THE INHIBITION EFFECT OF SOME PYRIMIDINE DERIVATIVES ON CORROSION OF ALUMINUM AND SOME OF ITS ALLOYS IN 2.0 M HCl SOLUTIONS

S. MAHMOUD
Chemistry Department, University College of Girls for Arts, Science and Education, Ain Shams University, Heliopolis, Cairo, Egypt

M. AHMED
Chemistry Department, University College of Girls for Arts, Science and Education, Ain Shams University, Heliopolis, Cairo, Egypt

THE INHIBITION EFFECT OF SOME PYRIMIDINE DERIVATIVES ON CORROSION OF ALUMINUM AND SOME OF ITS ALLOYS IN 2.0 M HCl SOLUTIONS

S.S MAHMOUD AND M.M. AHMED

Chemistry Department, University College of Girls for Arts, Science and Education, Ain Shams University, Heliopolis, Cairo, Egypt

Abstract

In the present study the corrosion of aluminum and some of its alloys in 2M HCl was studied. The effect of some pyrimidine derivatives, as organic inhibitors, on the corrosion of aluminum and its alloys in HCl solution was studied. The techniques used of measurements were: (i) linear polarization (ii) galvanostatic polarization and (iii) electrochemical impedance spectroscopy. The corrosion rate of the investigated electrodes was found to be depended on the type and composition of the metal electrode. The pyrimidine derivatives acted as mixed inhibitors in acidic media.

It was found that the inhibition efficiency of the inhibitor greatly depended on the type, size, and concentration of the compound and on the electron density of the adsorption centers. The inhibitory effect of the investigated compounds resulted from their adsorption on the metallic surface via adsorption centers and /or electrostatic interaction between the organic compound and electrode. The adsorption of inhibitors on the metallic surface from 2.0 M HCl solutions obeyed the Temkin's adsorption isotherm. Results obtained from linear polarization, galvanstatic polarization and impedance measurements are in a good agreement.

Introduction

Alloying of aluminum with different elements in general improves its mechanical and physical properties. Aluminum is often alloyed with silicon and /or copper. The study of the corrosion of aluminum and its alloys is a subject of pronounced practical significance because it can find widespread applications in many industries. Hydrochloric acid solutions are used for pickling of aluminum and its alloys and for chemical and electrochemical etching of aluminum foil and lithographic panels substitute metallic zinc [1]. Since the metal dissolution in such solutions is rather large, it is necessary to inhibit it by the addition of inhibitors, which should provide a good quality pickled metal surface.

In recent years new data have been obtained on the pitting corrosion of aluminum due to the presence of chloride ions in different aqueous solutions[2-7]. Generally, local corrosion attack can be prevented by the action of adsorptive

inhibitors which prevent the adsorption of the aggressive anions, by the formation of a more resistant oxide film on the metallic surface [8].

A number of organic compounds have been introduced as aluminum corrosion inhibitors in acid media [9,10]. Investigations of various aliphatic and aromatic amines as well as nitrogen- heterocyclic compounds [11-16] showed that, their inhibitory action is connected with several factors such as :(i) the structure of molecules, (ii) the number and type of adsorption sites (iii) electron density on the adsorption sites and (iv) the type of interaction between organic molecules and the metallic surface. The efficiency of these compounds as corrosion inhibitors can be attributed to the number of mobile electron pairs, the π orbital character of free electrons, and the electron density around nitrogen atoms.

In this study the corrosion behavior of aluminum and some of its alloys was studied in 2 M HCl solution. The effect of some pyrimidine derivatives on the corrosion behavior of aluminum and its alloys in acidic medium was investigated using different electrochemical techniques of measurements. The selection of these organic compounds is based on the fact that they can adsorb readily on the metal surface through nitrogen atoms. The toxicity of these compounds is very low and they are readily soluble acid solutions. The choice of 2 M HCl solution as an aggressive medium aims to testify the inhibiting efficiency of pyrimidine compounds in highly acidic media.

Experimental

The working electrodes were prepared from cylindrical rods of aluminum and its alloys, having the dimensions of 0.70 cm and 2 cm length. These electrodes have the chemical composition shown in Table (1) and were supplied from Misr company of Aluminum, Egypt. The electrodes were jammed in a small copper with about 30 cm wire tail which was fixed in a glass tube with Araldite (Ciba-production, Switzerland) epoxy adhesive resin . The exposed area of electrode was 2 cm^2. Before each experiment the electrodes were polished mechanically with successive grades of emery papers from 1/0 to 5/0. The final polish was made by rubbing with a fine tissue paper so that the surface appears as a bright mirror. The electrodes were subsequently degreased with trichloroethylene before use.
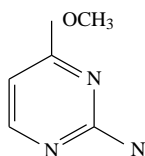
The organic compounds used as inhibitors have the following structures:
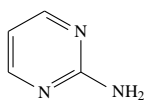
2- aminopyrimidine (compound a)
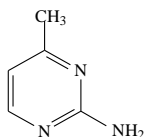
2- amino-4-methylpyrimidine (compound b)

2- amino –4- methoxypyrimidine (compound c)

The aggressive solution, namely HCl, was prepared using Analar grade HCl and the appropriate concentration of the acid was prepared using triply distilled water. The concentration of the inhibitor compounds was in the range 10^{-6} –10^{-3} M in 2.0 M HCl.

