

## Corrosion Inhibition of Aluminum Alloy 5083

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### Abstract

The corrosion inhibition of aluminum alloy 5083 by an environment friendly compound called (8- Hydroxyquinoline) in acidic and alkaline solutions of pH (2 and 12) respectively were studied using weight loss and polarization techniques. Also to examine the main and combined effects of the inhibitor concentration, pH, and contact time using factorial experimental design. Results show that corrosion rate decreased with increasing both inhibitor concentration and contact time and increased with increasing pH value. The polarization curves show that 8-hydroxyquinoline is a cathodic inhibitor

**Keywords:** Corrosion inhibition, 8-Hydroxyquinoline, Aluminum alloy, LPR.

### Introduction

Aluminum is one of the world's most commonly used metals. Its lightness coupled with its strength, conductivity, and its barrier properties have all been and continue to be its most important advantages and the main reasons for the continued growth in the usage of aluminum [1]. Aluminum is a very active metal, exposed to a source of oxygen; it reacts to form a thin transparent oxide film over the whole of the exposed metal surface. This film controls the rate of corrosion and protects the substrate metal, allowing the production of long life components in aluminum and its alloys. If the film is damaged and cannot be repaired, corrosion of the substrate is very rapid [2], this film is stable in aqueous media when the pH is between about 4.0 and 8.5, but this amphoteric surface film dissolves substantially when the metal is exposed to high acidity or alkalinity environment [3,4]. Hydrochloric acid solutions are normally used for pickling of aluminum and for its chemical and electrochemical etching, process that normally lead to substantial loss of the metal to corrosion. An important applications in which aluminum is deployed in service in strong alkaline environment is the alkaline cleaning, pickling before surface treatments and the aluminum/air battery system. In efforts to mitigate aluminum corrosion,

the main strategy is to effectively isolate the metal from corrosive agents. This can be achieved by the use of corrosion inhibitors. Inorganic substances such as phosphates, chromates, dichromate and arsenates have been found effective as inhibitors of metal corrosion, but a major disadvantage is their toxicity and as such their use has come under sever criticism. Among the alternative corrosion inhibitors, organic substances containing polar functions with nitrogen, oxygen and/or sulphur atoms in a conjugated system have been reported exhibit good inhibiting properties. Corrosion inhibition occurs by adsorption of their molecules on the corroding metal surface [4].

8-Hydroxyquinoline is an organic compound with the formula  $C_9H_7NO$ . It is a derivative of the heterocyclic quinoline by placement of an OH group on carbon number 8. This colorless compound is widely used commercially, although under a variety of names (e.g., I, azanaphthalene-8-ol, Fennosan H30, and Quinophenol). The complexes as well as the heterocyclic itself exhibit antiseptic, disinfectant, and pesticide properties. Its solution in alcohol is used as liquid bandages. It once was of interest as an anti-cancer drug [5]. It has the stable metal complexes (p) that are not ionic in nature and can be characterized by the general formula  $M_nX_n$ , where n is the charge of the metal ion M [6]:



The metal ion is bound in five membered rings linking the oxygen atom of the phenolic group and the heterocyclic nitrogen atom. Factorial design is an experimental technique by which factors involving in a process can be identified and their relative importance assessed. It is thus a means of separating those factors that are important from those that are not, and identifying the interactions, if any, between the factors chosen, thus, the construction of a factorial design involves the selection of parameters and the choice of responses [7].

## Experimental Work

### Solutions and Chemicals

Acidic and alkaline solutions of pH (2 and 12) adjusted by HCl acid and NaOH respectively, were prepared from distilled water using annular chemicals.

Table (1) lists the compounds and chemicals used in this investigation.

