

**SOME B-BLOCKER COMPOUNDS AS INHIBITORS  
FOR THE CORROSION OF ALUMINUM  
IN HCL SOLUTION**

**A.S.Fouda\* , G.Y. Elewady and K. Shalabi**

Department of Chemistry, Faculty of Science, El-Mansoura

University, El-Mansoura- 35516, EGYPT:

E-mail: [asfouda48@yahoo.com](mailto:asfouda48@yahoo.com)

(Received: 10 / 8 / 2008)

**ABSTRACT**

The corrosion behavior of aluminum in 0.1 M HCl solution in the absence and presence of four compounds of  $\beta$ -blockers (Propranolol, timolol, atenolol and nadolol) was investigated using weight loss, potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. The results of these techniques show that, the inhibition efficiency of these compounds depends on their concentration and chemical structure. The inhibitive actions of these compounds were discussed in terms of blocking the electrode surface by adsorption of the molecules through the active centers contained in their structure. The adsorption process was found to obey Frumkin isotherm. The effect of temperature on the rate of corrosion in the absence and presence of these compounds was also, studied. Some activated thermodynamic parameters were computed. Potentiodynamic polarization data indicated that these compounds act as cathodic type inhibitors

**Keywords:** Aluminum; corrosion;  $\beta$ -blockers; HCl; EIS.

**1. INTRODUCTION**

Aluminum and its alloys are used widely in many industries because of their advantages. Hydrochloric acid solutions are used for pickling, chemical and electrochemical etching of Al. It is very important to add corrosion inhibitors to decrease the corrosion rate of Al in such solutions. Numerous organic compounds serve effectively as corrosion inhibitors. Aliphatic and aromatic amines as well as nitrogen heterocyclic

compounds were studied as corrosion inhibitors for dissolution of Al in acidic media [Rosenfeld et al., (1981); Desai et al., (1976); Hackerman et al., (1958) and El-Awady et al., (1985)]. Generally, it has been assumed that the first stage in the mechanism of the inhibitors in aggressive acid media is the adsorption of the inhibitors onto the metal surface. The processes of adsorption of inhibitors are influenced by the nature and surface charge of the metal, the chemical structure of organic inhibitors, the distribution of charge in the molecule, the type of aggressive electrolyte and the type of interaction between organic molecules and the metallic surface [Granese, et al., (1988); Mimani et al., (1993); Schmitt et al., (1985); Hukovic et al., (1994) and Mahmoud et al., (1997)]. Physical (electrostatic) adsorption and chemisorption are the principle types of interaction between organic inhibitors and the metal surface.

The aim of this study is to investigate the inhibition efficiency of some  $\beta$ -blocker compounds on aluminum corrosion in HCl using chemical and electrochemical measurements. EIS was used to determine the mechanism of inhibition.

## 2. EXPERIMENTAL

Al metal was provided from "Aluminum Company of Egypt, Nagh Ammady", its chemical composition is 0.100% Si, 0.250% Fe, 0.047% Mn, 0.007% Mg, 0.002% Ni, 0.008% Cr, 0.003% Zn, 0.012% Ga, 0.001% Na, 0.007% V, 0.001% Zr, 0.007% Ti and 99.550% Al.

### i) Chemical technique (Weight loss method)

Aluminum sheets were cut into 2 x 2 x 0.1 cm. They were mechanically polished with emery paper (a coarse paper was used initially and then progressive fine grades were employed), ultrasonically degreased in alkaline degreasing mixture [Fouda et al., (1986)] washed with distilled water and finally dried between filter papers and weighed. Aluminum pieces were immersed in 100 ml of the test solution with and without the inhibitors for one day. After the test, the pieces were removed, washed with distilled water, dried as before and weighed again. The weight loss of the metal in the corrosive solution is given by:

$$\Delta W = W_1 - W_2 \quad (1)$$

where  $W_1$  and  $W_2$  are the weight of metal before and after exposure to the corrosive solution, respectively. The percentage inhibition efficiency (%)

IE) and the degree of surface coverage ( $\theta$ ) of the investigated compounds were calculated from equations:

$$\% \text{ IE} = [1 - (\Delta W_{\text{inh}} / \Delta W_{\text{free}})] \times 100 \quad (2)$$

$$\theta = [1 - (\Delta W_{\text{inh}} / \Delta W_{\text{free}})] \quad (3)$$

Where  $\Delta W_{\text{free}}$  and  $\Delta W_{\text{inh}}$  are weight losses of metal per unit area in the absence and presence of inhibitor at given time period and temperature, respectively.

## ii) Electrochemical techniques (potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques)

Aluminum electrodes were a cylindrical rod embedded in araldite with exposed surface area of  $0.785 \text{ cm}^2$  was employed. Prior to each experiment the surface of Al specimens were mechanically polished with different grades of emery paper, degreased with alkaline solution and rinsed by distilled water. Three compartment cell with a saturated calomel reference electrode (SCE) and a platinum foil auxiliary electrode was used. For potentiodynamic polarization measurements the corrosion current density ( $i_{\text{corr}}$ ) is determined, which is a measure of corrosion rate. These methods are Stern-Geary [Stern et al., (1957)] method and intercept [Maayta et al., (2004)] method and they are based on anodic and/ or cathodic Tafel curves. Stern-Geary method used for the determination of corrosion current is performed by extrapolation of anodic and cathodic Tafel lines of charge transfer controlled corrosion reactions to a point which gives  $\log i_{\text{corr}}$  and the corresponding corrosion potential ( $E_{\text{corr}}$ ) for inhibitor free acid and for each concentration of inhibitor. Then  $i_{\text{corr}}$  was used for calculation of inhibition efficiency and surface coverage ( $\theta$ ) as below :

$$\% \text{ IE} = [1 - (i_{\text{corr (inh)}} / i_{\text{corr (free)}})] \times 100 \quad (4)$$

$$\theta = [1 - (i_{\text{corr (inh)}} / i_{\text{corr (free)}})] \quad (5)$$

Where  $i_{\text{corr (free)}}$  and  $i_{\text{corr (inh)}}$  are the corrosion current densities in the absence and presence of inhibitor, respectively.

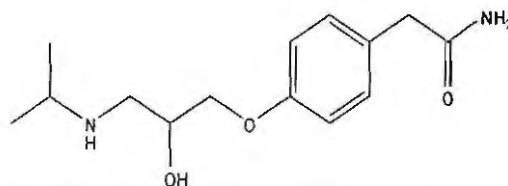
The potentiodynamic current-potential curves were recorded by changing the electrode potential automatically from  $-1500$  to  $500 \text{ mV}$  at a scan rate  $5 \text{ mVs}^{-1}$  by using Volta Lab PGZ100, and a personal computer with Volta Master 4 version 7.08 software for calculations. All the experiments were carried out at  $25 \pm 1^\circ \text{C}$  by using ultracirculating thermostat. The solutions were not deaerated to make the conditions identical to weight loss measurements.