The techniques used of measurements were: (i) linear polarization, (ii) galvanostatic polarization and (iii) electrochemical impedance spectroscopy. The cell assembly consisted of a working electrode, platinum foil counter electrode, and a saturated calomel electrode (SCE) as the reference electrode. All experiments were carried out at 25 ± 2°C. The polarization current values derived from a constant current unit (DC Power Supply GP- 4303, LG Precision Co Ltd , Korea). The potential and current measurements were carried out using multimeter (model 1008, Kyoritsu Electrical Instruments Work Ltd, Japan) with high input impedance. The impedance measurements were carried out using impedance measurements system (1 M6 Zahner Electrik, Meβtechnik; Germany). Impedance measurements were conducted, with an excitation amplitude of 10 mV peak to peak and the frequency domain from 0.1 Hz to 100 kHz. Impedance measurements were used to determine Nyquist plots for inhibited 2M HCl solutions and uninhibited solutions and inhibitor efficiency values were calculated. The impedance measurements were carried out at steady state under open- circuit conditions.

Results And Discussion

Linear polarization measurements:

Fig.(1) represents the plots of potential, E, and current density, i, of the linear polarization measurements for electrode (I) immersed in 2M HCl solution in absence

and in presence of different concentrations of organic compound (a). Similar plots were obtained for electrode (I) in presence of organic compounds (b) and (c) and for the other investigated electrodes (II - V) in 2M HCl solutions in absence and in presence of different concentrations of the organic compounds (a, b, c), but not shown. The obtained plots were straight lines, where from their slopes the different values of the polarization resistance were deduced ($R_p=\Delta E/\Delta i$). The values of R_p for the investigated electrodes in 2M HCl solution without inhibitors were: 2000,1666.7, 2500, 2333.3, 1250 $\Omega.cm^{-2}$ for the electrodes I,II,III,IV and V, respectively. This means that the value of R_p for the investigated electrodes in uninhibited 2M HCl solutions increases according to the order: V<II<I<IV<III.

The values of surface coverage of the electrodes, θ, and inhibition efficiency of the organic compounds, I%, were calculated using the following equations:

$$\theta = 1- \frac{(R_p)_{free}}{(R_p)_{inh}} \tag{1}$$

$$I\% = [1- \frac{(R_p)_{free}}{(R_p)_{inh}}] \text{ X } 100 \tag{2}$$

Where $(R_p)_{inh}$, $(R_p)_{free}$ are the linear polarization resistances with and without inhibitor, respectively. The calculated values of θ and I% for the organic additives are listed in Table (2). Figs (2-4) represent the variation of inhibition efficiency, I%, as a function of concentration, M, of the organic compounds (a ,b and c), respectively. It is clear from the results of Table (2) and Figs. (2-4) that the increase of inhibitor concentration increases its inhibition efficiency, I%. Also the values of I% were found to be depended on the molecular structure of the investigated organic compounds, where these values increase according to the order: a < b < c.

Galvanostatic polarization measurements:

Fig.(5) represents the galvanostatic cathodic and anodic polarization curves of electrode (I) immersed in 2M HCl solutions in absence and presence of different concentrations of compound (a). Similar plots were obtained for the electrode (I) in presence of organic compounds (b,c) and for the other electrodes (II,III,IV,V) in absence and   presence of the investigated organic compounds (a, b and c) , but not shown. From the polarization curves of Fig. (5) and similar ones the values of corrosion current density, i_{corr}, and corrosion potential, E_{corr}, were deduced by Tafel's extrapolation method. The values of surface coverage, θ, and the inhibition

efficiency, I%, were calculated from i_{corr} data for the different concentrations of the investigated organic compounds (a, b and c) by using the following equations:

$$\theta = 1 - \frac{(i_{corr})_{free}}{(i_{corr})_{inh}} \qquad (3)$$

$$I\% = [1 - \frac{(i_{corr})_{free}}{(i_{corr})_{inh}}] \times 100 \qquad (4)$$

where $(i_{corr})_{inh}$ and $(i_{corr})_{free}$ are the corrosion current densities in HCl solutions with and without inhibitor, respectively. The calculated values of θ and I% are listed in Table (3). The values of i_{corr} and E_{corr} for the investigated electrodes (I-V) immersed in 2M HCl solutions are listed in Table (4).

It is clear from the plots of Fig. (5) and similar ones that the presence of increasing concentration of the investigated organic compounds in 2M HCl solutions increases both cathodic and anodic polarization of the investigated electrodes.