Table (1) specifications of chemicals and compounds

Compound	Formula	Source	Purity %
Acetone	C <sub>3</sub> H <sub>6</sub> O	Hop kin and Williams Ltd	99.5
Benzene	C <sub>6</sub> H <sub>6</sub>	Hop Kin and Williams Ltd	-
Hydrochloric acid	HCl	BDH chemicals Ltd England	98.9
Sodium hydroxide	NaOH	Seeze-Hanover	95
8-Hydroxyquinoline	C <sub>9</sub> H <sub>7</sub> NO	BDH chemicals Ltd England	99.5

### Experimental Procedure

#### Weight loss Measurements:

The experiments were carried out using rectangular aluminum coupons, the dimensions of each specimen were measured with vernia to the 2 decimal of millimeter, after polishing and cleaning, accurately weighed to the 4 decimal of gram before it used. Specimen was completely immersed in (250 ml) of corroding solution contained in (500 ml) beakers. They were exposed for a period of 24 hr or 48hr, according to the test, at desired temperature, inhibitor concentration, and pH.

After each test, the specimen was washed with running tap water, scrubbed with a brush to remove corrosion products, then washed with tap water followed by distilled water and dried, immersed in benzene, dried, immersed in acetone, and then reweighed. The weight loss was then determined and the rate of corrosion was expressed in (mg/m<sup>2</sup>.day).

#### Electrochemical Measurements:

##### Half-cell measurements:

The change in potential of the working electrode AA5083 was recorded as a function of time against Saturated Calomel Electrode (SCE) which bridged by a luggin Haber probe. The "half cell" potential was carried directly on the display of voltmeter.

##### Potentiostatic polarization measurements:

The data were obtained in three electrode mode. Graphite and saturated calomel electrodes were used as counter and reference electrodes respectively, the specimens used as working electrode. Corrosion cell parts were joined to each other, and then connected to a power supply, resistors, ammeter, and voltmeter, starting with cathodic polarization until reaching the corrosion potential then continuing with anodic polarization

## Results and Discussion

#### Weight loss technique:

Corrosion rate calculations from weight loss data was performed according to the following equation:

$$CR = \frac{\text{weightloss (mg)}}{\text{Area (m}^2\text{)} * \text{Time (day)}} \quad (1)$$

The factors and the low and high levels of the factors mentioned are shown in table (2), the matrix of the factorial design is shown in table (3).

Table (2) factors and levels used in the 2<sup>3</sup> factorial design.

Variables	Low level	High level
8-hydroxyquinoline concentration (ppm), X <sub>1</sub>	750 (-1)	2500 (+1)
Contact time (h), X <sub>2</sub>	24 (-1)	48 (+1)
pH, X <sub>3</sub>	2 (-1)	12 (+1)

Table (3) matrix of the 2<sup>3</sup> factorial designs for the Al-alloy 5083 corrosion inhibition.

Experimental run	Coded Value			Response corrosion rate (mg/m <sup>2</sup> .day)
	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	
1	-1	-1	-1	661
2	1	-1	-1	93
3	-1	1	-1	634
4	1	1	-1	68
5	-1	-1	1	834
6	1	-1	1	123
7	-1	1	1	801
8	1	1	1	74

The results for the corrosion inhibition of Al-alloy 5083 as weight loss in (mg/m<sup>2</sup>.day) during the contact time are listed in table (4). Based on the data obtained, the main effects of the factors under study and their interaction were calculated using the following equation[7]

$$\text{Effect of variable} = \frac{\sum (+1) - \sum (-1)}{\text{No. of runs} / 2} \quad (2)$$

Table (4) effects and interaction of the selected factors on the corrosion inhibition of Al-alloy 5083.

Factor	Main effect and interaction
X <sub>1</sub>	-643
X <sub>2</sub>	-335
X <sub>3</sub>	94
X <sub>1</sub> X <sub>2</sub>	-3.5
X <sub>1</sub> X <sub>3</sub>	-76
X <sub>2</sub> X <sub>3</sub>	-7.5