The AC impedance measurements were carried out using AC signals of amplitude 10mV peak to peak at open circuit potential in the frequency range  $10^{-5}$  Hz to 0.5 Hz by using Potentiostat/Galvanostat (Gamry PCI 300/4) and a personal computer with EIS300 software for calculations.

All chemicals and reagents were of analytical grade.

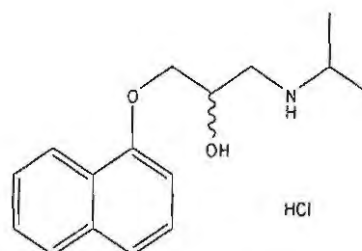
The measurements were performed in 0.1 M HCl without and with the presence of the investigated  $\beta$ -blocker compounds in the concentration range ( $2 \times 10^{-6}$  to  $12 \times 10^{-6}$  M).

The names and molecular structures of the investigated  $\beta$ -blocker compounds are given below:



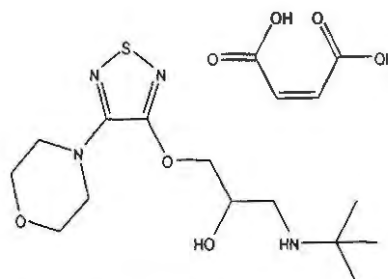
Compound (I)

2-(4-(2-hydroxy-3-(isopropylamino)propoxy)phenyl)acetamide  
 Chemical Formula:  $C_{14}H_{22}N_2O_3$   
 Molecular Weight: 266.34  
 Atenolol



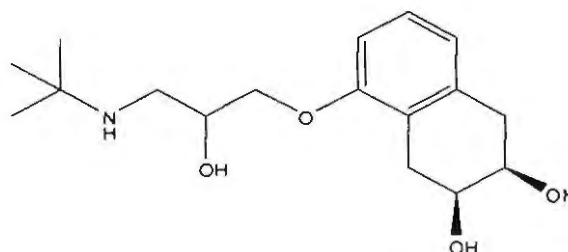
Compound(II)

1-(isopropylamino)-3-(naphthalen-1-yloxy)propan-2-ol hydrochloride  
 Chemical Formula:  $C_{18}H_{22}ClNO_2$   
 Molecular Weight: 295.80  
 Propranolol



Compound(III)

1-(*tert*-butylamino)-3-(4-morpholino-1,2,5-thiadiazol-3-yloxy)propan-2-ol maleate  
Chemical Formula: C<sub>17</sub>H<sub>29</sub>N<sub>4</sub>O<sub>7</sub>S  
Molecular Weight: 432.49  
Timolol



Compound(IV)

(2*R*,3*S*)-5-(3-(*tert*-butylamino)-2-hydroxypropoxy)-1,2,3,4-tetrahydronaphthalene-2,3-diol  
Chemical Formula: C<sub>17</sub>H<sub>27</sub>NO<sub>4</sub>  
Molecular Weight: 309.40  
Nadolol

### 3. RESULTS AND DISCUSSION

#### 3.1-Weight loss measurements.

Fig. (1) shows the weight loss-time curves for the corrosion of aluminum in 0.1M HCl in the absence and presence of different concentrations of compound (I) at 25±1°C. It is revealed that on increasing the concentration of compound (I), the weight loss of aluminum samples are decreased. This means that the presence of this compound retards the corrosion of aluminum in 0.1M HCl and acts as inhibitor.

The linear variation of weight loss with time in uninhibited and inhibited 0.1M HCl acid indicates the absence of insoluble surface films during corrosion. In the absence of any surface films, the inhibitors are first adsorbed onto the metal surface and thereafter impede corrosion

either by merely blocking the reaction sites (anodic and cathodic) or by altering the mechanism of the anodic and cathodic partial processes.

From the calculated values of % IE at 25°C as shown in Table (1), the order of decreasing inhibition efficiency of the investigated compounds is as follows:

