh, A.K. Dey, Synergistic effects of inorganic and organic cations on inhibitive performance of propargyl alcohol on steel dissolution in boiling hydrochloric acid solution, Corrosion 49 (1993) 594-600.
[3] G. Banerjee, S.N. Malhotra, Contribution to the adsorption of aromatic amines on mild steel surfaces from HCl solutions by impedance, UV Raman spectroscopy, Corrossion 48 (1992) 10-15.
[4] S.T. Arab, E.A. Noor, Inhibition of acid corrosion of steel by some s-alkylisothiouronium iodides, Corrosion 49 (1993) 122-129.
[5] I.A. Raspini, Influence of sodium salts of organic acids as additives on localized corrosion of aluminum and its alloys, Corrosion 49 (1993) 821-828.
[6] N. Hajjaji, I. Ricco, A. Srhiri, A. Lattes, M. Soufiaoui, A. Benbachir, Effect of n-alkylbetaines on the corrosion of iron in one molar hydrochloric acid solution, Corrosion 49 (1993) 326-334.
[7] M. Elachouri, M.S. Hajji, M. Salem, S. Kertit, R. Coudert, E.M. Essassi, Some surfactants in the series of 2-(alkyldimethylammonio) alkanol bromides as inhibitors of the corrosion of iron in acid chloride solution, Corros. Sci. 37 (1995) 381-389.
[8] H. Luo, Y.C. Guan, K.N. Han, Inhibition of mild steel corrosion by sodium dodecyl benzene sulfonate and sodium oleate in acidic solutions, Corrosion 54 (1998) 619-627.
[9] M.A. Migahed, E.M.S. Azzam, A.M. Al-Sabagh, Corrosion inhibition of mild steel in 1 M sulfuric acid solution using anionic surfactant, Mater. Chem. Phys. 85 (2004) 273-279.
[10] M.M. Osman, A.M. Omar, A.M. Al-Sabagh, Corrosion inhibition of benzyl triethanol ammonium chloride and its ethoxylate on steel in sulphuric acid solution, Mater. Chem. Phys. 50 (1997) 271-274.
[11] F. Zucchi, G. Trabanelli, G. Brunoro, The influence of the chromium content on the inhibitive efficiency of some organic compounds, Corros. Sci. 33 (1992) 1135-1139.
[12] R.F.V. Villamil, P. Corio, J.C. Rubim, M.L. Siliva Agostinho, Effect of sodium dodecylsulfate on copper corrosion in sulfuric acid media in the absence and presence of benzotriazole, J. Electroanal. Chem. 472 (1999)112-119.
[13] T.P. Zhao, G.N. Mu, The adsorption and corrosion inhibition of anion surfactants on aluminum surface in hydrochloric acid, Corros. Sci. 41 (1999) 1937-1944.
[14] S.S.A.E. Rehim, H. Hassan, M.A. Amin, Corrosion inhibition of aluminum by 1,1(lauryl amido)propyl ammonium chloride in HCl solution, Mater. Chem. Phys. 706 (2001) 4-72.
[15] S.S.A.E. Rehim, H. Hassan, M.A. Amin, The corrosion inhibition study of sodium dodecyl benzene sulphonate to aluminum and its alloys in 1.0 M HCl solution, Mater. Chem. Phys. 78 (2003) 337-348.
[16] R. Guo, T. Liu, X. Wei, Effects of SDS and some alcohols on the inhibition efficiency of corrosion for nickel, Colloids Surf. A 209 (2002) 37-45.
[17] V. Branzoi, F. Golgovici, F. Branzoi, Aluminum corrosion in hydrochloric acid solutions and the effect of some organic inhibitors, Mater. Chem. Phys. 78 (2002) 122-131.
[18] F. Bentiss Traisnel, M. Lagrenee, The substituted 1, 3, 4-oxadiazoles: a new class of corrosion inhibitors of mild steel in acidic media, Corros. Sci. 42 (2000) 127-146.
[19] M.A.B. Christopher, A.R.G. Isabel Jenny, The electrochemical behavior and corrosion of aluminum in chloride media, the effect of inhibitor anions, Corros. Sci. 36 (1994) 915-923.
[20] M. Elachouri, M.S. Hajji, M. Salem, S. Kertit, J. Aride, R. Coudert, E. Essassi, Some nonionic surfactants as inhibitors of the corrosion of iron in acid chloride solutions, Corrosion 52 (1996) 103-108.
