Corrosion Inhibition of Al-Si-Cu Alloy in the Basic Media by Using Six Inhibitors at Four Temperatures

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Abstract

The research involved attempt to inhibit the corrosion of Al-Si-Cu alloy in $2.5x10^{-3}$ $mol.dm^{-3}$ NaOH solution (pH=11.4) by addition of six different inhibitors with three concentrations ($1x10^{-3}$, $1x10^{-2}$, and 0.1 $mol.dm^{-3}$). These inhibitors include three organic materials (sodium acetate, sodium benzoate, and sodium oxalate) and three inorganic materials (sodium chromate, disodium phosphate, and sodium sulphate).

The data that concerning polarization behaviour are calculates which include the corrosion potential (E_{corr}) and current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p).

Protection efficiency (P%) and activation energy (E_a) values were calculated for inhibition by the six inhibitors. The results indicated the effect of temperature on the inhibition in basic media.

Introduction

The inhibition of corrosion by chemical control of the environment is frequently defined in electrochemical term [1], since corrosion itself is a combination of a least two electrochemical electrode reactions. It follows that if the velocities of either or both of these reactions can be reduced, then some degree of inhibition of the corrosion will be achieved. So a simple definition of inhibitor is: It is a chemical substance, when added in small concentrations to an environment, effectively decreases the corrosion rate of the metal which is exposed to such environment [2].

The use of the corrosion inhibitors is an important technique in the prevention of metallic corrosion in practice [3] when the presence of the inhibitor brings about a retardation of the corrosion reaction by modifying the processes at the metal solution interface [3].Inhibitors may be classified as anodic, cathodic or mixed inhibitors according to the interference with the corrosion reactions by preferentially attaching themselves to anodic or cathodic areas or whether they attach to both. Anodic inhibitors usually function in neutral or alkaline solutions and act by producing a passivity oxide film primarily at these parts of the surface where metal cations are formed at anodic sites. Since these sites appear randomly at the surface, the whole surface becomes covered by the passive and protecting film [4, 5].

Cathodic inhibitor act by inhibiting the cathodic regions without greatly affecting the anodic sites. Alternatively, cathodic inhibitors may operate by filming the cathodic areas. Anodic and cathodic inhibitors can be distinguished experimentally by observing the effect they produce on the corrosion potential of the metal, anodic inhibitors shift the corrosion potential to more noble while cathodic inhibitors to more active. Mixed inhibitors, however, which operate by filming the metal surface, affect both the anodic and cathodic processes,thus,the corrosion potential is a little affected.

Lorking and Mayne [6] classified the anions into three categories according to their action on aluminium:

(i) Anions not forming complexes: (a) Non-oxidizing anions such as benzoate, phosphate, and acetate which inhibit corrosion within the neutral range of pH.,

(b) Oxidizing anions such as chromate and nitrate which inhibit corrosion in wider range of pH than class (a).

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(ii) Anions forming soluble complexes with aluminum such as citrate and tartrate. The corrosion rate in the presence of such anions is higher than solution of class (i).

(iii) Anions forming soluble complexes, but cause corrosion of aluminium in neutral solution, such as chlorides.

Materials and Methods

Al-Si-Cu alloy was cut into cylinder shape with (1.7cm)diameter,and made into electrode by pressing a copper wire into a hole on one side and then insulating all but one side with an epoxy resin.

The open side was polished mechanically to a mirror finish,rinsed in distilled water and stored in a desiccators. The chemical composion of alloy was shown in Table (1)which obtained by chemical analysis in Naser Company for mechanical industries. The electrochemical cell was of the usual type with provision for working electrode (Al-Si-Cu alloy),auxiliary electrode (Pt electrode), and a Luggin capillary for connection with an SCE reference electrode.The basic solution was $2.5x10^{-3}$mol.dm^{-3}NaOH solution (obtained by Ferak with M.wt 40 g.mol^{-1} and purity >99.5%)which prepare in distilled water (specific conductivity $1x10^{-6}$ S.m^{-1}).

To study effect of inhibition used three concentrations ($1x10^{-3}$,$1x10^{-2}$,and 0.1 mol.dm^{-3}) of six different inhibitors which include sodium acetate,sodium benzoate, sodium oxalate, sodium chromate, disodium hydrogen phosphate, and sodium sulphate.

Electrochemical measurements were performed with a potentiostat (Corroscript) which was obtained from Tacussel (France) at a scan rate of 0.3 Volt per minute. The main results obtained were expressed in terms of the corrosion potentials (E_{corr}) and corrosion current density (i_{corr}) in addition to calculate the cathodic and anodic Tafel slopes by using extrapolation method.

Results and discussion

i- Polarization Curves

The results are reported in fig. (1) and table (2) indicates the polarization behavior of Al-Si-Cu alloy in $2.5x10^{-3}$ mol.dm^{-3} NaOH solution which consist of three stages: **(a)** The cathodic Tafel region (abc section) which representing by migration of electrons through the surface oxide films and subsequent interaction of those electrons with hydrogen ions and dissolved oxygen at film/solution interface,**(b)** The passivity region (cde section)which due to formation of aluminium oxide (Al_2O_3) on a surface, where thermodynamically aluminium an unstable metal and reacts spontaneously with oxygen to give aluminium oxide [7]:

$$4Al + 3O_2 \rightarrow 2Al_2O_3 + 800\ kcal \quad .....(i)$$

Finally, **(c)** The anodic Tafel region along (efg) section, where the breakdown of the protective film would occur.

The initial reactions in aqueous solution of sodium hydroxide may be represented as [8]:

$$Al + 3H_2O \rightarrow Al(OH)_3 + 3/2H_2 \quad .....(ii)$$

This is then followed by the reaction

$$Al(OH)_3 + OH^{-} \rightarrow AlO_2^{-} + 2H_2O \quad .....(iii)$$

The net reaction thus being [9]

$$Al + NaOH + H_2O \rightarrow NaAlO_2 + 3/2H_2 \quad ....(iv)$$

The reaction (iii) may also be represented as[10]:

$$Al(OH)_3+NaOH+2H_2O \rightarrow Na^{+}+[Al(OH)_4.2H_2O]^{-}(v)$$

Despite the excellent mechanical and physical properties of the Al-Si-Cu hypereutectic alloy, their corrosion resistance in aggressive environments is not yet well known. Some work has been carried out to evaluate the corrosion resistance of this alloy in alcoholic fuels[11,12].It has been suggested that corrosion of Al-Si-Cu alloy starts at the matrix/precipitate interface [13].

These precipitate particles were rich in Al and Cu,and could therefore be intermetallic $CuAl_2$.Considering that the electrical conductivities of Al($3.77x10^{7}ohm^{-1}m^{-1}$)and Cu($5.98x10^{7}ohm^{-1}m^{-1}$)are higher than that of Si ($1x10^{3}ohm^{-1}m^{-1}$), and that the hydrogen evolution reaction is more polarized on Al (i_o of approximately 10^{-10} A/cm^{-2}) than on Cu (i_o around 10^{-7} A/cm^{-2}) [14], it is likely that the cathodic hydrogen evolution reaction occurs on the copper rich intermetallic precipitates.