Table (4) shows that an increase in both the inhibitor concentration and duration time results a decrease in corrosion rate of aluminum alloy. It is clear this decrease is sharp and more pronounced as a result of increasing inhibitor concentration compared with the effect of increasing duration time, while the pH, sharply increases the corrosion rate within the range studied. In other words, the relative importance of the main effect coefficients in present investigation indicates that: The

effect of inhibitor concentration, duration time, and pH of the environment with coefficients: -643, -335 and 94 respectively is not the same (i.e., inhibitor concentration and duration time lead to decrease corrosion rate while solution pH in hence it). In terms of interactions, the relation between inhibitor concentration and pH of solution (X<sub>1</sub>,X<sub>3</sub>) is more significant than that between inhibitor concentration and contact time (X<sub>1</sub>,X<sub>2</sub>), and between contact time and pH (X<sub>2</sub>,X<sub>3</sub>). To develop a response surface equation to predict the corrosion behavior of aluminum alloy 5083. The data were analyzed using a commercially available package (statistica). A 24 factorial design was chosen because it allows the estimation of complex response function up to the quadratic order. To follow the levels adopted in this design, the factors studied needed to be decoded. The decoding formula was as follows:

$$\text{Coded variable} = \frac{\text{realvalue} - 0.5(\text{highlevel} + \text{lowlevel})}{0.5(\text{highvalue} - \text{lowvalue})} \quad (3)$$

The polynomial equation obtained correlates the inhibitor concentration (X<sub>1</sub>), duration time (X<sub>2</sub>), and the solution pH (X<sub>3</sub>). With corrosion rate of Al-alloy 5083 (Y) was:

$$Y = 411 - 321.5X_1 - 16.75X_2 + 47X_3 - 1.75X_1X_2 - 38X_1X_3 - 3.75X_2X_3 \quad (4)$$

Equation (4) is statistically accepted with a correlation coefficient of 0.99.

The effect of inhibitor concentration X<sub>1</sub> = 750 ppm (-1), 2500 ppm (+1), duration time X<sub>2</sub> = 24 h (-1), 48 h (+1) in both acidic and alkaline solutions coded X<sub>3</sub> = -1 (pH=2), +1 (pH=12) respectively can be seen in figures (1) and (2). Using equation (4) is possible to obtain a three dimensional surface for corrosion rate of Al-alloy 5083 as response for the variation of contact time and inhibitor concentration at fixed level pH, as it is shown in figures (1) and (2). It has been reported that localized corrosion of aluminum surface can be prevented by the action of adsorptive inhibitors, which prevented the adsorption of the aggressive ions or by formation of insoluble protection film of chelate of aluminum Al<sup>3+</sup> + (8.Q<sup>-</sup>)<sub>3</sub> Complex, which competes with formation of the insulating aluminum oxide film on the metal surface. Also, the corrosion rate decreases with increasing contact time, meaning that single 8-HQ concentration behave as a good inhibitor at a relatively higher contact time, so the effect of 8-HQ for corrosion inhibition of aluminum improved by increasing contact time. Experiments were conducted at pH = 2 and 12. The inhibition is more significant with higher concentration of inhibitor and in acidic media as shown in figures (1) and (2).

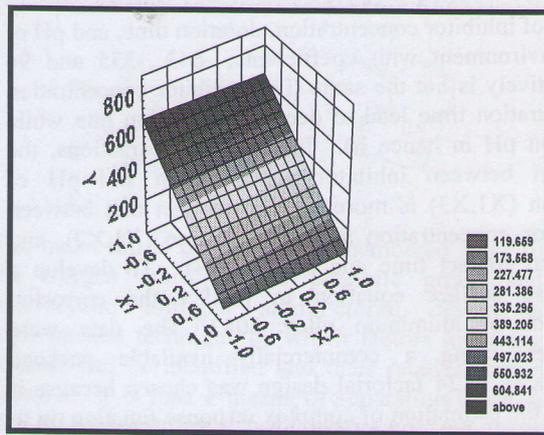


Fig.1 Corrosion rate response surface as function of inhibitor concentration and contact time at fixed  $X_3 = 2 (-1)$