The results of Table (3) indicated that, for all electrodes, the increase of inhibitor concentration increases the values of θ and I%. Also, the values of θ and I% were found to be depended on the molecular structures of the investigated organic inhibitors, where these values increase according to the order: a<b<c .The value of i_{corr} for the investigated electrodes in 2M HCl solutions without inhibitors (listed in Table (4)) decreases according to the order: V> II >I > IV>III. The previously mentioned orders are the same as those obtained by linear polarization measurements.

Electrochemical Impedance studies ;

Fig. (6) represents the impedance diagrams (Nyquist plots) for electrode (I) immersed in 2M HCl in absence and in presence of increasing concentration of organic compound (a). Similar Nyquist plots were obtained for electrode (I) in presence of organic compounds (b,c) and for the other electrodes (II, III ,IV ,V) in absence and presence of the organic compounds (a,b,c,), but not shown. The obtained impedance diagrams are not perfect semi-circles as seen from Fig. (6) and similar ones. This result has been attributed to frequency dispersion [17,18]. The fact that impedance diagrams have a semicircular appearance shows that the corrosion of the investigated electrodes is controlled by a charge transfer process and the

presence of an inhibitor doesn't alter the mechanism of dissolution of electrodes in HCl. The equivalent circuit at the electrode interface can be presented by the parallel combination of a capacitor and a resistor. The charge transfer resistance ,R_t, can be determined by fitting semicircle on the Nyquist plots as described elsewhere [19,20]

The double layer capacitance, C_{dl}, was determined from the frequency, f, at which Z_i was maximum, using the relationship:

$$f \ (- Z_i) \quad = \quad (\ 2 \pi \ \ C_{dl} \ R_t \ )^{-1} \tag{5}$$

The inhibition efficiency, I%, of electrodes was calculated from the charge transfer resistance, R_t, using the following equation:

$$I\% = \frac{R_{t\,corr}^{-1} - R_{t\,corr(inh)}^{-1}}{R_{t\,corr}^{-1}} \tag{6}$$

where $R_{t\,corr\,(inh)}$ and $R_{t\,corr}$ are the charge transfer resistance values with and without inhibitor. The values of R_t , C_{dl} and I% derived from impedance measurements are listed in Table (5). These results indicated that as the inhibitors concentration increase the values of R_t and I% increase, but the value of C_{dl} decreases. This indicates the occurrence of adsorption of inhibitors on the electrodes surface. Also, the inhibition efficiency, I%, of the investigated inhibitors increases according to the order: a<b<c. the value of R_t of the electrodes immersed in uninhibited 2M HCl solution increases according to the order: V<II<I<IV<III. These two orders are the same orders obtained by the linear polarization and galvanostatic polarization measurements.

In this system where the electrodes immersed in HCl solution, the chloride ions and inhibitor molecules compete each other for the adsorption onto the electrode surface. The amount of adsorbed chloride ions decreases with the increase of inhibitor concentrations. For higher concentrations of inhibitor the adsorption of activating chloride ions can be excluded completely.

The obtained results of galvanostatic polarization measurements indicated that the investigated organic compounds affected both the cathodic and anodic polarization curves. The presence of these inhibitors in the aggressive media increases both the cathodic and anodic polarization. It has been found that the magnitude of the displacement of the polarization curves appeared to be dependent on the molecular structure of the inhibitor. Also, the E_{corr} values for the electrodes did not shift significantly in the presence of these compounds. These observations

show clearly that the inhibition of corrosion is under mixed control. Also, the cathodic and anodic polarization curves gave rise to more or less parallel Tafel's lines, indicating that the hydrogen evolution and metal dissolution were activation controlled and the addition of the investigated organic compounds did not modify the mechanism of these processes[20,21].
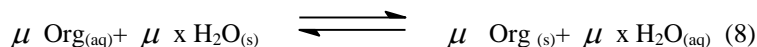
Adsorption Isotherm:

The adsorption of an organic compound on the surface of the electrodes can be regarded as a substitutional adsorption process between the organic compound in the aqueous phase, Org $_{(aq)}$, and water molecules adsorbed on the electrode surface, $H_2O_{(s)}$[22].

$$Org_{(aq)} + x H_2O_{(s)} \rightleftharpoons Org_{(s)} + x H_2O_{(aq)} \qquad (7)$$
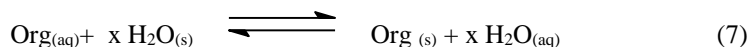
where x is the size ratio , which is the number of water molecules replaced by one molecule of organic adsorbate.

The above process attains equilibrium when

$$\mu\ Org_{(aq)} + \mu\ x H_2O_{(s)} \rightleftharpoons \mu\ Org_{(s)} + \mu\ x H_2O_{(aq)} \quad (8)$$

Where μ is the chemical potential.