$$I > II > III > IV$$

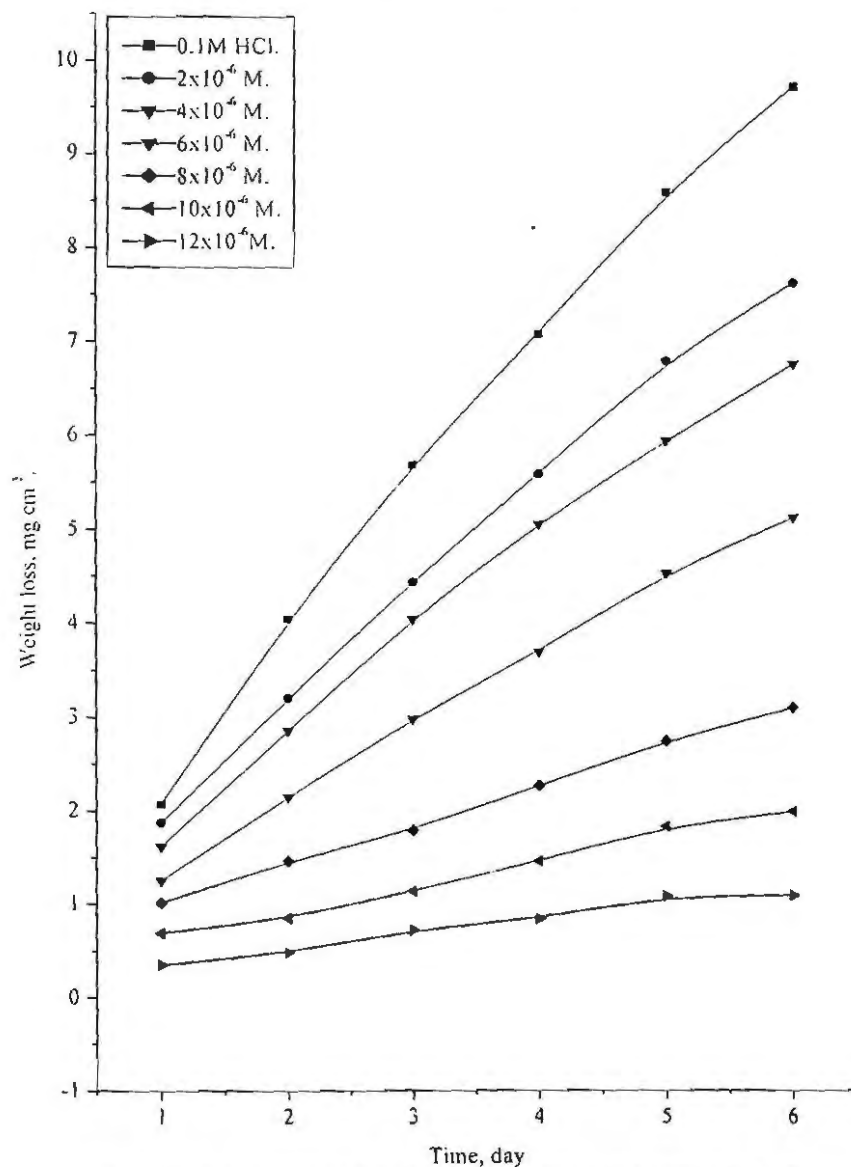


Fig.(1): Weight loss-time curves for the corrosion of aluminum in 0.1M HCl in the absence and presence of different concentrations of compound (I) at 25°C.

**Table (1):** % Inhibition efficiency at different concentrations of the investigated compounds for the corrosion of aluminum in 0.1M HCl at 25°C.

Concentration M	% IE			
	(I)	(II)	(III)	(IV)
$2 \times 10^{-6}$	21.31	15.86	15.77	9.89
$4 \times 10^{-6}$	28.57	28.057	26.79	25.00
$6 \times 10^{-6}$	47.81	40.90	39.39	38.21
$8 \times 10^{-6}$	68.01	63.80	56.22	51.17
$10 \times 10^{-6}$	79.42	72.31	69.51	66.33
$12 \times 10^{-6}$	88.16	81.93	78.10	72.93

### 3.2-Adsorption isotherm

The plots of  $\theta$  vs.  $\log C$  (Frumkin adsorption plots) for the investigated compounds on the surface of aluminum in 0.1M HCl at 25°C are shown in Fig.(2). The data gave S-shape indicating that Frumkin's isotherm is valid for these systems.

### 3.3-Potentiodynamic polarization

In potentiodynamic polarization method the aluminum electrode was under potential control and the corresponding current was allowed to vary. Potentiodynamic polarization curves of aluminum in 0.1M HCl in the absence and presence of different concentrations of the investigated compound (I) at 25°C are illustrated in Fig (3). Various corrosion parameters such as corrosion potential ( $E_{corr}$ ), anodic and cathodic Tafel slopes ( $\beta_a$ ,  $\beta_c$ ), the corrosion current density ( $I_{corr}$ ), the degree of surface coverage ( $\theta$ ) and the inhibition efficiency (IE%) are given in table (2). It can be seen from the experimental results that these investigated compounds decrease  $I_{corr}$  significantly at all the studied concentrations. The presence of these compounds resulted in a slightly shift of corrosion potential towards the active direction in comparison to the result obtained in the absence of the inhibitor. Both the anodic and cathodic current densities were decreased indicating that these compounds suppressed both the anodic and cathodic reactions, although mainly the cathodic one. For anodic polarization in the presence of different concentrations, a higher anodic current was produced, indicating that the desorption of adsorbed inhibitors on the electrode surface [Wang et al., (1995) and

Feng et al., (1999)]. The constancy of Tafel slopes in the presence of the inhibitors, indicating the inhibitors acted by merely blocking the reaction sites of the metal surface without changing the anodic and cathodic reaction mechanisms.

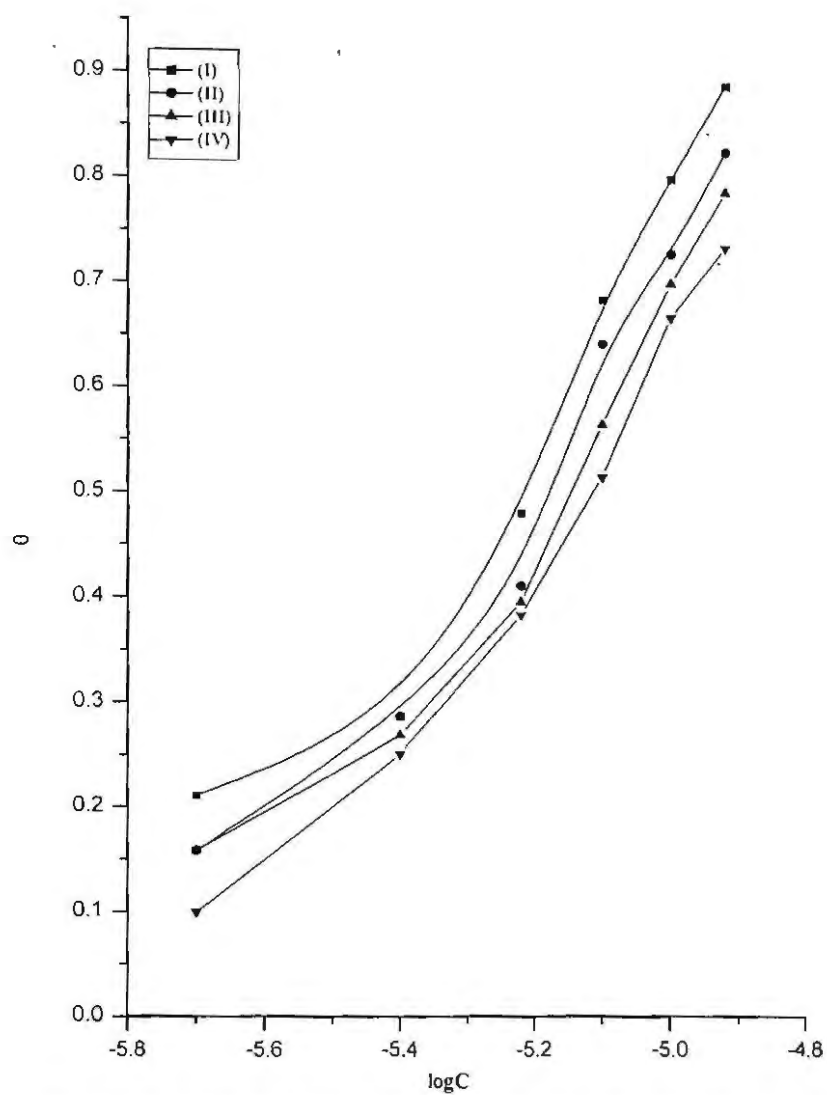


Fig.(2):  $\theta$  vs.  $\log C$  for corrosion of aluminum in 0.1M HCl in presence of different concentrations of some  $\beta$  blocker compounds at 25°C.