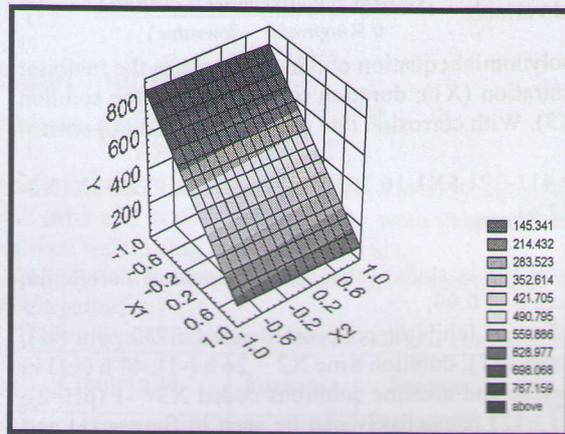


Fig. 2 Corrosion rate response surface as function of inhibitor concentration and contact time at fixed  $X_3 = 12 (+1)$

The corrosion potentials obtained from polarization measurements were observed to be influenced by the variables studied. Tables (5) shows results of the corrosion potential of Al-alloy 5083. It can be seen that:

1. the corrosion potential of Al-alloy 5083 shifts to more negative direction as the inhibitor concentration increases in both acidic and alkaline solutions, which indicates that 8-hydroxyquinoline acts as cathodic inhibitor.
2. The values of  $E_{corr}$  also show that the corrosion potential shifts to more negative direction with time.
3. The corrosion potential of Al-alloy 5083 shifts to more positive direction in alkaline solution compared with acidic one.

Table (5) summarizes the result of the corrosion potential of Al-alloy 5083 in solutions of pH (2 and 12).

Coded variables			Real variables			Corrosion potential (mV) vs. SCE
$X_1$	$X_2$	$X_3$	Inhibitor concentration (ppm)	Duration time (h)	Acidity pH	
-1	-1	-1	750	24	2	-705
1	-1	-1	2500	24	2	-751
-1	1	-1	750	48	2	-745
1	1	-1	2500	48	2	-793
-1	-1	1	750	24	12	-642
1	-1	1	2500	24	12	-676
-1	1	1	750	48	12	-657
1	1	1	2500	48	12	-688

A widely used polarization method is linear polarization resistance (LPR). The polarization resistance of a material defined as the slope of potential, current density ( $\Delta E/\Delta i$ ) curve at the free corrosion potential yielding the polarization resistance  $R_p$  <sup>(6)</sup>:

$$R_p = \frac{(\Delta E)}{(\Delta i)_{\Delta E \rightarrow 0}} \quad (5)$$

$$i_{corr} = \beta / R_p \quad (6)$$

The measurement of potentials and current flow directly associated with corrosion reactions in the linear polarization resistance technique represent a direct corrosion rate measurement.

The constant  $B$  which relates to anodic and cathodic Tafel slopes by:

$$B = \frac{b_a b_c}{2.3 (b_a + b_c)}$$

Is taken as 0.025 for aluminum to calculate  $i_{corr}$  <sup>(7)</sup>. Figures (3, 6, 9, and 12) represent the galvanostatic cathodic and anodic polarization curves of the working electrode in different pH solutions containing different concentrations of inhibitor used at different duration times. The above mentioned plots are associated with figures represents the plots of potential vs. current density, for the working electrode in the presence of different concentrations of the inhibitor under investigation: from the slopes of the obtained straight lines, the values of  $R_p$  ( $\Delta E/\Delta i$ ) are deduced for the Al-alloy 5083. The values of  $R_p$  for the working electrode in the presence of different concentrations of the inhibitor at above mentioned conditions are listed in table (6).

Table 6 Values of polarization resistance of Aluminum at different operating conditions

variables			Rp (kΩ.cm <sup>2</sup> )	i <sub>corr</sub> (A/cm <sup>2</sup> )
inhibitor concentration (ppm)	duration time (h)	acidity pH		
750	24	2	49.5	5.05*10 <sup>-7</sup>
2500	24	2	107.5	2.235*10 <sup>-7</sup>
750	48	2	69.1	3.618*10 <sup>-7</sup>
2500	48	2	138	1.811*10 <sup>-7</sup>
750	24	12	45.6	5.482*10 <sup>-7</sup>
2500	24	12	99.1	2.523*10 <sup>-7</sup>
750	48	12	53.9	4.642*10 <sup>-7</sup>
2500	48	12	115.1	2.172*10 <sup>-7</sup>