[21] A.S. Algaber, E.M. El-Nemma, M.M. Saleh, Effect of octylphenol polyethylene oxide on the corrosion inhibition of steel in 0.5 M H_2SO_4, Mater. Chem. Phys. 86 (2004) 26-32.
[22] V. Branzoi, F. Golgovici, F. Branzoi, Aluminum corrosion in hydrochloric acid solutions and the effect of some organic drugs, Mater. Chem. Phys. 78 (2002) 122-131.
[23] R. Oukhrib, B. El-Ibrahimi, H. Bourzi, A. Jmiai, L. Bammou, L. Bazzi, et al., Quantum chemical calculations and corrosion inhibition efficiency of biopolymer “chitosan” on copper surface in 3% NaCl, J. Mater. Environ. Sci. 8(1) (2017) 195-208.
[24] A.M. Al-Azzawi, K.K. Hammud, Newly antibacterial/anti-rusting oxadiazoleporomellitic di-imids of CS / hydrochloric acid interface: Temkin isotherm model, Int. J. Res. Pharm. Chem. 6(3) (2016) 391-402.
[25] L. El Ouasif, I. Merimi, H. Zarrok, M. El ghoul, R. Achour, M. Guenbour, et al., Synthesis and inhibition study of CS corrosion in hydrochloric acid of a new surfactant derived from 2-mercaptobenzimidazole, J. Mater. Environ. Sci. 7(8) (2016) 2718-2730.
[26] U.M. Sani, U. Usman, Electrochemical corrosion inhibition of mild steel in hydrochloric acid medium using the antidiabetic drug janumet as inhibitor, Int. J. Novel Res. Phy. Chem. Math. 3(3) (2016) 30-37.
[27] A.M. Kolo, U.M. Sani, U. Kutama, U. Usman, Adsorption and Inhibitive properties of januvia for the corrosion of Zn in 0.1 M HCl, Pharm. Chem. Jour. 3(1) (2016) 109-119.
[28] P.O. Ameh, U.M. Sani, Cefuroxime axetil: a commercially available pro-drug as corrosion drug for aluminum in hydrochloric acid solution, J. Heterocyc. 1(1) (2015) 2-6.
[29] H.I. Al-Shafey, R.S. Abdel Hameed, F.A. Ali, A.S. Aboul-Magd, M. Salah, Effect of expired drugs as corrosion drugs for CS in 1 M HCL solution, Int. J. Pharm. Sci. Rev. Res. 27(1) (2014) 146-152.
[30] R. Kushwah, R.K. Pathak, Inhibition of mild steel corrosion in 0.5 M sulphuric acid solution by aspirin drug, Inter. J. Emerg. Technol. Adv. Eng. 4(7) (2014) 880-884.
[31] A.S. Fouda, M.N. EL-Haddad, Y.M. Abdallah, Septazole: Antibacterial drug as a green corrosion drug for copper in hydrochloric acid solutions, Int. J. Innovat. Res. Sci. Eng. Technol. 2(12) (2013) 7073-7085.
[32] S.U. Ofoegbu, P.U. Ofoegbu, Corrosion inhibition of mild steel in 0.1 M hydrochloric acid media by chloroquine diphosphate, J. Eng. Appl. Sci. 7(3) (2012) 272-276.
[33] G.N. Mu, T.P. Zhao, M. Liu, T. Gu, Effect of metallic cations on corrosion inhibition of an anionic surfactant for mild steel, Corrosion 52 (1996) 853-856.
[34] J. Lipkowski, P.N. Ross (Eds.), Adsorption of molecules at metal electrodes, VCH, New York, 1992.
[35] S.L.F.A. Da Costa S.M.L. Agostinho, Electrochemical studies of Cu-Al alloys in sulphate – SciELO, Corrosion 45 (1989) 472-477.
[36] J. Aljourani, K. Raeissi, M.A. Golozar, Benzimidazole and its derivatives as corrosion inhibitors for mild steel in 1M HCl solution, Corros. Sci. 51 (2009) 1836-1843.
[37] H. Amar, A. Tounsi, A. Makayssi, A. Derja, J. Benzakour, A. Outzourhit, Corrosion inhibition of armco iron by 2-mercaptobenzimidazole in sodium chloride 3% media, Corros. Sci. 49 (2007) 2936-2945.
[38] M.A. Migahed, E.M.S. Azzam, S.M.I. Morsy, Electrochemical behaviour of CS in acid chloride solution in the presence of dodecyl cysteine hydrochloride self-assembled on gold nanoparticles, Corros. Sci. 51 (2009) 1636-1644.