The purpose of this investigation is attempt to inhibit the corrosion of Al-Si-Cu alloy in basic media and to study some of the parameters concerning of polarization behavior.

Figures (2) to (7) show effect of six inhibitors additives to 2.5×10^{-3} mol.dm^{-3} NaOH solution with three concentration of each inhibitor (1×10^{-3},1×10^{-2}, and 0.1 mol.dm^{-3}) on corrosion of Al-Si-Cu alloy. Addition of these inhibitors shift the corrosion potential (E_{corr}) either toward active or noble direction, but addition of these inhibitors lead to shift the corrosion current density (i_{corr}) to lower values.

ii- The Tafel Slopes (b)

The reduction of the H_2O molecule is a common cathodic reaction for the corrosion of metals in neutral and alkaline solutions:

$H_2O + e \rightarrow 1/2H_2 + OH^{-}$ ……(vi)

The hydrogen evolution reaction (h.e.r) has been the most widely studied electrode reaction.

However, it is important to note that the discharge step involves adsorption of hydrogen atoms at available sites on the metal surface, and is followed by desorption that may be either a chemical step, or an electrochemical step in which further charge transfer occurs. A value of the cathodic Tafel slope of (-0.120 V.decade^{-1})may be diagnostic of a proton discharge-chemical desorption mechanism in which the proton discharge is the rate-determining step (r.d.s).

In chemical desorption step the adsorbed H atom diffuse about on the metal surface, either by threading their way through adsorbed water molecules or by pushing them aside, until two collide to form an H_2 molecule which escapes into the solution. This chemical step will be independent of overpotential, since charge transfer is not involved, and the rate will be proportional to the concentration or coverage θ_H of adsorbed H_{ads} and may occur at coverage that range from very small to almost complete.

If the discharge process is followed by a rate-determining step involving chemical desorption (C.D.), the expected value of the cathodic Tafel slope should be (-0.03 V.decade^{-1}).

On the other hand, the electrochemical desorption (E.D.) step is far more complex since it involves reaction between an adsorbed H atom, a hydrated proton H_3O^+ and an electron, and for desorption to occur the proton must discharge onto a hydrogen atom adsorbed on the metal surface.

Under these circumstances the probability of collision well be low unless the coverage θ_H is high. When electrochemical desorption becomes the rate-determining step for (h.e.r) on the cathode, the expected value of b_c will be (-0.05 V.decade^{-1}).

In fact, in certain cases the mechanism will change from a C.D. to an E.D. step when the overpotential has attained a sufficiently large value[15]. The results of tables (3) to (8) show the effect of addition the inhibitors on the rate-determining step which indicates that the cathodic Tafel slopes, in general, ranges from a C.D. to an E.D. step except some cases.

HamiHa and Co-worker[16] observed that the electrochemical process of Al-Si-Cu alloy occurring at high rate is probably due to charge transfer processes associated to reduction of Si to form silicon hydride (at pH=3.3) and the anodic dissolution of the matrix can be balanced by the hydrogen evolution reaction on the intermetallic particles, and by reduction of Si and O_2.

$Si + 4H + 4e \rightarrow SiH_4$ and $O\ 4H + 4e \rightarrow 2H_2O$

Further, the decrease in kinetics of the anodic process with time, resulting from the conversion of Si to SiH_4, would also decrease the overall cathodic reaction rate, and consequently the dissolution (anodic) rate[16].

iii- The Polarization Resistance (R_p)

The polarization resistance (R_p) may be defined as [17, 18]:

$$R_p = \frac{d(E - E_{corr})}{di} \quad \ldots\ldots(1)$$

Where E and E_{corr} are the applied corrosion potential (Volt) respectively, I is the current density (A.cm^{-2}).

For small polarization, one may write approximation [17,18]:

$$R_p = \frac{d(E - E_{corr})}{di} = \frac{E_{corr}}{i_{corr}} \quad \ldots.(2)$$

where E_{corr} and i_{corr} are the corrosion potential (V) and corrosion current density (A.cm^{-2}). The ratio (E_{corr}/i_{corr}) thus corresponds to the resistance of the metal/solution interface to charge-transfer reaction. It is also a measure of the resistance of the metal to corrosion in the solution in which the metal is immersed.

For low-field polarization [19]:

$$\frac{\eta}{i}=\frac{RT}{Fi_o}\ \ldots\ldots(3)$$

and $$\frac{E_{corr}}{i_{corr}}=\frac{RT}{Fi_o}=R_p\quad \ldots..(4)$$

Where $\eta=E-E_{corr}$ and i_o is the equilibrium exchange current density ($A.cm^{-2}$). The reaction resistance (R_p), which mainly depends upon the equilibrium exchange current density (i_o) determines what may be termed the polarizability, i.e., what overpotential ($\eta=E-E_{corr}$) a particular current density needs or produces since[20]:

$$R_p=\frac{d\eta}{di}=\frac{d(E-E_{corr})}{di}=\frac{E_{corr}}{i_{corr}}=\frac{RT}{Fi_o}\ \ldots(5)$$

The polarization resistance (R_p) was also determined in another way from Stern-Geary equation, where:

$$R_p=\left(\frac{dE}{di}\right)_{i=0}=\frac{b_a b_c}{2.303(b_a+b_c)i_{corr}}\quad \ldots..(6)$$

The values of R_p have been calculated from eq.(6), which are presented in tables (2) to (8).

The results of tables (2) to (8) indicates that the R_p of Al-Si-Cu alloy in $2.5x10^{-3}$ $mol.dm^{-3}$ NaOH solution with out addition is lower than its value in the presence of inhibitor in solution. The R_p values increases with increasing concentration of inhibitor except in the presence of acetate and sulphate ions, since the highest value of R_p is notes at $1x10^{-2}$ $mol.dm^{-3}$ of these ions. The order of R_p for solution in presence of inhibitors takes the following sequence:

$\mathbf{R_p}$ $0.1mol.dm^{-3}CrO_4^{=}>0.1mol.dm^{-3}PO_4^{=}>1x10^{-2}mol.dm^{-3}SO_4^{=} > 1x10^{-2}mol.dm^{-3}CH_3COO^{-}>0.1mol.dm^{-3}\ C_2O_4^{=} > 0.1mol.dm^{-3}$ ph-COO^{-}

iv- Protection Efficiency (P%)

The corrosion current densities in the presence (i_2) and absence (i_1) of inhibitor in the corrosion medium have been used to determining the protection efficiency (P%) by using the relation:

$$P\%=100\left[1-\frac{i_2}{i_1}\right]\quad \ldots\ldots.(7)$$

The results in table (9) indicate that the values of P% are positive which indicates the inhibition of corrosion by the added additives to solution of NaOH. When add the lowest concentration of inhibitors, P% were <60% except in the case of sulphate ions, whileP% increases with increasing the concentration except in the case of acetate and sulphate ions since the highest value of P% was observed at $1x10^{-2}$ $mol.dm^{-3}$ of these inhibitors.