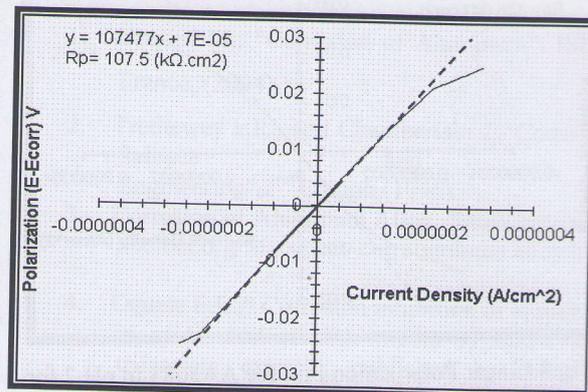


Fig.5 Linear Polarization Plot for AA5083 in pH 2, for Exposure Time 24 h, Inhibitor Concentration 2500 ppm.

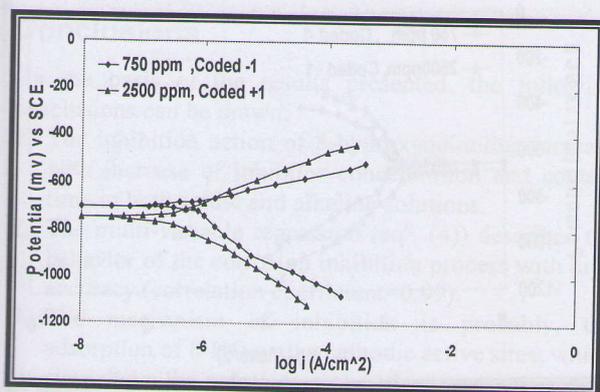


Fig.3 Effect of inhibitor concentration on the polarization curves for AA5083 in pH 2, for exposure time 24h.

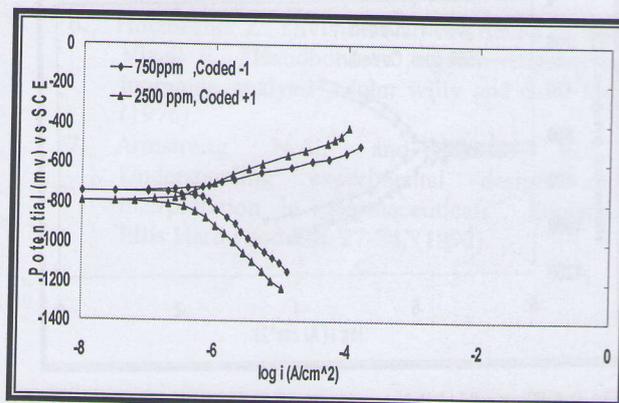


Fig.6 Effect of inhibitor concentration on the polarization curves for AA5083 in pH 2, for exposure time 48h.

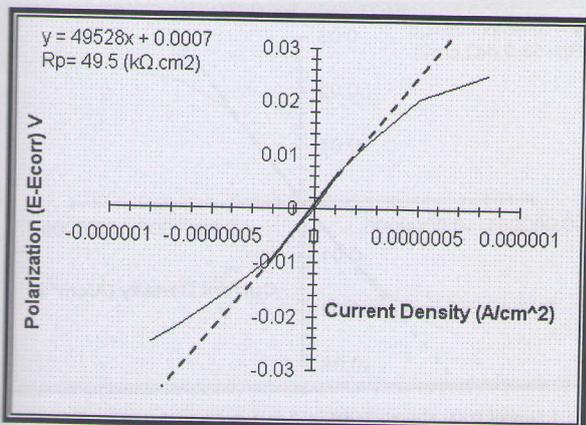


Fig.4 Linear Polarization Plot for AA5083 in pH 2, for Exposure Time 24 h, Inhibitor Concentration 750 ppm.