The surface coverage values, θ, were tested graphically for fitting a suitable adsorption isotherm. The values of θ calculated from the galvanostatic polarization measurements can be used for this graphical fitting, because there were great agreements between the results obtained by the different used techniques of measurements in this study. The plots of θ versus logarithm of inhibitors concentration (log C) yielded straight lines, clearly providing that the adsorption of the organic compounds (a,b,c) in 2M HCl solution on the metallic electrodes obeyed Temkin adsorption isotherm, Figs.(7a-e). This observation supports the conclusion that the inhibition of corrosion by these organic compounds is due to their adsorption on the metallic surface. The Temkin adsorption isotherm can be written in the form [23].

$$f\ (\ \theta, x\ )\ \exp(-a\ \theta\ )\ =\ KC \qquad (9)$$

where f(θ,x) is the configurationally factor that depends essentially on the physical model and assumptions underlying derivation of the isotherm, and K is the equilibrium constant of the adsorption process. The equilibrium constant of

adsorption is related to the standard free energy of adsorption $\Delta G^o_{ads.}$ by the relation:

$$K \; = \; \frac{1}{55.5} \; \exp (- \frac{\Delta G^o_{ads}}{RT}) \qquad\qquad (10)$$

where R is the universal gas constant, T is the absolute temperature and the value 55.5 is the molar concentration of water in the solution .

The values of $\Delta G^o_{ads.}$ of   inhibitors adsorbed on the surface of electrodes were calculated and ranged from – 65 to –100 kJ/ moles depending on the type of electrode and type of inhibitor and its concentration.

The negative value of ΔG^o_{ads} indicates that the adsorption of these compounds on the metallic surface spontaneously occurs.

Corrosion inhibition of aluminum and its alloys (electrodes I –V) in 2 M HCl solutions by the investigated organic compounds (pyrimidine derivatives) was found to be depended on the concentration, size of inhibitor and electron density on the adsorption centers (N- atoms). Thus the adsorption of the investigated organic compounds on the metal surface can occur directly via donor- acceptor interaction between the π electrons of the heterocyclic compounds and the vacant orbital of the metal surface atoms, involving the displacement of water molecules from the metal surface and the sharing of electrons between the nitrogen atoms and the metal surface.

These heterocyclic nitrogen compounds may also adsorb via electrostatic interactions between the positively charged atom and the negatively charged confirm metal surface. It has been observed that the adsorption of the inhibitor can be influenced by the nature of anions in acidic solution [24-26]. The specific adsorption of anions with a smaller degree of hydration , such as chloride ions, is expected to be more pronounced. Being specifically adsorbed, they create a layer of excess negative charge directed towards the solution and promote further adsorption of inhibitor.

It can be proposed that the investigated compounds may be protonated in acidic solutions according to the following reaction:
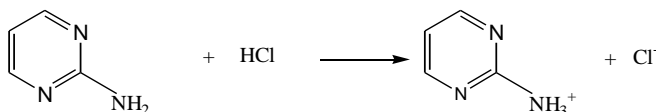
The formation of the promoted compound greatly facilitates their adsorption on the metallic surface through the electrostatic interaction.

The above mentioned increasing order of inhibition efficiency of the organic inhibitors can be accounted for in terms of constant (σ) , Hammett's constant. The value of this constant reflects the influence of substituent on the electron density of the adsorption centers (N- atoms) of the molecule. It is negative in the case of electron donating substituent, and it becomes positive when the substituent is electron withdrawing. Compound (c) is the most efficient   inhibitor because of the presence of highly electron   releasing   methoxy group (σ =-0.27) which enhances the delocalized π - electrons on the active centers of the compound (c). Compound (b) comes after compound (c), this is due to its lower Hammett's constant (σ = -0.17) . Compounds (a) (σ =0.00) comes after compound (b) in inhibition efficiency, this is due to its lower molecular size than compound (b) and (c) and lower electron density on the adsorption centers of the molecule.

Alloying of aluminum with different elements in general improves its mechanical and physical properties. Certain alloying additions impart better corrosion resistance to aluminum whereas others decrease it. Most of the alloying additions create metallurgical differences in aluminum causing electrochemical local cells to develop. Aluminum is often alloyed with silicon and /or copper. However, copper (due to its low solubility in aluminum) readily forms an intermetallic compound that improves the electro migration resistance, but increases the susceptibility to corrosion [27]. The addition of copper to aluminum lowers the overall corrosion resistance of aluminum while silicon addition leads to slight increase in corrosion resistance [28]. This means that the corrosion resistance of the electrodes greatly depends on their chemical composition.

Table (1): Chemical analysis of working electrodes

Element Wt%	Working electrode				
	I	II	III	IV	V
Si	7.040	0.450	8.790	11.050	0.060
Fe	0.090	0.180	0.130	0.110	0.160
Cu	0.000	0.001	0.980	0.000	0.0004
Mn	0.004	0.011	0.006	0.005	0.0015
Mg	0.291	0.490	0.360	0.182	0.001

Table (2): Data from linear polarization measurements for electrodes in 2.0 M HCl containing different concentrations of organic compounds(a,b,c).