Figure (8) show effect of inhibitor concentration on the protection efficiency. The better protection for Al-Si-Cu alloy observes when add $0.1mol.dm^{-3}$ sodium chromate to basic solution.

v- Effect of Temperature

Generally, the increasing of temperature shifts the corrosion potential (E_{corr}) toward the noble direction except some case and the corrosion current density (i_{corr}) to the higher values. While, it is observes that in all the cases the extent of inhibition decreased with a rise in temperature (table 9).From the corrosion rates at different temperatures, the values of the activation energy were calculated following the equation[8]:

$$\log\frac{S_2}{S_1}=\frac{E^{*}_{app}}{2.303R}\left[\frac{1}{T_1}-\frac{1}{T_2}\right]\quad \ldots\ldots(8)$$

where S_1 and S_2 are the corrosion rates at the temperature T_1 and T_2 (K) respectively and E^{*}_{app} is the activation energy.

The data are given in table (10) may be generalized that the E^{*}_{app} values are in general higher in presence of the inhibitors than the values in their absence. However, because of the vividness of the E^{*}_{app} values no specific generalizations could be drawn regarding the relationship between the inhibitor efficiency and the energy of activation. In comparing the activation energies obtained it must be realized that they are only apparent values,i.e.they have been determined at constant bulk inhibitor concentrations. The protection efficiency and the degree of surface coverage θ change with temperature[21]. This change is incorporated in the value of (E^{*}_{app}). The more sensitive the protection efficiency and the degree of surface coverage to temperature changes, the larger are the differences in activation energy between the inhibited and uninhibited solutions. To eliminate this effect, the activation energy should be determined at a constant surface inhibitor activity, i.e. at a constant degree of surface coverage[22].

Also the apparent activation energy (E^*_{app})depend on the many factors according to the following equation:

$$E^*_{app} = E^* + \beta F(\phi - \psi_2) \quad \ldots\ldots\ldots (9)$$

where E^* the activation energy not depended on the potential of electrode, β the transfer coefficient,F faraday number,ϕ the total difference in potential at electrical double layer, and ψ_2 Zeta potential.

Where the adsorbent particles which increase the Zeta potential ψ_2 is decreases the apparent activation energy for corrosion reaction, while the adsorbent particles which decrease the Zeta potential ψ_2 lead to increasing in the apparent activation energy.

Discussion of Inhibition Action

The inhibiting action achieved by organic compounds is usually attributed to interactions by adsorption between the inhibitor and the metal surface. Adsorption can be of a purely physical nature by means of electrostatic or Van der Waals forces, which are easily removed from the surface, or a chemical nature which forms chemical compounds. Inhibitor efficiency is higher for a compound which can donate electrons easily for the molecular site of adsorption and corresponds to high electron density at the presumed adsorption center in the molecular. Most organic inhibitors are compounds with at least one polar function; the polar function is regarded as the reaction center for the establishment of the chemisorbed bond, whose strength is determined by the electron density of the atom acting as the reaction center [23].

Generally, organic compounds are adsorbed on the metal surface and interface with either cathodic or anodic reaction occurring at the adsorption site.

Acetate(CH_3COO^-)and oxalate ($C_2O_4^=$) ions gave rise to small irregularly shaped pits with clear crystallographic features. This observation suggested that the acetate and oxalate ion was neither a passivator nor a blocking inhibitor. Its action must be either to isolate the surface from hydroxide ions by preferential adsorption or to act buffer. While benzoate ($C_6H_5COO^-$) ions act as blocking inhibitors by forming insoluble precipitates. It was noticeable that such deposited formed at a slight distance from pits after initiation.This inhibitor arrested pit propagation at an early stage rather than prevented pit initiation.

The bulky molecules limit the diffusion of oxygen to the surface or they trap the metal ions on the surface, reducing the rate of dissolution, while inorganic oxidizing substance that promote the passivity on the surface by shifting the corrosion potential in the noble direction.

Chromates ($CrO_4^=$) is efficient inhibitors of the corrosion of aluminium and its alloys. The redox reaction between (Cr^{6+}) ions and aluminium metal, however revealed, occurs, forming alumina and solid chromic oxide[24]:

$2Al + 3H_2O \rightarrow Al_2O_3 + 6H^+ + 6e$ ...(vii)

$2CrO_4^{2-} + 10H^+ + 6e \rightarrow CrO_3 + 5H_2O$ ...(viii)

Although the valency states of particular chromium-containing species could not be determined, the data were taken to indicate the initial general presence of chromate species which had penetrated the anodic alumina film and the local development, at likely flaw sites, of solid Cr_2O_3 plugs. The local development of $Al(OH)_3$plugs, at anodic sites, the precipitation of which is catalyzed by chromate species, was not discounted.

The data of various workers, using different experimental conditions and examination techniques, suggest that Cr(III) is present predominantly on specimens supporting air-formed film whilst Cr(VI) is detected in the outer regions of specimens supporting relatively thick barrier-type film, with local presence of Cr(III).

Chromate solution greatly decreased the O_2 reduction rate on the alloy surface and the cathodic inhibition by Cr(VI) solution was accompanied by a transient reduction current equivalent to generation of approximately a monolayer of Cr(III) oxyhydroxide [25]. On the other hand, chromate is mobile in solution and migrates to exposed areas on the Al alloy surface and adsorbs on the active sites of the surface and is reduced to form a monolayer of a Cr(III) species which is effective at reducing the activity of both cathodic sites and anodic sites in the matrix.The anodic inhibition is related to the inhibition stage of localized corrosion and not propagation [26].

Phosphate ($PO_4^{\equiv}$) ions behaves same behavior of benzoate ions, generally in benzoate and phosphate solutions more than one pit was initiated and the overlapping of the transient behavior for each pit masked the kinetics of each individual pit. While sulphate ($SO_4^{=}$) ions worked not by healing the film but by displacing the hydroxide ion from the metal surface.

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Table (1): Chemical composion (weight %) of Al-Si-Cu alloy obtained by chemical analysis.

Element	*Si*	*Cu*	*Mg*	*Fe*	*Zn*	*Ni*	*Mn*	*Ti*	*Cr*	*Al*
Wt%	12.587	3.563	1.168	0.857	0.683	0.513	0.335	0.070	0.049	Bal.

Table (2): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in $2.5x10^{-3}$ $mol.dm^{-3}$ NaOH solution (pH=11.4) at four temperatures.