The order of decreasing inhibition efficiency of the investigated compounds is as follow:

$$I > II > III > IV$$

This is also in agreement with the observed order of corrosion inhibition by the weight loss method.

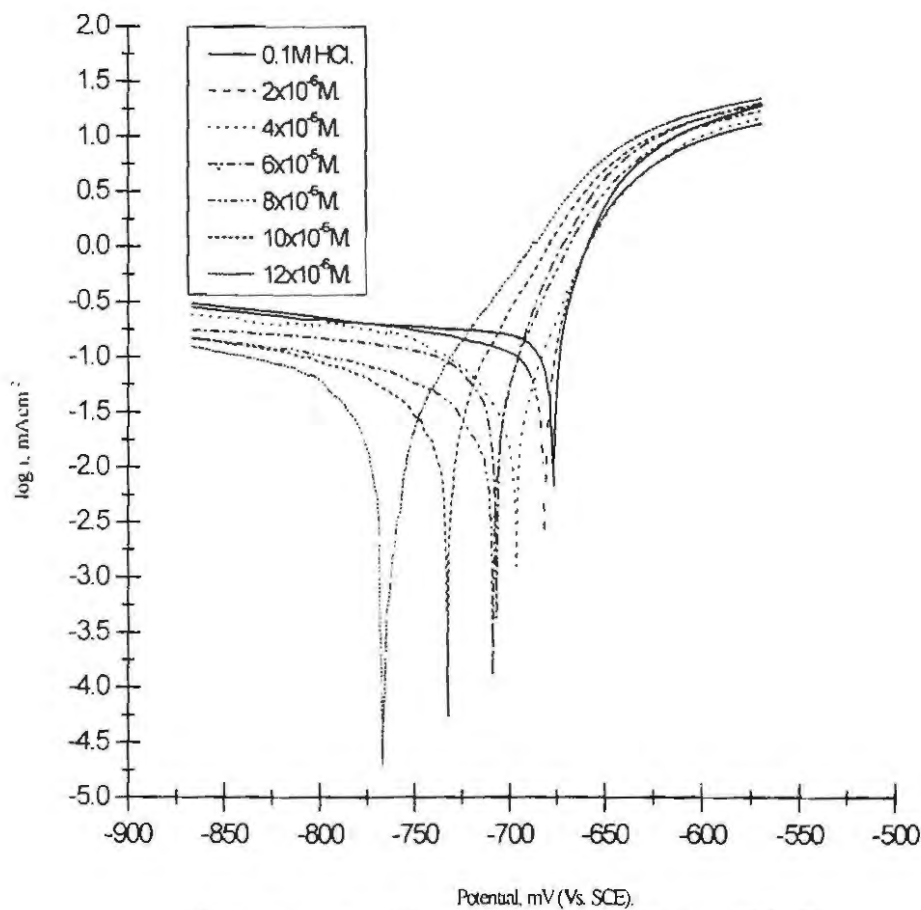


Fig. (3) potentiodynamic polarization curves for the corrosion of aluminum in 0.1M HCl in the absence and presence of different concentrations of compound (I) at 25°C.

Table (2): The effect of concentration of the investigated compounds on the free corrosion potential ( $E_{corr}$ ), corrosion current density ( $i_{corr}$ ), Tafel slopes ( $\beta_a$  &  $\beta_c$ ), inhibition efficiency (% IE), degree of surface coverage ( $\theta$ ) and corrosion rate for the corrosion of aluminum in 0.1M HCl at 25°C.

Compounds	Conc.,M	$E_{corr}$ vs SCE, mV	$i_{corr}$ mA cm <sup>-2</sup>	$-\beta_c$ mV dec <sup>-1</sup>	$\beta_a$ mV dec <sup>-1</sup>	$\theta$	% IE	Corrosion rate mm/year
Free acid	0	-681.5526	0.1552	793.8363	26.5855	0.0000	0.00	1.6893
I	2x10 <sup>-4</sup>	-684.5957	0.1187	400.1235	27.3784	0.2355	23.55	1.2916
	4x10 <sup>-4</sup>	-697.4234	0.0991	313.4193	37.2374	0.3617	36.17	1.0783
	6x10 <sup>-4</sup>	-707.7521	0.0783	252.2677	31.2129	0.4958	49.58	0.8518
	8x10 <sup>-4</sup>	-712.0835	0.0431	222.9128	32.0020	0.7222	72.22	0.4693
	10x10 <sup>-4</sup>	-735.2399	0.0299	118.1476	36.8944	0.8076	80.76	0.3251
	12x10 <sup>-4</sup>	-764.8934	0.0127	52.6639	39.0632	0.9180	91.80	0.1385
II	2x10 <sup>-4</sup>	-689.6713	0.1198	512.5083	26.4738	0.2280	22.80	1.3042
	4x10 <sup>-4</sup>	-697.2235	0.1076	443.0898	26.0595	0.3069	30.69	1.1709
	6x10 <sup>-4</sup>	-695.5242	0.0850	347.7716	26.8355	0.4521	45.21	0.9255
	8x10 <sup>-4</sup>	-699.4891	0.0574	282.5341	26.0384	0.6299	62.99	0.6252
	10x10 <sup>-4</sup>	-705.5309	0.0289	116.2939	26.1957	0.8139	81.39	0.3144
	12x10 <sup>-4</sup>	-713.4607	0.0153	55.3123	26.9947	0.9012	90.12	0.1669
III	2x10 <sup>-4</sup>	-684.9067	0.1250	498.9591	26.4335	0.1943	19.43	1.3612
	4x10 <sup>-4</sup>	-689.9045	0.1092	318.3405	26.7315	0.2964	29.64	1.1887
	6x10 <sup>-4</sup>	-691.1040	0.0912	268.8731	23.7290	0.4122	41.22	0.9930
	8x10 <sup>-4</sup>	-693.3030	0.0769	183.8117	20.9551	0.5429	54.29	0.7722
	10x10 <sup>-4</sup>	-694.9023	0.0464	93.5733	22.0173	0.7012	70.12	0.5048
	12x10 <sup>-4</sup>	-695.3021	0.0283	67.9251	16.4176	0.8138	81.38	0.3146
IV	2x10 <sup>-4</sup>	-686.5060	0.1283	522.4478	22.7756	0.1735	17.35	1.3963
	4x10 <sup>-4</sup>	-688.1053	0.1130	423.4141	25.0805	0.2716	27.16	1.2305
	6x10 <sup>-4</sup>	-690.3043	0.0883	187.1762	24.5240	0.4311	43.11	0.9611
	8x10 <sup>-4</sup>	-692.3034	0.0698	161.5938	22.3499	0.5500	55.00	0.7602
	10x10 <sup>-4</sup>	-695.5020	0.0508	131.5229	19.6722	0.6728	67.28	0.5527
	12x10 <sup>-4</sup>	-699.7001	0.0387	85.4089	22.3513	0.7505	75.05	0.4215

### 3.4- Effect of temperature and activation parameters of inhibition process

The influence of temperature on the corrosion rate of aluminum in 0.1M HCl in absence and presence of  $2 \times 10^{-6}$ M of the investigated compounds was investigated by the potentiodynamic polarization technique in temperature range from 30 to 60°C.