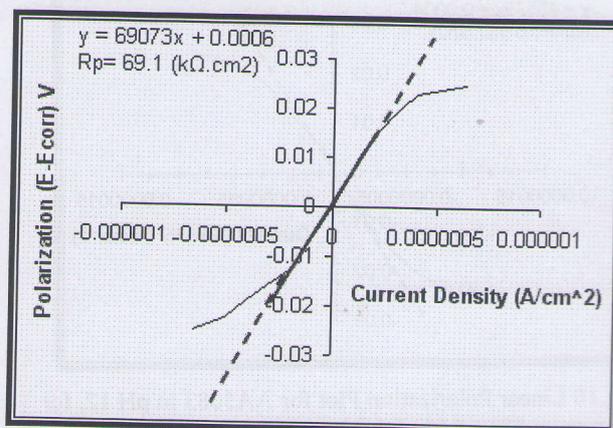


Fig.7 Linear Polarization Plot for AA5083 in pH 2, for Exposure Time 48 h, Inhibitor Concentration 750 ppm.

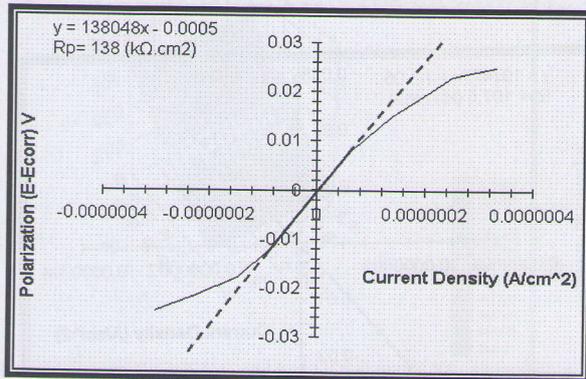


Fig.8 Linear Polarization Plot for AA5083 in pH 2 for Exposure Time 48 h, Inhibitor Concentration 2500 ppm.

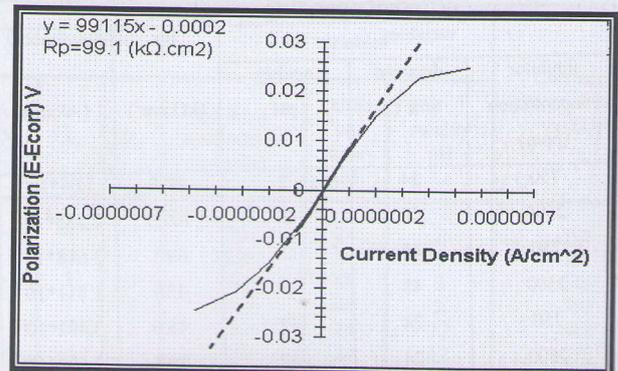


Fig.11 Linear Polarization Plot for AA5083 in pH 12, for Exposure Time 24 h, Inhibitor Concentration 2500 ppm.

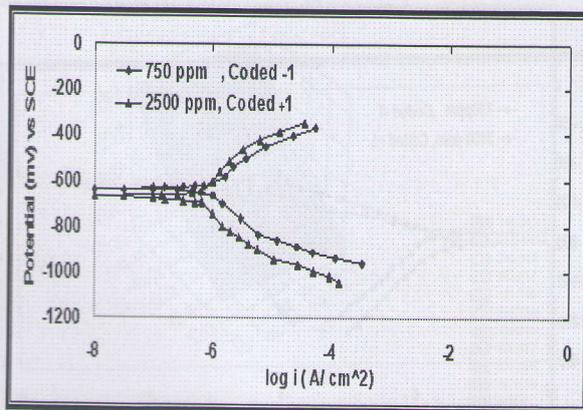


Fig.9 Effect of inhibitor concentration on the polarization curves for AA5083 in pH 12, for exposure time 24h.