Electrode	I		II		III		IV		V	
Conc. M	θ	I %	θ	I %	θ	I %	θ	I %	θ	I%
(a)										
10^{-6}	0.399	40	0.3333	33.33	0.375	37.5	0.31	31	0.5	50
10^{-5}	0.556	55.6	0.583	58.3	0.545	54.5	0.491	49.1	0.667	66.7
10^{-4}	0.68	68	0.71	71	0.667	66.7	0.689	68.9	0.75	75
10^{-3}	0.771	77.1	0.778	77.8	0.75	75	0.78	78	0.81	81
(b)										
10^{-6}	0.467	46.7	0.5	50	0.48	48	0.528	52.8	0.50	50
10^{-5}	0.7	70	0.667	66.7	0.625	62.5	0.627	62.7	0.69	69
10^{-4}	0.8	80	0.75	75	0.714	71.4	0.767	76.7	0.817	81.7
10^{-3}	0.86	86	0.833	83.3	0.80	80	0.844	84.4	0.84	84
(c)										
10^{-6}	0.52	52	0.556	55.6	0.50	50	0.53	53	0.62	62
10^{-5}	0.73	73	0.714	71.4	0.6	60	0.69	69	0.75	75
10^{-4}	0.826	82.6	0.80	80	0.714	71.4	0.767	76.7	0.83	83
10^{-3}	0.886	88.6	0.87	87	0.833	83.3	0.867	86.7	0.9	90

Table (3): Data from galvanostatic polarization measurements for electrodes in 2.0 M HCl containing different concentrations of organic compounds.

Electrode	I		II		III		IV		V	
Conc. M	θ	I%	θ	I%	θ	I%	θ	I%	θ	I%
(a)										
10^{-6}	0.4	40	0.35	35	0.37	37	0.34	34	0.33	33
10^{-5}	0.54	54	0.58	58	0.55	55	0.52	52	0.52	52
10^{-4}	0.66	66	0.7	70	0.66	66	0.68	68	0.67	67
10^{-3}	0.78	78	0.78	78	0.76	76	0.78	78	0.78	78
(b)										
10^{-6}	0.46	46	0.49	49	0.52	52	0.53	53	0.52	52
10^{-5}	0.65	65	0.65	65	0.64	64	0.64	64	0.66	66
10^{-4}	0.76	76	0.75	75	0.73	73	0.75	75	0.77	77
10^{-3}	0.84	84	0.84	84	0.83	83	0.85	85	0.86	86
(c)										
10^{-6}	0.53	53	0.542	54.2	0.52	52	0.53	53	0.57	57
10^{-5}	0.74	74	0.71	71	0.65	65	0.68	68	0.72	72
10^{-4}	0.83	83	0.81	81	0.75	75	0.77	77	0.8	80
10^{-3}	0.89	89	0.895	89.5	0.86	86	0.88	88	0.89	89

Table (4): The values of i$_{corr}$ and E$_{corr}$ for the investigated electrodes (I-V) in 2M   HCl solutions.

Electrode	E$_{corr}$ mV	I$_{corr}$ μ A/cm^2
I	-760	65
II	-830	76
III	-655	50
IV	-762	58
V	-905	100

Table (5): Data from impedance measurements of electrodes in 2M HCl containing different concentrations of organic Compounds (a,b,c)