T (K)	***Corrosion***		***b (V.decade^{-1})***		***Rp/10^{+4} (Ω.cm^{-2})***
	-E_{corr} (V)	***i_{corr} (A.cm^{-2})***	***-b_c***	***+b_a***	
298	1.49	$3.305x10^{-6}$	0.120	0.100	0.716
303	1.45	$3.437\ x10^{-6}$	0.090	0.095	0.583
308	1.39	$3.613\ x10^{-6}$	0.070	0.089	0.470
313	1.35	$3.746\ x10^{-6}$	0.065	0.085	0.426

Table (3): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in $2.5x10^{-3}$ $mol.dm^{-3}$ NaOH solution (pH=11.4) in presence of the sodium acetate (CH_3COONa) at four temperatures.

Conc. of Inhibitor	***T (K)***	***Corrosion***		***b (V.decade^{-1})***		***Rp/10^{+4} (Ω.cm^{-2})***
		-E_{corr} (V)	***i_{corr} (A.cm^{-2})***	***-b_c***	***+b_a***	
$1x10^{-3}$ $Mol.dm^{-3}$	298	1.48	$2.203\ x10^{-6}$	0.065	0.120	0.831
	303	1.46	$2.379\ x10^{-6}$	0.062	0.115	0.735
	308	1.43	$2.556\ x10^{-6}$	0.052	0.107	0.594
	313	1.41	$2.644\ x10^{-6}$	0.045	0.100	0.509
$1x10^{-2}$ $Mol.dm^{-3}$	298	1.44	$2.203\ x10^{-7}$	0.045	0.076	5.570
	303	1.43	$2.556\ x10^{-7}$	0.044	0.068	4.538
	308	1.42	$2.864\ x10^{-7}$	0.042	0.065	3.868
	313	1.41	$3.085\ x10^{-7}$	0.034	0.061	3.072
0.1 $Mol.dm^{-3}$	298	1.37	$2.203\ x10^{-7}$	0.049	0.049	4.829
	303	1.36	$2.644\ x10^{-7}$	0.048	0.048	3.941
	308	1.35	$3.305\ x10^{-7}$	0.044	0.042	2.823
	313	1.34	$3.746\ x10^{-7}$	0.032	0.040	3.434

Table (4): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in 2.5x10^{-3} mol.dm^{-3} NaOH solution (pH=11.4) in presence of the sodium benzoate (C_6H_5COONa) at four temperatures.

Conc. of Inhibitor	*T (K)*	*Corrosion*		*b (V.decade^{-1})*		*Rp/10^{+4} (Ω.cm^{-2})*
		-E_{corr} (V)	*i_{corr} (A.cm^{-2})*	*-b_c*	*+b_a*	
1x10^{-3} Mol.dm^{-3}	298	1.55	1.322 x10^{-6}	0.050	0.100	1.094
	303	1.53	1.542 x10^{-6}	0.046	0.076	0.806
	308	1.50	1.762 x10^{-6}	0.041	0.068	0.630
	313	1.48	1.983 x10^{-6}	0.040	0.052	0.495
1x10^{-2} Mol.dm^{-3}	298	1.47	0.528 x10^{-6}	0.071	0.096	3.356
	303	1.46	0.793 x10^{-6}	0.046	0.091	1.673
	308	1.45	0.881 x10^{-6}	0.041	0.082	1.347
	313	1.44	0.969 x10^{-6}	0.034	0.068	1.015
0.1 Mol.dm^{-3}	298	1.44	2.644 x10^{-7}	0.130	0.136	10.915
	303	1.43	2.864 x10^{-7}	0.034	0.130	4.086
	308	1.42	3.085 x10^{-7}	0.025	0.125	2.932
	313	1.41	3.305 x10^{-7}	0.020	0.088	2.141

Table (5): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in 2.5x10^{-3} mol.dm^{-3} NaOH solution (pH=11.4) in presence of the sodium oxalate ($Na_2C_2O_4$) at four temperatures.

Conc. of Inhibitor	*T (K)*	*Corrosion*		*b (V.decade^{-1})*		*Rp/10^{+4} (Ω.cm^{-2})*
		-E_{corr} (V)	*i_{corr} (A.cm^{-2})*	*-b_c*	*+b_a*	
1x10^{-3} Mol.dm^{-3}	298	1.52	1.895 x10^{-6}	0.060	0.088	0.817
	303	1.50	1.983 x10^{-6}	0.056	0.078	0.713
	308	1.49	2.203 x10^{-6}	0.051	0.065	0.563
	313	1.48	2.644 x10^{-6}	0.042	0.062	0.411
1x10^{-2} Mol.dm^{-3}	298	1.47	3.217 x10^{-7}	0.046	0.100	4.252
	303	1.46	3.966 x10^{-7}	0.042	0.091	3.146
	308	1.45	4.186 x10^{-7}	0.040	0.075	2.706
	313	1.42	4.407 x10^{-7}	0.038	0.060	2.292
0.1 Mol.dm^{-3}	298	1.45	3.085 x10^{-7}	0.044	0.350	5.501
	303	1.44	3.305 x10^{-7}	0.039	0.300	4.534
	308	1.43	3.525 x10^{-7}	0.032	0.211	3.422
	313	1.42	3.746 x10^{-7}	0.027	0.150	2.652

Table (6): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in 2.5x10^{-3} mol.dm^{-3} NaOH solution(pH=11.4) in presence of the sodium chromate (Na_2CrO_4) at four temperatures.

Conc. of Inhibitor	*T (K)*	*Corrosion*		*b (V.decade^{-1})*		*Rp/10^{+4} (Ω.cm^{-2})*
		-E_{corr} (V)	*i_{corr} (A.cm^{-2})*	*-b_c*	*+b_a*	
1x10^{-3} Mol.dm^{-3}	298	1.54	1.752 x10^{-6}	0.081	0.120	1.198
	303	1.51	1.851 x10^{-6}	0.069	0.107	0.984
	308	1.46	1.939 x10^{-6}	0.060	0.096	0.826
	313	1.43	2.027 x10^{-6}	0.057	0.093	0.757
1x10^{-2} Mol.dm^{-3}	298	1.43	0.528 x10^{-6}	0.081	0.120	3.976
	303	1.42	0.572 x10^{-6}	0.073	0.115	3.389
	308	1.40	0.617 x10^{-6}	0.061	0.110	2.761
	313	1.37	0.661 x10^{-6}	0.055	0.100	2.330
0.1 Mol.dm^{-3}	298	1.28	0.617 x10^{-7}	0.120	0.088	35.729
	303	1.27	0.749 x10^{-7}	0.110	0.083	27.424
	308	1.26	0.837 x10^{-7}	0.085	0.065	19.108
	313	1.25	0.925 x10^{-7}	0.083	0.046	13.893

Table (7): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in 2.5x10^{-3} mol.dm^{-3} NaOH solution (pH=11.4) in presence of the disodium hydrogen phosphate (Na_2HPO_4) at four temperatures.