The plots of logarithm of corrosion rate ( $\log k$ ), with the reciprocal of absolute temperature ( $1/T$ ) for aluminum in 0.1M HCl at  $2 \times 10^{-6}$ M for the investigated compounds are shown in Fig. (4). A straight lines with slope of  $-E_a^*/2.303R$  and intercept of A were obtained according to Arrhenius-type equation:

$$k = A \exp(-E_a^*/RT) \quad (8)$$

where  $k$  is the corrosion rate.  $A$  is a constant depends on a metal type and electrolyte,  $E_a^*$  is the apparent activation energy,  $R$  is the universal gas constant and  $T$  is the absolute temperature.

The plots of  $\log(\text{corrosion rate}/T)$  vs.  $1/T$  for aluminum in 0.1M HCl at  $2 \times 10^{-6}$ M for the investigated compounds are shown in Fig. (5). As shown from these Figures, straight lines with slope of  $(-\Delta H^*/2.303R)$  and intercept of  $(\log R/Nh + \Delta S^*/2.303R)$  were obtained according to transition state equation:

$$\text{Rate} = RT/Nh \exp(\Delta S^*/R) \exp(-\Delta H^*/RT) \quad (9)$$

where  $h$  is Planck's constant.  $N$  is Avogadro's number.  $\Delta H^*$  is the activation enthalpy and  $\Delta S^*$  is the activation entropy.

The calculated values of the apparent activation energy,  $E_a^*$ , activation enthalpies,  $\Delta H^*$  and activation entropies,  $\Delta S^*$  are given in Table (3). These values indicate that the presence of the additives increases both the activation energy,  $E_a^*$  and the activation enthalpy,  $\Delta H^*$  and decreases the activation entropy,  $\Delta S^*$  for the corrosion process. The increase in the activation energy indicating a strong adsorption of the inhibitor molecules on aluminum surface and indicates the energy barrier caused by the adsorption of the additive molecules on aluminum surface. The increase in the activation enthalpy ( $\Delta H^*$ ) in presence of the inhibitors implies that the addition of the inhibitors to the acid solution increases the height of the energy barrier of the corrosion reaction to an extent depends on the type and concentration of the present inhibitor. The entropy of activation ( $\Delta S^*$ ) in the blank and inhibited solutions is large and negative indicating that the activated complex represents association

rather than dissociation step. [Gomma et al., (1995) and Soliman et al., (1995)].

The order of decreasing inhibition efficiency of the investigated compounds as gathered from the increase in  $E_a^*$  and  $\Delta H_{ads}^*$  values and decrease in  $\Delta S_{ads}^*$  values, is as follows:

$$I > II > III > IV$$

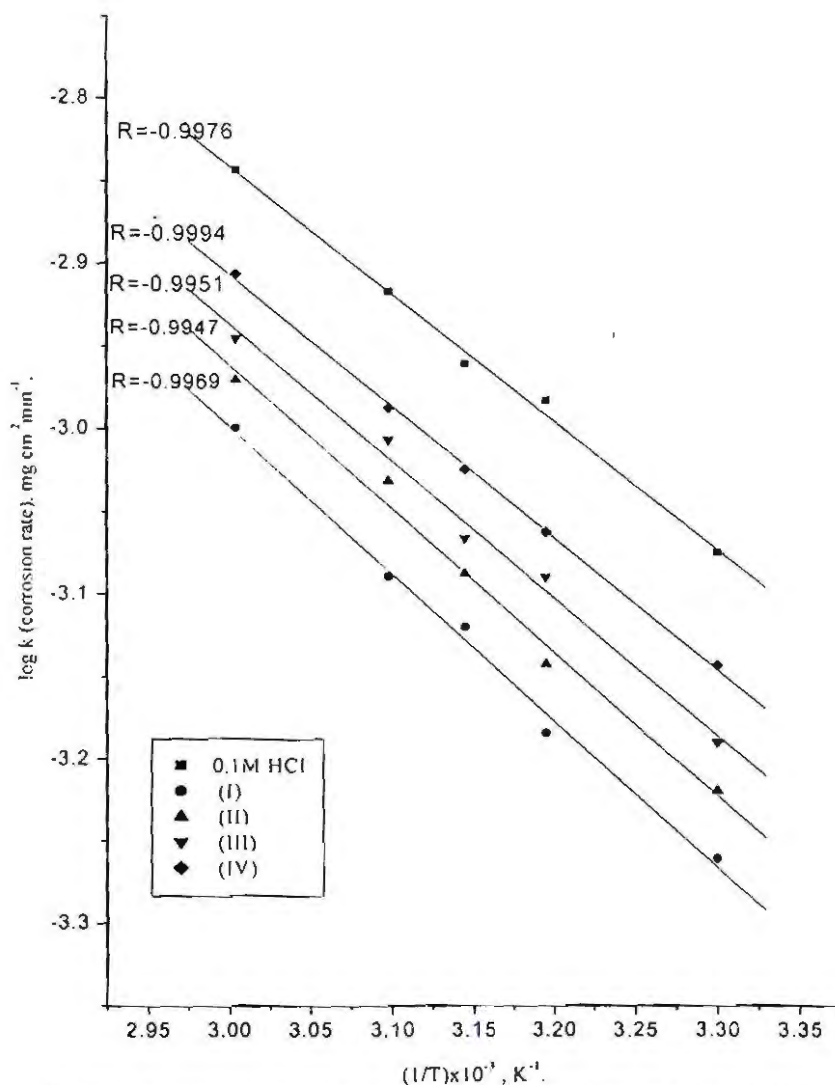


Fig.(4): log corrosion rate-  $1/T$  curves for the corrosion of aluminum in 0.1M HCl at  $2 \times 10^{-6}$  M for the the investigated compounds.