| Elect-rode	I			II			III			IV			V		
Conc. M	R$_t$ Ω cm^2	C$_{dl}$ μ F.cm$^-_2$	I%	R$_t$ Ω cm^2	C$_{dl}$ μ F.cm$^-_2$	I%	R$_t$ Ω cm^2	C$_{dl}$ μ F.cm$^-_2$	I%	R$_t$ Ω cm^2	C$_{dl}$ μ F.cm$^-_2$	I%	R$_t$ Ω cm^2	C$_{dl}$ μ F.cm^{-2}	I%
(a)															
0.00	130	1224.9	-	110	1447.6	-	150	1061.6	-	140	1137.4	-	100	1592.36	-
10^{-6}	213	747.6	39	172	925.79	36	234.4	679.3	36	215.4	739.26	35	151.5	1051.1	34
10^{-5}	280	568.7	53.5	255	624.45	57	340.9	467.1	56	297.9	534.53	53	212.8	748.29	53
10^{-4}	371.4	428.75	65	367	433.88	70	454.5	350.35	67	451.6	352.6	69	312.5	509.6	68
10^{-3}	553	287.95	76.5	500	318.47	78	652.2	244.15	77	636.4	250.21	78	476.2	334.4	79
(b)															
0.00	130	1224.9	-	110	1447.6	-	150	1061.6	-	140	1137.4	-	100	1592.36	-
10^{-6}	240.7	661.6	46	211.5	752.9	48	306.1	520.23	51	304.35	523.2	54	212.8	748.29	53
10^{-5}	382.4	416.43	66	314.3	506.7	65	405.4	392.8	63	400	398.1	65	285.7	557.35	65
10^{-4}	565.2	281.74	77	458.3	437.5	76	535.7	297.26	72	583.3	272.99	76	416.7	382.14	76
10^{-3}	866.7	183.73	85	733.3	217.16	85	937.5	169.86	84	933	170.7	85	666.7	238.84	85
(c)															
0.00	130	1224.9	-	110	1447.6	-	150	1061.6	-	140	1137.4	-	100	1592.36	-
10^{-6}	282.61	563.47	54	239	666.26	54	319.2	498.9	53	318.2	500.4	56	227.3	700.55	56
10^{-5}	520	306.22	75	392.9	405.28	72	483.9	329.07	69	437.5	363.97	68	333.3	477.76	70
10^{-4}	764.7	208.23	83	611.1	260.57	82	714.3	222.93	79	666.7	238.8	79	500	318.47	80
10^{-3}	1300	122.49	90	1000	159.26	89	1250	127.39	88	1272.7	127.1	89	1000	159.26	90
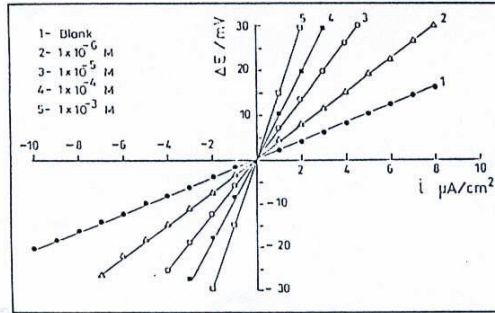
Fig.(1) : Linear polarization curves for electrode (I) in 2M HCl solutions in absence and in presence of different concentrations of organic compound(a).
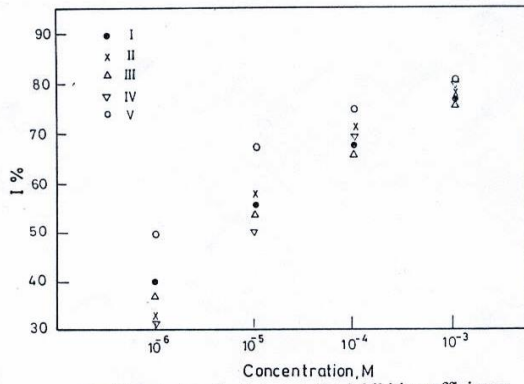

Fig.(2): relationship between the inhibition efficiency, I%, and concentration, M ,of the organic compound(a).
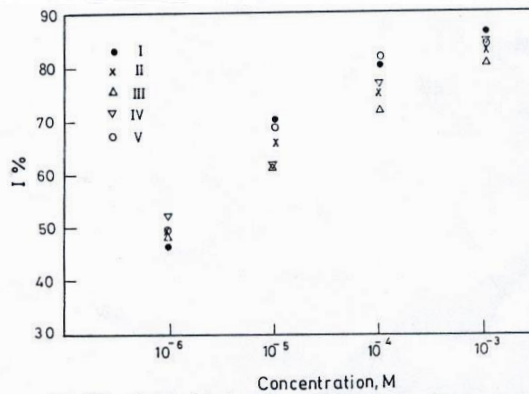

Fig.(3): relationship between the inhibition efficiency, I%, and concentration, M ,of the organic compound(b).
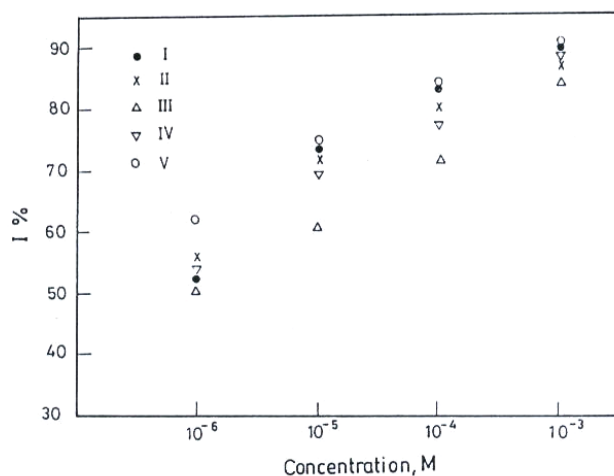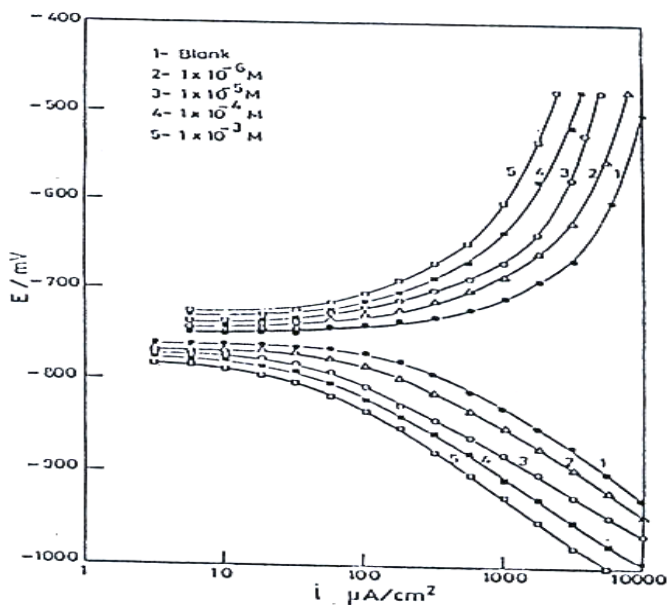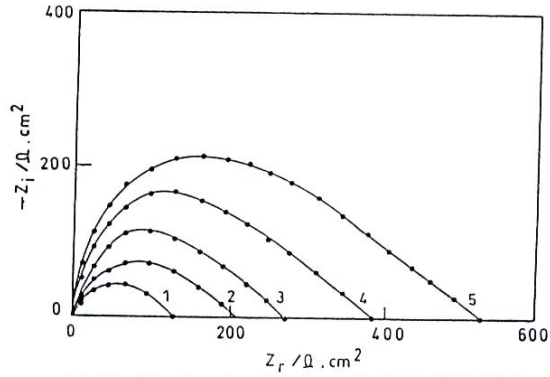
Fig.(4): relationship between the inhibition efficiency,
I%, and concentration, M,of the organic compound(c).