Conc. of Inhibitor	*T (K)*	*Corrosion*		*b (V.decade^{-1})*		*Rp/10^{+4} (Ω.cm^{-2})*
		-E_{corr} (V)	*i_{corr} (A.cm^{-2})*	*-b_c*	*+b_a*	
1x10^{-3} Mol.dm^{-3}	298	1.53	1.718 x10^{-6}	0.100	0.120	1.378
	303	1.52	1.762 x10^{-6}	0.075	0.100	1.056
	308	1.51	1.851 x10^{-6}	0.055	0.093	0.810
	313	1.48	1.955 x10^{-6}	0.051	0.091	0.725
1x10^{-2} Mol.dm^{-3}	298	1.47	0.484 x10^{-6}	0.058	0.122	3.526
	303	1.46	0.528 x10^{-6}	0.057	0.112	3.106
	308	1.45	0.572 x10^{-6}	0.050	0.094	2.477
	313	1.44	0.617 x10^{-6}	0.042	0.075	1.894
0.1 Mol.dm^{-3}	298	1.32	1.057 x10^{-7}	0.120	0.125	25.15
	303	1.29	1.542 x10^{-7}	0.110	0.120	16.16
	308	1.26	1.762 x10^{-7}	0.100	0.111	12.96
	313	1.23	2.203 x10^{-7}	0.069	0.100	17.21

Table (8): Values of corrosion potential(E_{corr}), corrosion current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and polarization resistance (R_p) for corrosion of Al-Si-Cu alloy in 2.5x10^{-3} mol.dm^{-3} NaOH solution (pH=11.4) in presence of the sodium sulphate (Na_2SO_4) at four temperatures.

Conc. of Inhibitor	*T (K)*	*Corrosion*		*b (V.decade^{-1})*		*Rp/10^{+4} (Ω.cm^{-2})*
		-E_{corr} (V)	*i_{corr} (A.cm^{-2})*	*-b_c*	*+b_a*	
1x10^{-3} Mol.dm^{-3}	298	1.43	0.617 x10^{-6}	0.060	0.120	2.815
	303	1.41	0.661 x10^{-6}	0.057	0.115	2.503
	308	1.40	1.013 x10^{-6}	0.053	0.085	1.399
	313	1.38	1.145 x10^{-6}	0.046	0.066	1.027
1x10^{-2} Mol.dm^{-3}	298	1.40	1.983 x10^{-7}	0.069	0.130	9.870
	303	1.39	2.071 x10^{-7}	0.055	0.120	7.907
	308	1.38	2.996 x10^{-7}	0.046	0.111	4.713
	313	1.37	3.305 x10^{-7}	0.042	0.100	3.885
0.1 Mol.dm^{-3}	298	1.43	0.572 x10^{-6}	0.045	0.130	2.537
	303	1.42	0.617 x10^{-6}	0.041	0.125	2.172
	308	1.41	0.661 x10^{-6}	0.038	0.120	1.895
	313	1.39	0.705 x10^{-6}	0.032	0.110	1.526

Table (9): The protection efficiency (P%) values of three different concentration of six inhibitors which add to 2.5x10^{-3} mol.dm^{-3} NaOH solution (pH=11.4) at four temperatures.

Organic Inhibitor	*T (K)*	*P%*			*Inorganic Inhibitor*	*T (K)*	*P%*		
		1x10^{-3}	*1x10^{-2}*	*0.1*			*1x10^{-3}*	*1x10^{-2}*	*0.1*
CH_3COONa	298	33.34	93.33	93.33	Na_2CrO_4	298	49.69	84.02	98.13
	303	30.78	93.56	92.30		303	46.14	83.36	97.82
	308	27.68	92.07	90.85		308	46.33	82.92	97.68
	313	29.42	91.76	90.00		313	45.89	82.35	97.53
C_6H_5COONa	298	60.00	84.02	92.00	Na_2HPO_4	298	48.02	85.36	96.80
	303	55.14	76.92	91.67		303	48.73	84.64	95.51
	308	51.23	75.62	91.46		308	48.77	84.17	95.12
	313	47.06	74.13	91.18		313	47.81	83.53	94.12
$Na_2C_2O_4$	298	42.66	90.27	90.67	Na_2SO_4	298	81.33	94.00	82.69
	303	42.30	88.46	90.38		303	80.77	93.97	82.05
	308	39.03	88.41	90.24		308	71.96	91.71	81.70
	313	29.42	88.24	90.00		313	69.43	91.18	81.18

Table (10): The energy of activation for Al-Si-Cu alloy in 2.5x10^{-3} mol.dm^{-3} NaOH solution in the presence of six different inhibitors with three concentrations for the temperature range (298-313)K.

Medium	*Ea (kcal.mol^{-1})*		
	1x10^{-3}	*1x10^{-2}*	*0.1*
NaOH only	1.548		
NaOH + CH_3COONa	2.255	4.162	6.561
NaOH + C_6H_5COONa	5.011	7.504	2.758
NaOH + $Na_2C_2O_4$	4.117	3.890	2.399
NaOH + Na_2CrO_4	1.732	2.777	5.005
NaOH + Na_2HPO_4	1.597	3.001	9.076
NaOH + Na_2SO_4	7.642	6.313	2.584

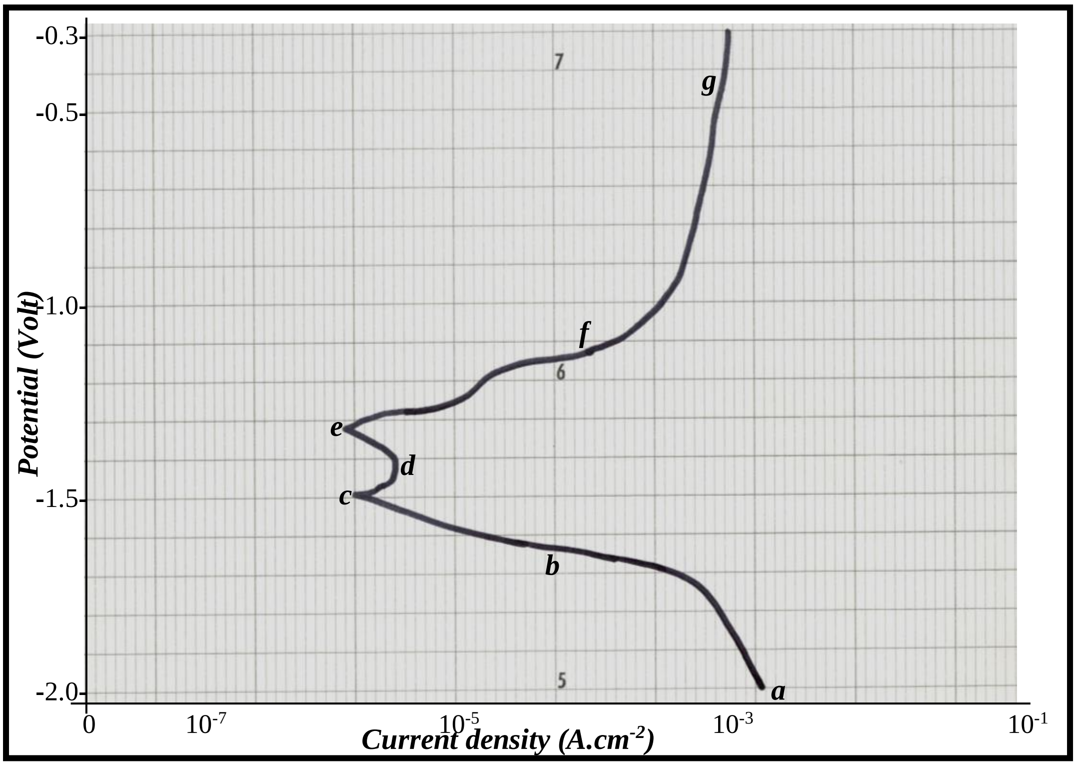

Fig. (1): Polarization curve for corrosion of Al-Si alloy in 2.5x10^{-3} mol.dm^{-3}NaOH solution (pH=11.4) at 298K.