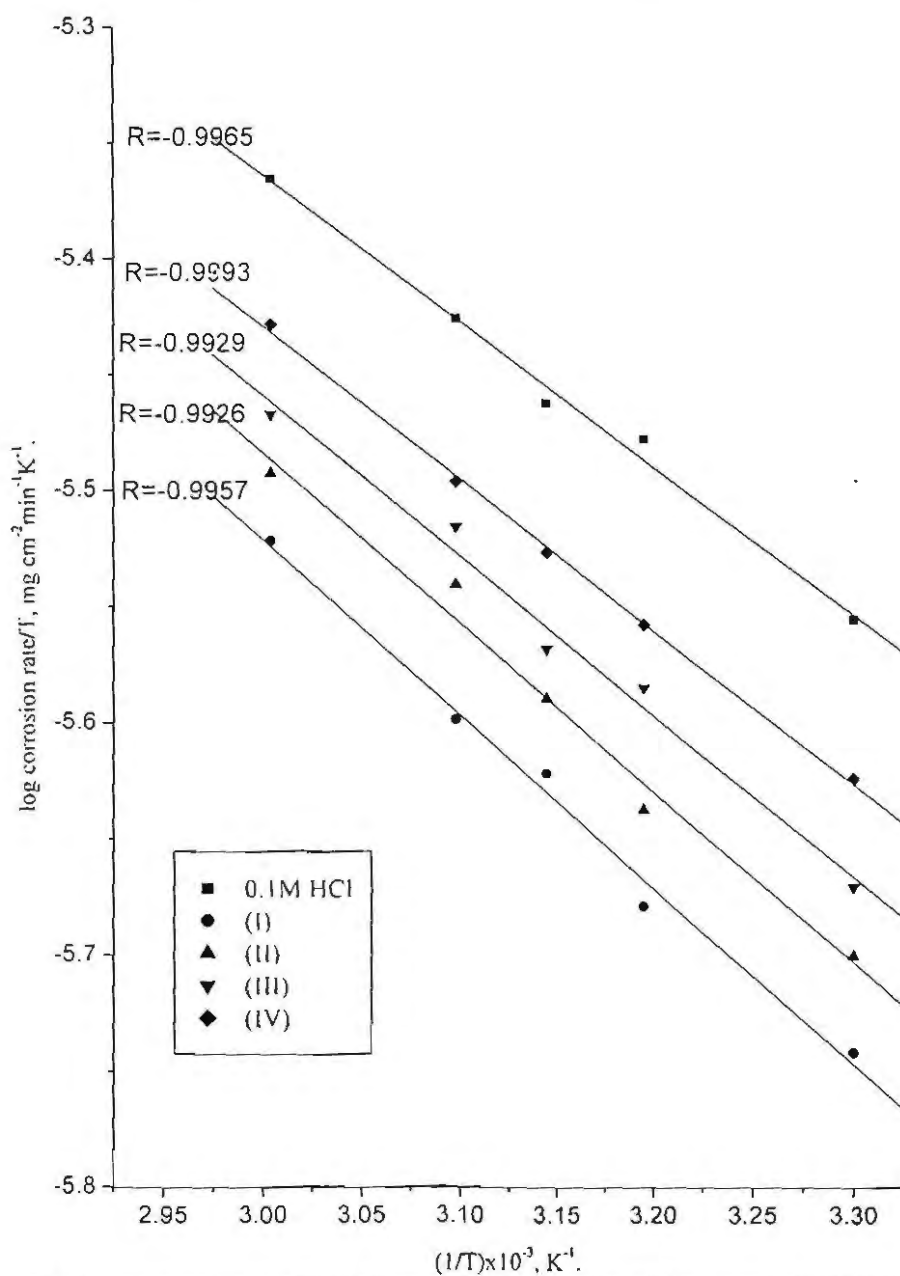


Fig.(5):  $\log (\text{corrosion rate}/T) - (1/T)$  curves for the corrosion of aluminum in 0.1M HCl at  $2 \times 10^{-6} \text{M}$  for the investigated compounds.

**Table (3):** Activation parameters of the corrosion of aluminum in 0.1M HCl at  $2 \times 10^{-6}$ M for the investigated compounds.

Compounds	Activation parameters		
	$E_a^*$ , kJ mol <sup>-1</sup>	$\Delta H^*$ , kJ mol <sup>-1</sup>	$-\Delta S^*$ , J mol <sup>-1</sup> K <sup>-1</sup>
Free acid	14.79	12.14	263.87
(I)	17.04	14.39	260.13
(II)	16.65	14.00	260.58
(III)	15.89	13.23	262.44
(IV)	15.26	12.60	263.73

### 3.5- Electrochemical impedance spectroscopy (EIS)

The corrosion behavior of aluminum in 0.1M HCl solution in the absence and presence of different concentrations of the investigated compounds was investigated by the EIS method at 25°C. Fig. (6) shows the Nyquist plots for aluminum in 0.1M HCl solution in the absence and presence of different concentrations of compound (I) at 25°C. The obtained Nyquist impedance diagrams in most cases does not show perfect semicircle, generally attributed to the frequency dispersion [paskossy et al., (1994)] as a result of roughness and inhomogenates of the electrode surface. The data reveal that, each impedance diagram consists of a large capacitive loop with low frequencies dispersion (inductive arc). This inductive arc is generally attributed to anodic adsorbed intermediates controlling the anodic process [Caprani et al., (1975); Bessone et al., (1983) and Epelboin et al., (1972)]. By following this, inductive arc was disregarded.

In 0.1 M HCl and presence of various concentrations of inhibitors, the impedance diagram shows the same trend (one capacitive loop). however, the diameter of this capacitive loop increases with increasing concentration.