[39] S. Bllglc, N. Caliskan, An investigation of some Schiff bases as corrosion inhibitors for austenitic chromium-nikel steel in H_2SO_4, Appl. Electro-chem. 31 (2001) 79-83.
[40] H. Ashassi-Sorkhabi, N. Ghalebsaz-Jeddi, Inhibition effect of polyethylene glycol on the corrosion of CS in sulphuric acid, Mater. Chem. Phys. 92 (2005) 480-486.
[41] A. El Maghraby, T.Y. Soror, Efficient surfactant as corrosion inhibitor for CS in hydrochloric acid solutions, Adv. App. Sci. 1 (2010) 156-168.
[42] I. Al-shafey, M.A. Abass, A.A. Hassan, S.A. Sadeek, Corrosion inhibition of CS in 1M HCl Solution by Schiff base compound obtained from 1,3-diaminopropane, Int. J. Adv. Pharm. Biol. Chem. 3 (2014) 1004-1015.
[43] A.S. Fouda, M.M. Gouda, S.I. Abd El-Rahman, Benzaldehyde, 2-hydroxybenzoyl hydrazone derivatives as inhibitors of the corrosion of aluminum in hydrochloric acid, Chem. Pharm. Bull. 48(5) (2000) 636-640.
[44] O.A. Hazazi, A. Fawzy, M. Awad, 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 (2014) 4086-4103.
[45] A.S. Fouda, A.M. El- Defrawy, M.W. El-Sherbeni, Pharmaceutical compounds as save corrosion inhibitors for CS in 1 M H_2SO_4 solution, J. Chem. 39 (2012) 1-27.
[46] A.S. Fouda, A.A. Al-Sarawy, E.E. El-Katori, Pyrazolone derivatives as corrosion inhibitors for Mild steel HCl solution, Desalination 201 (2006) 1-13.
[47] A.A. Farag, I.M. Ibrahim, Influence of nonionic surfactant on the CS corrosion in hydrochloric acid solution, Int. J. Sci. Res. 3 (2014) 1087-1091.
[48] O. Benalli, L. Larabi, M. Traisnel, L. Gengembra, Y. Harek, Electrochemical, theoretical and XPS studies of 2-mercapto-1-methylimidazole adsorption on mild steelin one molar hydrochloric acid, Appl. Surf. Sci. 253 (2007) 6130-6139.
[49] S. Kshama Shetty, A. Nityananda Shetty, Ionic liquid as an effective corrosion inhibitor on Al-15 Composite in 0.1M H_2SO_4 medium, An ecofriendly approach, Canad. Chem. Trans. 3 (2015) 41-64.
[50] E. Kus, F. Mansfeld, An evalation of the electrochemical frequency modulation (EFM) technique, Corros. Sci. 48 (2006) 965-979.
[51] G.A. Caigman, S.K. Metcalf, E.M. Holt, Thiophene substituted dihydropyridines, J. Chem. Cryst. 30 (2000) 415-422.
[52] R.W.J. Bosch Hubrecht, W.F. Bogaerts, B.C. Syrett, Electrochemical frequency modulation: a new electrochemical technique for online corrosion monitoring, Corros. Sci. 57 (2001) 60-70.
[53] A.S. Fouda, Y.M. Abdallah, D. Nabil, Dimethyl pyrimidine derivative as corrosion inhibitors for CS in hydrochloric acid solutions, Int. J. Innovat. Res. Sci. Eng. Technol. 3 (2014) 12965-12982.
[54] A.S. Fouda, G. El-Ewady, A.H. Ali, Modazar as promising corrosion inhibitor of carbon steel in hydrochloric acid solution, Green Chem. Lett. Rev. 10(2) (2017) 88–100.
[55] A.S. Fouda, G. El-Ewady, A.H. Ali, Corrosion protection of carbon steel by using simvastatin drug in HCl medium, J. Applicable Chem. 6(5) (2017) 701-718.
[56] Abd El-Aziz, S. Fouda, A.H. Ali, Egydronate drug as promising corrosion inhibitor of C-steel in aqueous medium, Jour. Mater. Prot. 59 (2018) 126-140.

https://doi.org/10.30799/jaec.050.18040101

Cite this Article as: Adel H. Ali, Electrochemical study of candesartan drug as corrosion inhibitor for carbon steel in acid medium, J. Adv. Electrochem. 4(1) (2018) 152–157.