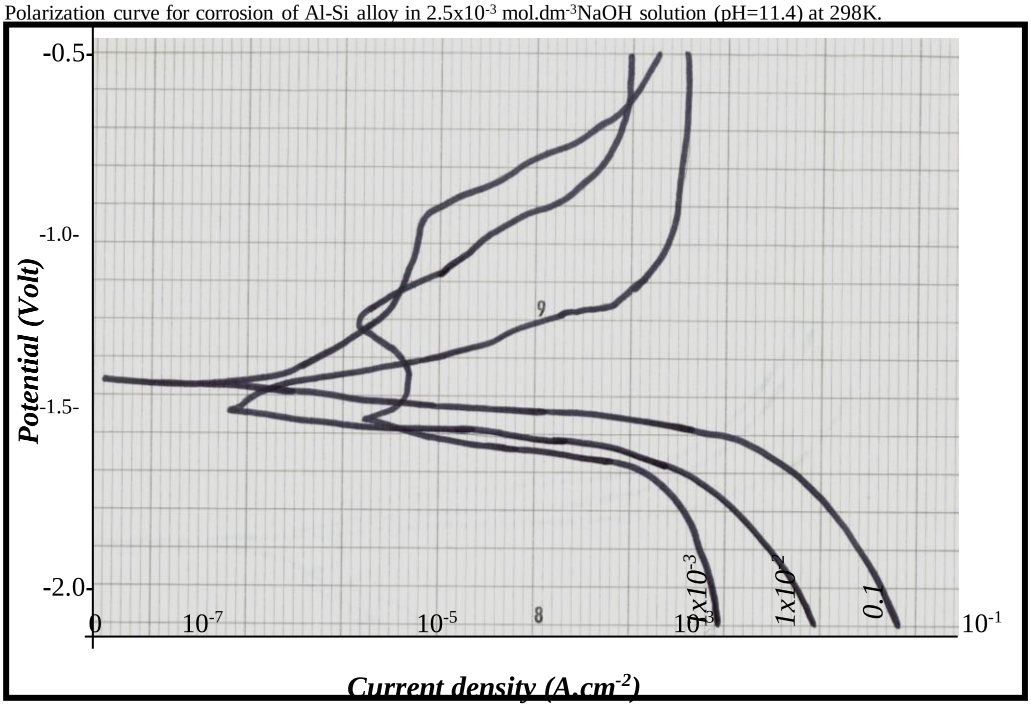

Fig. (2): Polarization curve for corrosion of Al-Si alloy in 2.5x10^{-3} mol.dmNaOH solution in the presence of CH_3COONa at 298K.

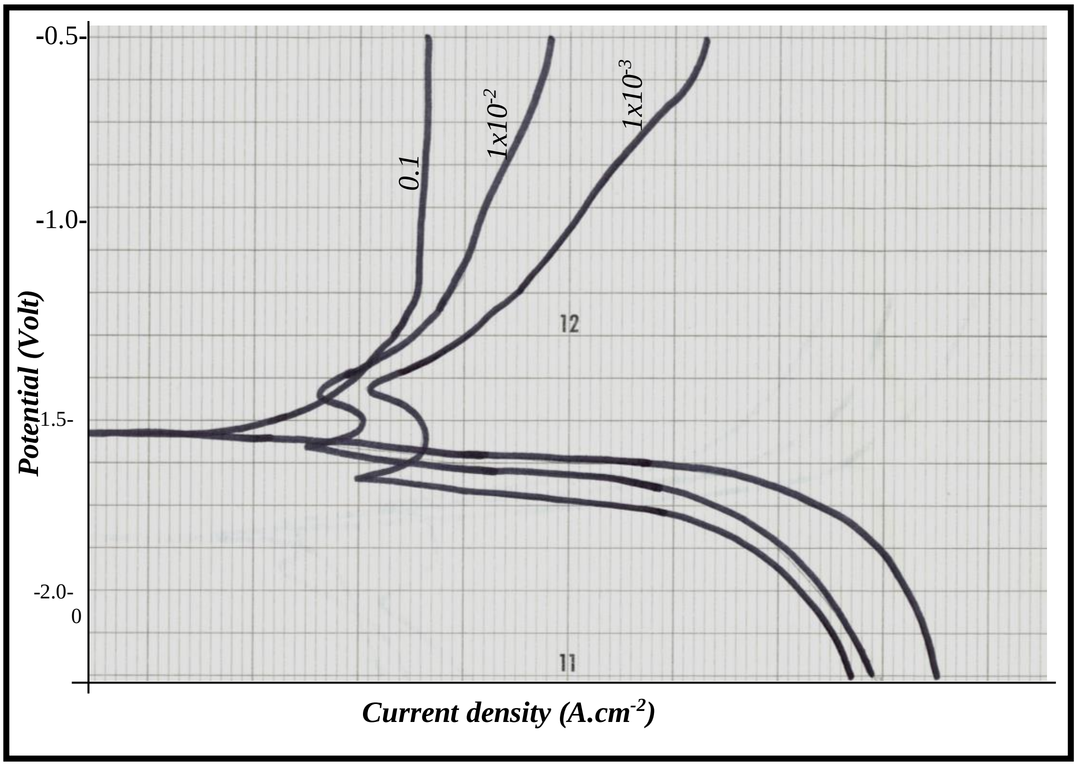

Fig. (3): Polarization curve for corrosion of Al-Si alloy in 2.5x10^{-3} mol.dm^{-3}NaOH solution in the presence of C_6H_5COONa at 298K.