The main parameters deduced from the analysis of Nyquist diagram are:

- The resistance of charge transfer  $R_{ct}$ (diameter of high frequency loop)
- The capacity of double layer  $C_{dl}$  which is defined as :

$$C_{dl} = \frac{1}{2\pi f_{max} R_{ct}} \quad (8)$$

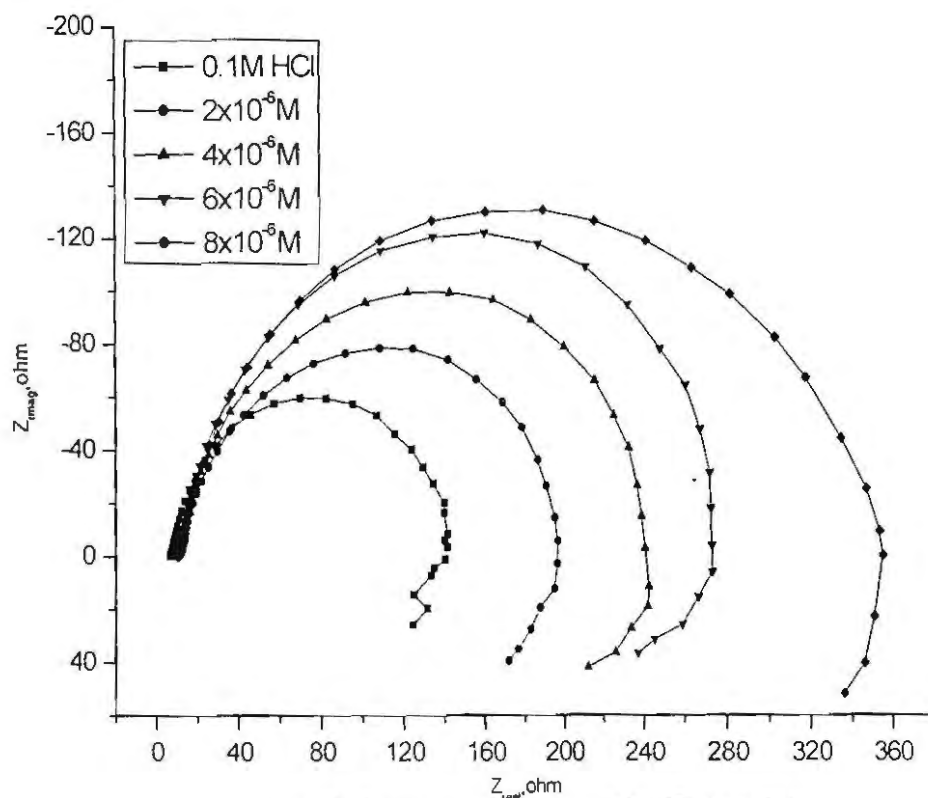


Fig (6) The Nyquist plots for aluminum in 0.1M HCl solution in the absence and presence of different concentrations of compound (I) at 25 °C

The inhibition efficiencies and the surface coverage ( $\theta$ ) obtained from the impedance measurements are defined by the following relations:

$$\%IE = \left( 1 - \frac{R_{ct}^{\circ}}{R_{ct}} \right) \times 100 \quad (9)$$

$$\theta = \left( 1 - \frac{R_{ct}^{\circ}}{R_{ct}} \right) \quad (10)$$

Where  $R_{ct}^{\circ}$  and  $R_{ct}$  are the charge transfer resistance in the absence and presence of inhibitor respectively. The associated with the diagrams impedance are given in Table (4).

From the impedance data given in Table (4), we conclude that:

- i. The value of  $R_{ct}$  increase with increase in the concentration of the inhibitors and this indicates an increase in the corrosion inhibition efficiency in acidic solution.

- ii. As the impedance diagram obtained has a semicircle appearance, it shows that the corrosion of Al is mainly controlled by a charge transfer process.
- iii. The value of double layer capacitance decrease by increasing the inhibitor concentration. This is due to the adsorption of these compounds on the electrode surface leading to a film formation on the Al surface.
- iv. The %IE obtained from EIS measurements are close to those deduced from polarization and weight loss methods.

The order of inhibition efficiency obtained from EIS measurements decreases as follows:

$$I > II > III > IV$$

**Table (4):** Electrochemical kinetic parameter obtained by EIS technique for the corrosion of aluminum in 0.1M HCl at different concentration of investigated compounds at 25°C.

Compounds	Concentration M	$C_{dl}, \mu F.cm^{-2}$	$R_{ct}, ohm$	$\theta$	% IE
Free acid	0	74.78	125.3	0.0000	0.00
I	$2 \times 10^{-6}$	52.29	167.4	0.2515	25.15
	$4 \times 10^{-6}$	47.39	211.6	0.4079	40.79
	$6 \times 10^{-6}$	45.83	246.3	0.4913	49.13
	$8 \times 10^{-6}$	43.71	346.49	0.6384	63.84
II	$2 \times 10^{-6}$	62.43	165.8	0.2443	24.43
	$4 \times 10^{-6}$	59.59	201.1	0.3769	37.69
	$6 \times 10^{-6}$	44.82	218.9	0.4276	42.76
	$8 \times 10^{-6}$	41.31	325.6	0.6152	61.52
III	$2 \times 10^{-6}$	61.29	154.2	0.1874	18.74
	$4 \times 10^{-6}$	49.92	179.9	0.3035	30.35
	$6 \times 10^{-6}$	45.7	213.2	0.4123	41.23
	$8 \times 10^{-6}$	34.49	289.36	0.5670	56.70
IV	$2 \times 10^{-6}$	56.5	150.7	0.1686	16.86
	$4 \times 10^{-6}$	54.67	166.2	0.2461	24.61
	$6 \times 10^{-6}$	52.14	211.8	0.4084	40.84
	$8 \times 10^{-6}$	47.75	273.8	0.5424	54.24



**3.6- Chemical structure and corrosion inhibition:**

Skeletal representation of the mode of adsorption the investigated compounds on Al surface is shown blow in Fig.(7). As shown from this figure, there are only three adsorption active centers( two oxygen atoms and one N atom) in the similar part in all molecules. So the type and structure of R is the effective part. Compound (I) contains one more active centre (N atom of NH<sub>2</sub>) and the compound lies flat on the Al surface, so, more surface area was covered and hence ,more inhibition efficiency was observed. Compound (II) has naphathayl ring which rotate around the bond of C---O and Covers more surface area but less than compound (I). Compounds III and IV are adsorbed on Al surface through the three active centre (two oxygen atoms and one N atom) and the remainder part of molecules is hanging in the solution so less surface area was covered and also the presence of t-methyl group in these molecules makes a steric hindrance for the adsorption of these molecules, so compound III and IV comes after compound I and II in inhibition efficiency.

**4. CONCLUSIONS**

1. The investigated  $\beta$ -blockers inhibit the corrosion of Al in 0.1M HCl medium.
2. The investigated compounds  $\beta$ -blockers affect both cathodic and anodic processes, although mainly cathodic one and don't change the mechanism of the process.
3. The inhibition is due to the adsorption of the investigated compounds on Al surface and blocking its active sites.
4. The inhibition efficiency increases with increasing of the inhibitor concentrations but decreases with the increase of the temperature.
5. The data obtained fit well the Frumkin isotherm model.
6. The data obtained from the three different methods namely, weight loss, potentiodynamic polarization and electrochemical impedance spectroscopy are in good agreement.