Fig.(5): Galvanostatic polarization curves of electrode
(I) in 2M HCl solution in absence and in presence of
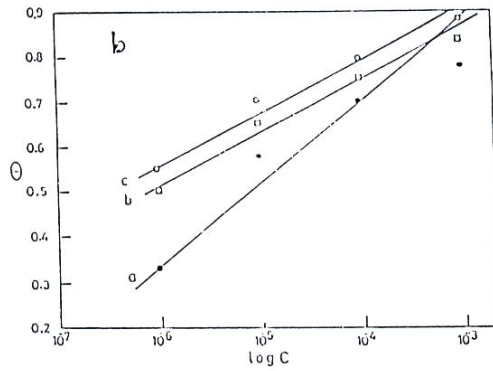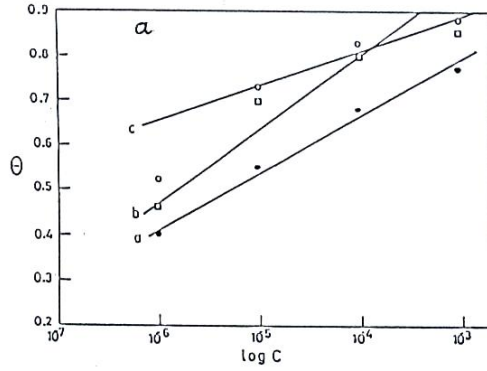different concentrations of organic compound(a).

Fig.(6): Nyquist plots for electrode (I) in 2M HCl in absence and in presence of different concentrations of compound (a).
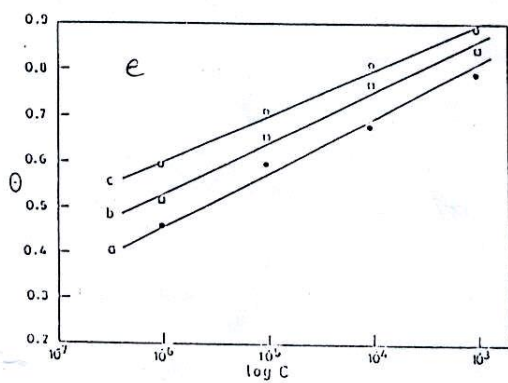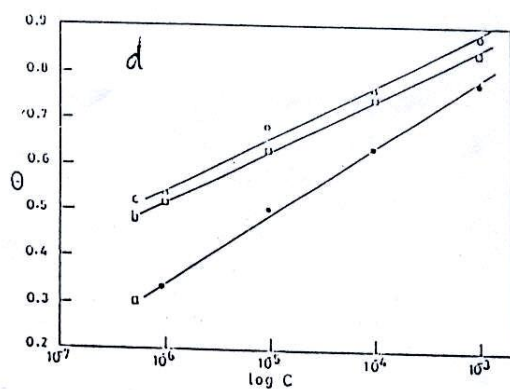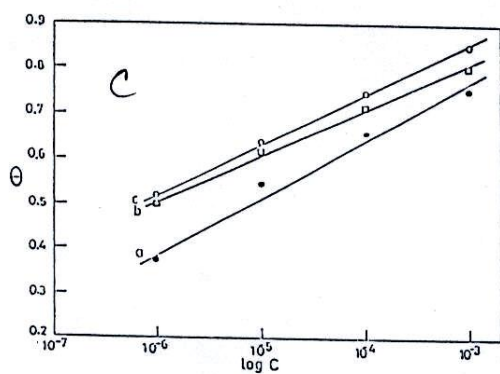
Fig.(7a-e): Temkin's isotherm of different inhibitors for the electrodes: a-(I), b-(II), c-(III), d-(IV), e-(V).