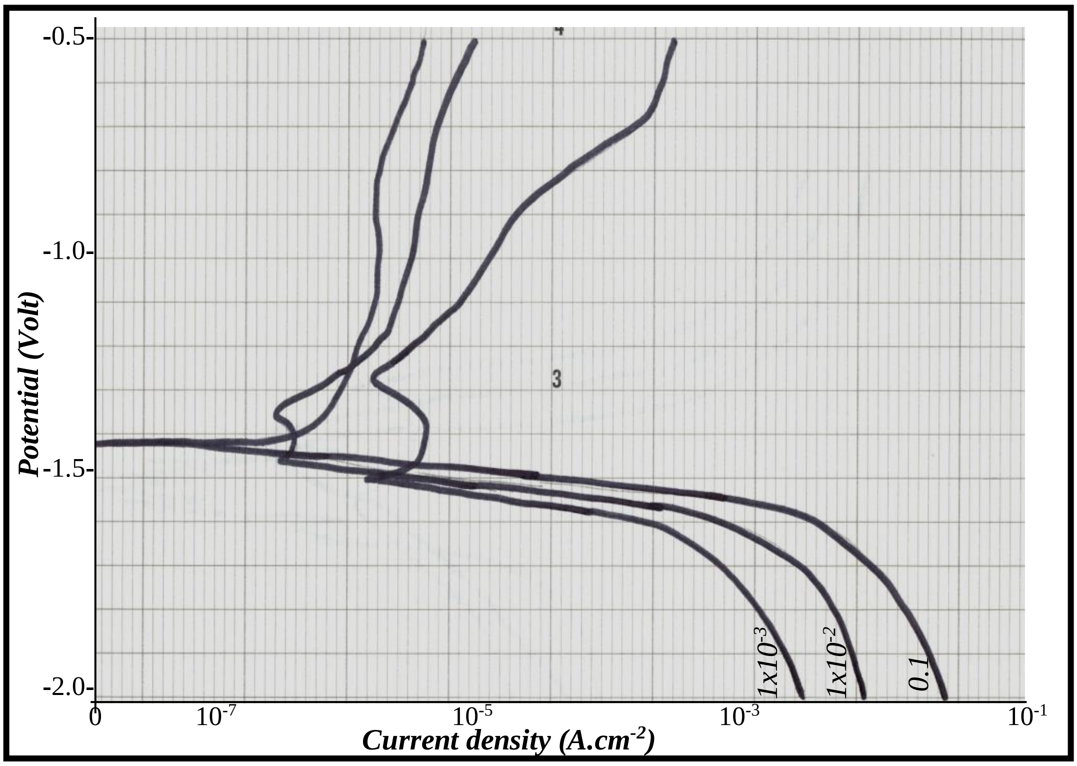

Fig. (4): Polarization curve for corrosion of Al-Si alloy in 2.5x10^{-3} mol.dm^{-3}NaOH solution in the presence of $Na_2C_2O_4$ at 298K.

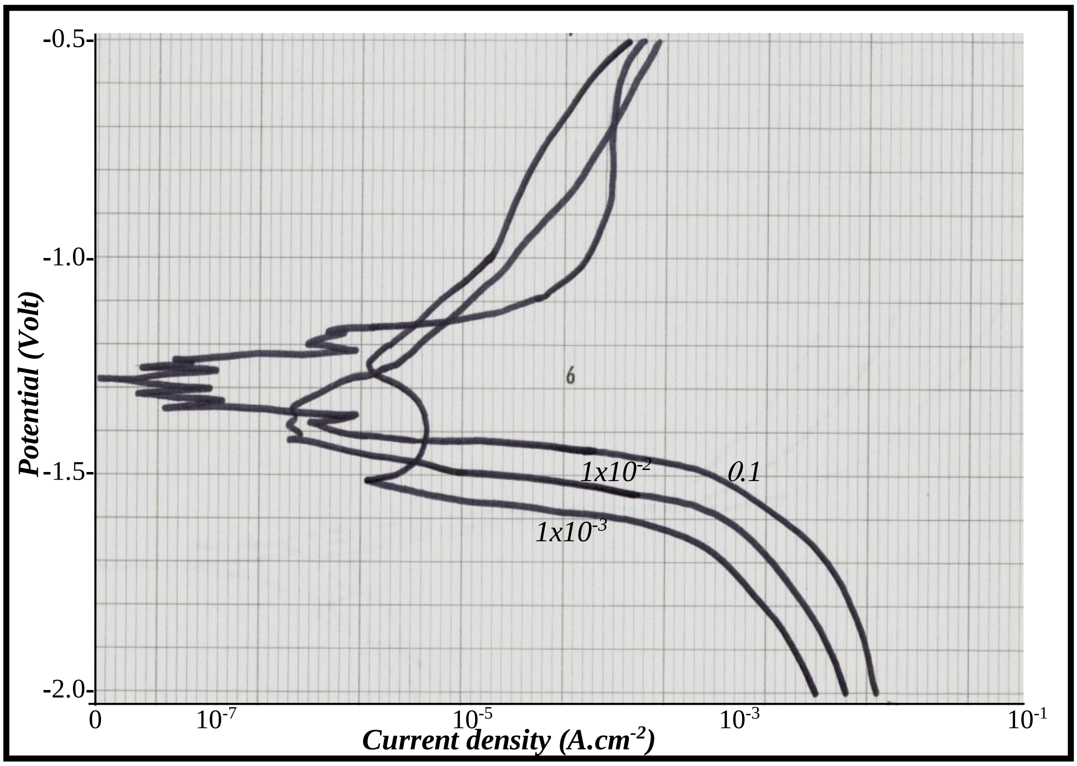

Fig. (5): Polarization curve for corrosion of Al-Si alloy in $2.5x10^{-3}$ $mol.dm^{-3}$NaOH solution in the presence of Na_2CrO_4 at 298K.