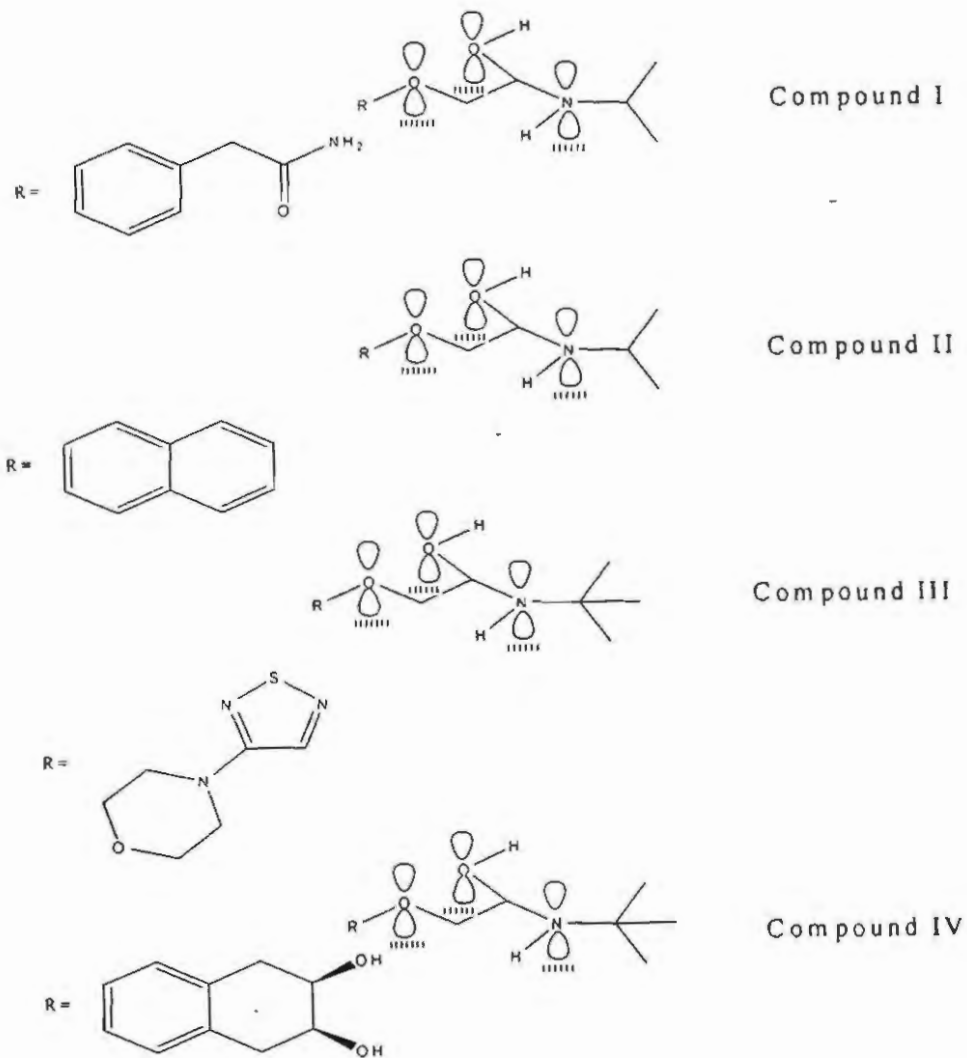


Fig. (7): Skeletal representation of the mode of adsorption of the investigated compounds.

REFERENCES

- Bessone J., Mayer C., Tuttner K. and Lorenz W. J., *Electrochim. Acta*, 28, 171(1983).
- Caprani A., Epelboin I., Morel Ph. and Takenouti H.: proceedings of the 4<sup>th</sup> European sym. on Corros. Inhibitors, Ferrara, Italy 1975, p. 571.
- Chmitt G. S and Bedlur K., *Werkst Korros.* 36, 273 (1985).
- Desai M. N., Thakar B.G., Chiaya P.M. and Gandii M.H., *Corros. Sci.* 16, 9 (1976).
- El-Awady Y.A. and Ahmed A.I., *J. Ind. Chem.* 24A 601(1985).
- Epelboin I., Keddou M. and Takenouti H., *J. Appl. Electrochem.* 2, 71(1972).
- Feng Y., Siow K. S., Teo W. K. and Hsieh A. K., *Corros. Sci.*, 41829(1999).
- Fouda A.S., El-Awady Y.A., Mostafa H.A. and Moussa M.N.H., *Proc. 1<sup>st</sup> Chem. Conf., Fac. Sci., Mansoura Univ.* (1986).
- Gomma G. K. and Wahdan M. H., *Mater. Chem. Phys.*, 30, 209 (1995).
- Granese S. L., *Corrosion* 44, 322 (1988).
- Hackerman N.H. and Kaesche H., *J. Electrochem. Soc.* 105 191,(1958).
- Hukovic M. A., Grubac Z. and Lisac E.S., *Corrosion* 50 (2) (1994) 146.
- Maayta A. K. and Rawshdeh N. A. F., 46, 1129 (2004).
- Mahmoud S. S. and El-Mahdy G.A., *Corrosion* 53 (6) 437(1997).
- Mimani T., Mayanna S.M. and Munichandraiah N., *J. Appl. Electrochem.* 23, 339 (1993).

Paskossy T., *J. Electroanal.Chem.*364, 111(1994).

Rosenfeld I.L., *Corrosion Inhibitors*, Mac. Grawen Hill, New York, (1981), p. 182.

Soliman M.S., Ph. D. Thesis, Alex. Univ., Egypt (1995).

Stern M. and Geary A.I.J., *J. Electrochem. Soc.*, 104, 56 (1957).

Wang J., Cao C., J. Chen., M. Zhang, G. Ye and H. Lin, *J. Chin. soc., protect*, 5, 241(1995).

الملخص العربي

تم استخدام بعض مركبات البيتا بلوكرز كمثبطات لتآكل الألومنيوم في ٠,١ مولر حمض الهيدروكلوريك عند ٢٥ م بطرق فقد الوزن والاستقطاب البوتنشوديناميكي والمعاوقة الكهربية. وجد من النتائج أن كفاءة التثبيط تعتمد على تركيز هذه المركبات والتركيب الكيميائي لها. وقد دلت طريقة الاستقطاب البوتنشوديناميكي على أن هذه المركبات تعمل كمثبطات كاثودية وأن ادمصاص هذه المركبات على سطح الألومنيوم تتبع ايزوثرم فرمكن. وتقل كفاءة التثبيط بارتفاع درجة الحرارة مما يدل ان ادمصاص هذه المركبات على سطح الألومنيوم ادمصاص فيزيائي.