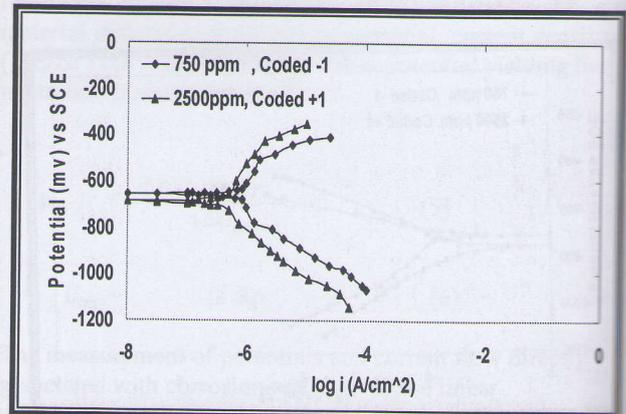


Fig.12 Effect of inhibitor concentration on the polarization curves for AA5083 in pH 12, for exposure time 48h.

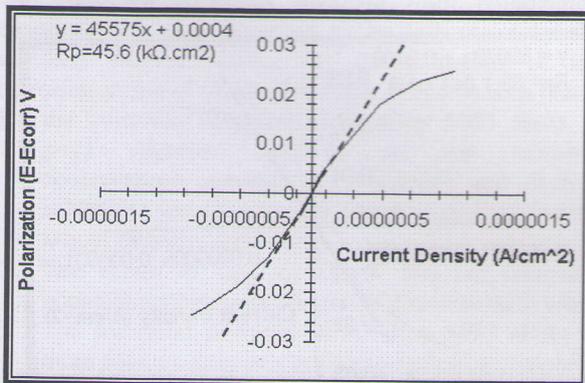


Fig.10 Linear Polarization Plot for AA5083 in pH 12, for Exposure Time 24 h, Inhibitor Concentration 750 ppm.

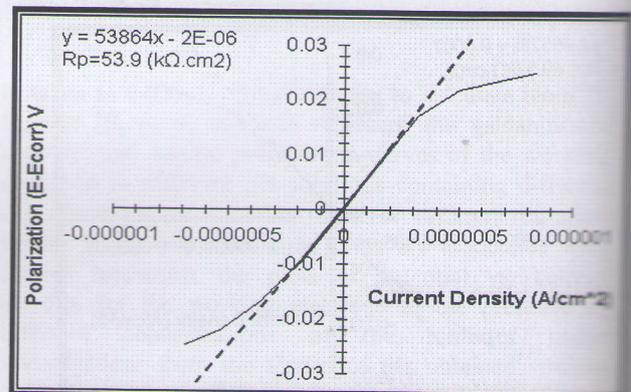


Fig.13 Linear Polarization Plot for AA5083 in pH 12, for Exposure Time 48 h, Inhibitor Concentration 750 ppm.

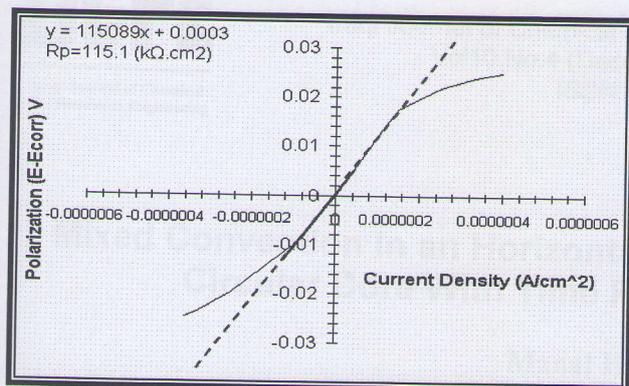


Fig.14 Linear Polarization Plot for AA5083 in pH 12, for Exposure Time 48 h, Inhibitor Concentration 2500 ppm.

## Conclusions

On the basis of the results presented, the following conclusions can be drawn:

1. The inhibition action of 8-hydroxyquinoline increase with increase of inhibitor concentration and contact time in both acidic and alkaline solutions.
2. The multi-variable regression (eq<sup>n</sup>. (4)) describes the behavior of the corrosion inhibition process with high accuracy (correlation coefficient=0.99).
3. The mechanism of inhibition is probably, the adsorption of 8-HQ on the cathodic active sites; which slow down the corrosion rate and prevents adsorption of the aggressive species and thus the destruction of the aluminum oxide layer. It is possible that an insoluble chelete of aluminum,  $Al^{3+} (8_Q)_3$ , be formed, which competes with the formation of the insulating aluminum hydroxide.

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