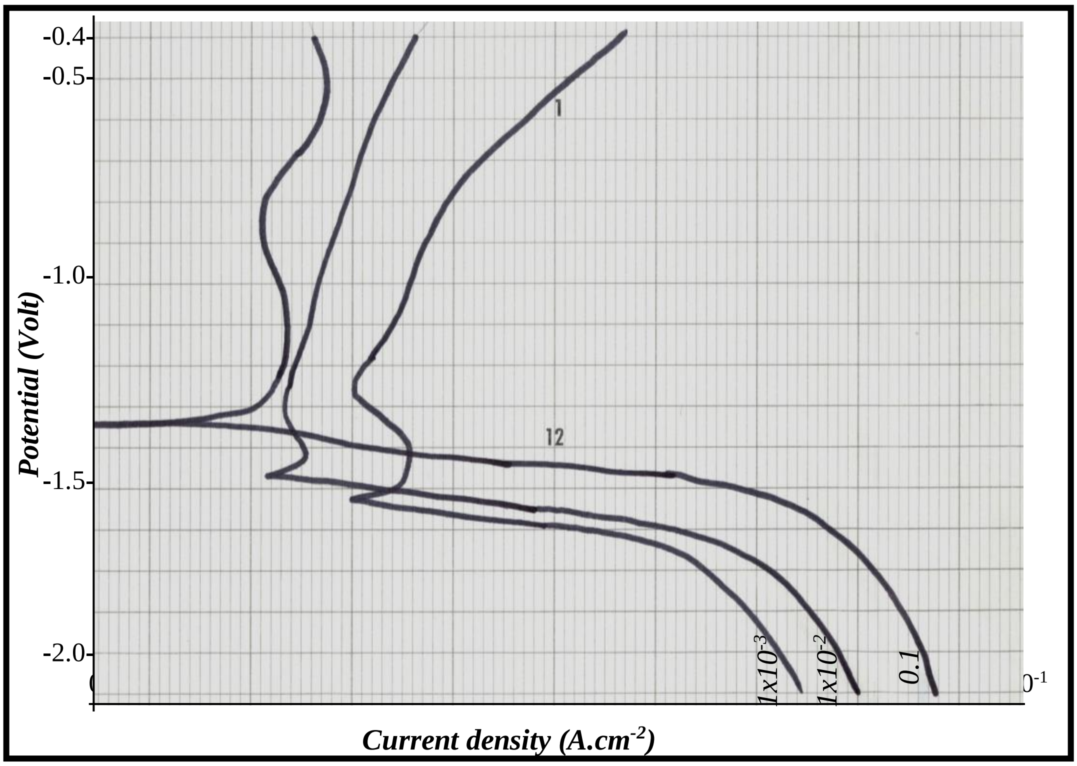

Fig. (6): Polarization curve for corrosion of Al-Si alloy in $2.5x10^{-3}$ $mol.dm^{-3}$NaOH solution in the presence of Na_2HPO_4 at 298K.

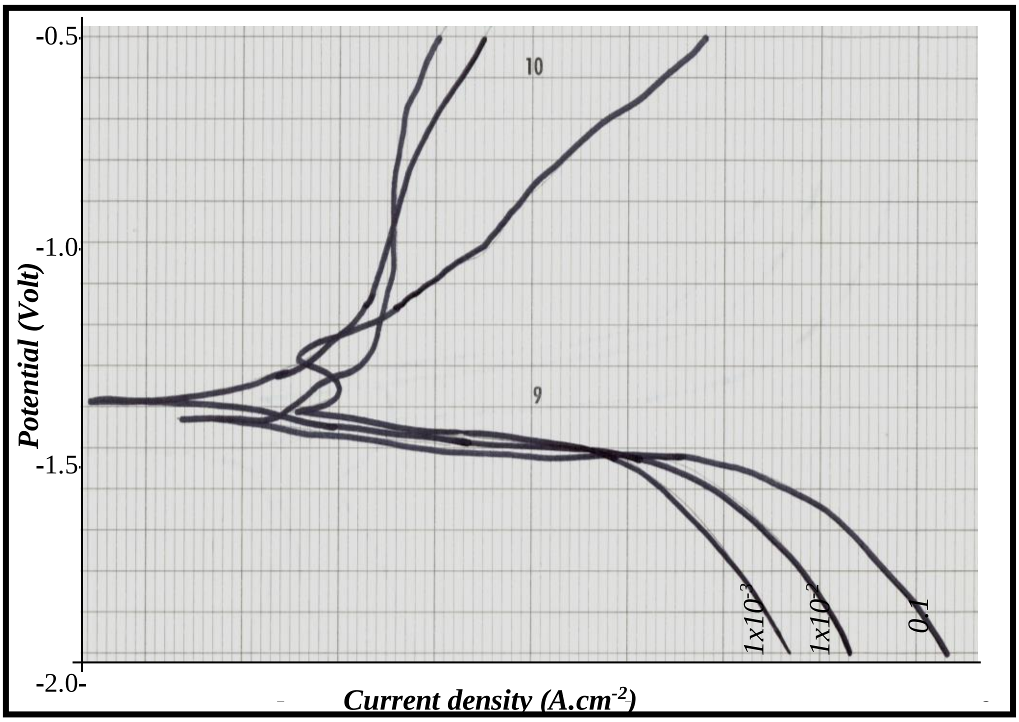

Fig. (7): Polarization curve for corrosion of Al-Si alloy in 2.5×10^{-3} mol.dm^{-3}NaOH solution in the presence of Na_2SO_4 at 298K.

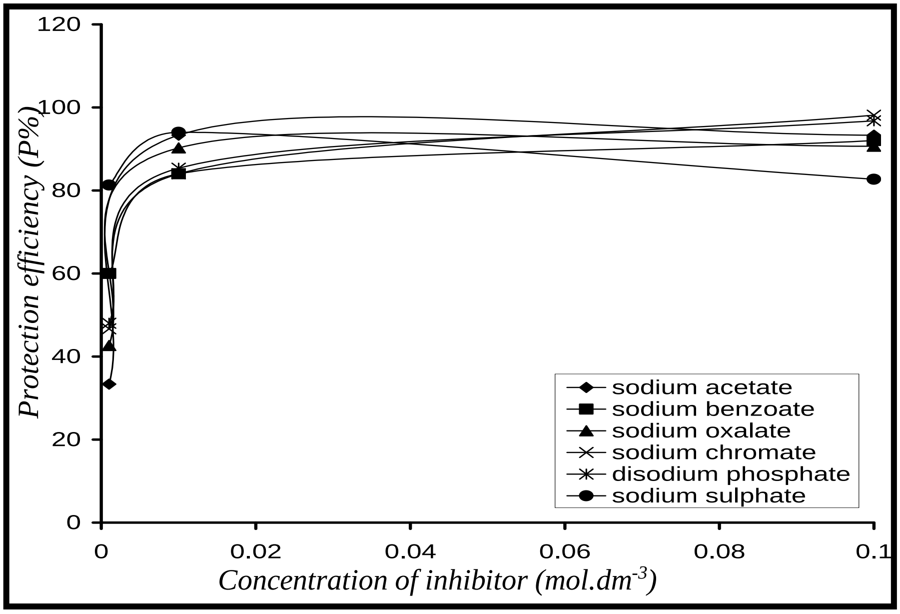

Fig. (8): Effect of concentration of inhibitors on protection efficiency.

تثبيط تأكل سبيكة المنيوم-سليكون-نحاس في وسط قاعدي باستخدام ستة مثبطات عند اربع درجات حرارية

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الخلاصة

يتضمن البحث محاولة لتثبيط تأكل سبيكة المنيوم-سليكون-نحاس في محلول 2.5×10^{-3} مول.دسم$^{-3}$ من هيدروكسيد الصوديوم عند اس هيدروجيني مساوياً لـ 11.4 باضافة ستة مثبطات بثلاث تراكيز من كل مثبط هي (1×10^{-3}، 1×10^{-2}، و0.1 مول.دسم$^{-3}$). تضمنت المثبطات ثلاث مواد عضوية هي خلات الصوديوم وبنزوات الصوديوم وأوكزالات الصوديوم وثلاث مواد لاعضوية هي كرومات الصوديوم وفوسفات الصوديوم وكبريتات الصوديوم. تم حساب البيانات التي تتعلق بالسلوك الاستقطابي والتي تضمنت جهد التأكل وكثافة تيار التأكل وميل تافل الكاثودي والأنودي ومقاومة الأستقطاب. تم ايضاً حساب كفاية الحماية للتثبيط باستخدام المثبطات الستة وقد وضحت قيم طاقة التنشيط تأثير درجة الحرارة على التثبيط في الوسط القاعدي.