Conclusions:

The main conclusions drawn from this study are:

1- The corrosion resistance of the investigated electrodes in 2 M HCl solution depends on the type and composition of electrodes.

2- The pyrimidine derivatives can be used as inhibitors for the corrosion of aluminum and its alloys in highly acidic HCl solutions.

3- The inhibition of corrosion of the electrodes in the presence of these organic compounds was found to be under mixed control in 2 M HCl solutions.

4- All the investigated pyrimidine derivatives inhibited the corrosion of the electrodes by being adsorbed on the metal surface via the adsorption centers of the inhibitor and / or by electrostatic interaction between the inhibitor and the metallic surface.

5- Adsorption of these organic compounds on the metallic surface from 2M HCl solution obeyed Temkin's adsorption isotherm.

6- The inhibition efficiency of the investigated organic compounds depends on the type, concentration, and molecular size of the inhibitor and may also depend on the electron density on adsorption centers in the molecule.

7- Results obtained from the different techniques of measurements used in this study are in a good agreement.

References

1. J.D. TALATI, D.K. GANDHI; Corros. Sci., 26,1315(1983).

2. J.BESSONE, D. R. SALINAS, C. E. MAYER, M. EBERT, W. J. LARENZ; Electrochim. Acta, 34, 2283(1992).

3. W.M. MOORE, C.T. CHEN, G.A.SHIRN; Corrosion, 40,644(1984).

4. T.R.BECK; Electrochim.Acta, 33, 1321(1988).

5. L.TOMCSANYI, K.VARGA, I. BARTIK, G. HORANYI, E. MATECZKI; Electrochim. Acta, 34, 855(1989).

6. S. SZKLARSKA- SMIALOWSKA; Corros., Sci, 33, 1193(1992).

7. C. BRETTI; Corros.Sci, 33, 203(1992).

8. S.SZKLARSKA- SMIALOWSKA "Pitting Corrosion of Metals"; NACE, Houston, Texas, (1986).

9. M.METIKOS- HUKOVIC, R. BABIC, Z. GRUBAC,S. BRINIC; J.Apl. Electrochem., 24, 325, 772(1994).

10. R.BABIC, M.METIKOS-HUKOVIC, S. OMANOVIC, Z. GRUBAC, S.BRINIC; Br.Corros.J.30, 288(1995).

11. I.L.ROZENFELD, "Corrosion Inhibitors" MacGraw- Hill, New York, (1981).

12. A.EL-SAYED; Denki Kagaku; 66,176(1998).

13. P.N.S. YADAV; Trans SAEST, 34(1) 30-31(1999) Eng.

14. P.N.S. YADAV; Trans SAEST, 34(2) 66-69(1999) Eng.

15. M.N. DESAI, B.C. THAKAR, P.M. CHIAYA, M.H. GANDI; Corros. Sci., 16,9(1976).

16. S.L. GRANESE, B.M.ROSALES; Proc.7th European Symp. Corrosion inhibitors, Ann. Uni. Ferrara, N.S. Sez. V. Suppl, N.9, 1990,P.73.

17. F. MANSFELD, M.W. KENDING, S. TSAI, Corrrosion, 37,301(1981).

18. F. MANSFELD, M.W. KENDING, S. TSAI, Corrosion, 38, 570(1982).

19. T.TSURU, S. HARUYAMA, BOSHKU GIJUTSU, J .Japan Soc. Corros. Engng. 27,573(1978).

20. F.BENTISS,M.TRAISNEL, M.LAGRENEE; Brit. Corros.J.,35, 315(2000).

21. S.KERTIT AND B.HAMMOUTI; Appl. Surf. Sci,93,59(1996).

22. B.G. ATEYA, B.E. ANADOULI, F.M. NIZAMY; Corros. Sci.,241(1984).

23. E. KHAMIS, Corrosion,46,6,476(1990).

24. N. HACKERMAN, E. SNAVELY, JR, J.S. PAYNE,JR; J. Electrochem.Soc., 113,677(1966).

25. Z.A.FOROULIS; Proc. 6 th European Symp.On Corrosion Inhibitors Ferrara, Italy, September,1985; Ann. Univ. Ferrara. Ns,Sez, V.,1985 (Suppl.8),130.

26. S. RENGAMATI, S. MURALIDHARAN, N. ANBU KULANDAINATHAN, S.V.K.IVER; J. Appl. Electrochem.,24,355(1994).

27. S.THOMAS, H.M.BERG; IEEE Transactions on Compments Hydrides and Manufacturing Technology (CHMT-10), 1987 PP 252-257.

28. A.J.GRAFFIN, JR,F.R.BROTZEN; J. Electrochem. Soc.,141,12(1994).