JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 14, Preprint 21 submitted 22 May 2011

Effect of Temperature on the Performance of Aloe Extract and Azadirachta Indica Extract in Absence and Presence of Iodide Ions on Aluminum Corrosion in Hydrochloric Acid

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ABSTRACT:

The effect of temperature in the range (20-60)^{o} C on the corrosion of aluminum in 0.5 M hydrochloric acid (HCl) have been investigated using chemical (mass loss (ML) and hydrogen evolution (HE)) and electrochemical (potetiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS)) measurements, and the effect of temperature on the performance of Aloe extract and/or Azadirachta Indica (AZI) extract in 0.5 M HCl in the absence and presence of iodide ions (I^-) on the corrosion of aluminum using electrochemical measurements were carried out. It was found that, the corrosion rate of aluminum increase with rising temperature, also the inhibition efficiency (Inh.%) of Aloe extract and/or AZI extract increase with rising temperature, this indicate that Aloe extract and AZI extract are good inhibitors in acid solution at high temperatures. The Inh.% in the presence of iodide are greater than that in the absence which indicate to the synergistic effect between iodide and the molecules of extract (Aloe and/or AZI) this is due to the stability of insoluble complex (ExI^-) formed on aluminum surface. The thermodynamic parameters E_a, ΔH^* and ΔS^* have been calculated and discussed.

KEYWORDS:

Corrosion, Aloe, Azadirachta Indica, Effect of Temperature, Aluminum.

1-INTRODUCTION:

Corrosion inhibition of aluminum is the suspect of tremendous technological importance due to the increased industrial application of this material. Recently, many

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ISSN 1466-8858 Volume 14, Preprint 21 submitted 22 May 2011

plant extracts are widely used as corrosion inhibitors for some metals and alloys in cleaning and pickling processes. Several authors [1-9] have been studied the corrosion inhibition of aluminum and its alloys by natural organic inhibitors. Like most chemical reactions, the rate of corrosion of metals in aqueous acid solutions increases with increasing temperature, especially when evolution of hydrogen accompanied corrosion, e.g., during dissolution of aluminum and zinc in alkaline or of mild steel in acids. If oxygen takes part in a cathodic reaction during corrosion, the relationship between corrosion rates and temperature becomes more complicated owing to the lower stability of oxygen at elevated temperature [10].

The effect of temperature in the range (20-60)$^{\circ}$ C on the performance of Aloe extract and AZI extract in the absence and presence of iodide ions (I^-) on the corrosion of aluminum in hydrochloric (HCl) acid will be carried out using chemical and electrochemical studies.

2-EXPERIMENTAL:

To investigate the effect of temperature on the corrosion of aluminum and the inhibition of aluminum corrosion by Aloe and/or AZI extract, gasometry and mass loss measurements were taken at various temperatures (20-60)^{o} C in 0.5 M HCl, and the electrochemical measurements were taken at various temperatures in 0.5 M HCl in :

- The absence and presence of constant concentration of Aloe extract and AZI extract under investigation.
- The presence of 0.01M iodide ions (I^-).

Details of chemical and electrochemical cell and measuring instruments are given elsewhere [11,12].

Aluminium electrode of chemical composition wt.%, 95.277%Al, 0.009% Mn, 0.043%Ni , 0.765%Fe , 0.014%Pb , 2.242%Si , 1.621%Zn and 0.009%Cr were used throughout the present study.

Before measurements, the electrode was mechanically polished with a series of emery papers of the type (231Qwetordry empirical Paple aesoc) as previously described [13-15].

The studied solutions (HCl and NaI) were prepared with analytical grade reagents (A.R.). The concentration of the inhibitors (extracts) was 48%v/v for Aloe extract and 24%v/v for AZI extract. Deionised water was used throughout for the preparation of solutions. Temperature was adjusted to ± 0.02° C using ultra-thermostat (Julabo U3 No 8311). The solutions were dearated with pure nitrogen for 15 minutes before starting electrochemical experiments.

3-RESULTS AND DISCUSSION:

The effect of temperature in the range (20-60)$^{\circ}$ C on the corrosion of aluminum in 0.5 M HCl was tested by chemical ((HE) and (ML) and electrochemical (PDP) and (EIS)) measurements and in 0.5 M HCl containing 48%v/v of Aloe extract and 24%v/v of AZI

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extract in the absence and presence of 0.01M iodide ions by electrochemical measurements.

3-1- Effect of temperature on the corrosion of aluminum in 0.5 M HCl:

3-1-1- Chemical methods:

Figure (1) shows the results of HE for the corrosion of aluminium in 0.5 M HCl at 30, 40, 50 and 60° C, and Figures (2 a, b) show the relation between corrosion rates (R' and R) for aluminum in 0.5 M HCl with temperature from both ML (Figure 2a) and HE (Figure 2b) methods, respectively. Corrosion rates R' and R are recorded in Table (1). It is clear that, the corrosion rate of aluminum increases rapidly with rising temperature, i.e., the slope of the straight lines increase (Figure (1)). And at 50° C and 60° C, the lines give a steady state at the long time of immersion, (above 50 min.), this is may be due to chemisorption of chloride ions in HCl on aluminum surface at high temperatures, which inhibit the metal dissolution.

Arrhenius plots is shown in Figures (3 a, b), which illustrate the relation between (logR' and/or logR) vs. (1/T). Activation energy (E_a) values were calculated from the slopes of the straight lines according to the relation [16]:

$$\log (R' \text{ or } R) = \log A - E_a/2.303\boldsymbol{R}T \qquad (1)$$

where, A is the Arrhenius constant, ***R*** is the ideal gas constant and T is absolute temperature. E_a values are recorded in table (2).

An alternative form of Arrhenius equation is the transition state equation [17-21]:

$$R' \text{ or } R = \boldsymbol{R}T/Nh \exp(\Delta S/\boldsymbol{R}) \exp(-\Delta H^*/\boldsymbol{R}T) \qquad (2)$$

$$\log(R'/T) = \log(\boldsymbol{R}/Nh) + \Delta S^*/2.303\,\boldsymbol{R} - \Delta H^*/2.303\boldsymbol{R}T \qquad (4)$$

$$\log(R/T) = \log(\boldsymbol{R}/Nh) + \Delta S^*/2.303\,\boldsymbol{R} - \Delta H^*/2.303\boldsymbol{R}T \qquad (4)$$

where, h is blank's constant, N is Avogadro's number, ΔS^* is the entropy of activation and ΔH^* is the enthalpy of activation.

The plots of log (R'/T) and/or log(R/T) vs.(1/T) will give a straight lines (Figures (4 a, b)), with a slope of $-\Delta H^*/2.303\boldsymbol{R}$ and an intercept of $\log(\boldsymbol{R}/Nh)+\Delta S^*/2.303\boldsymbol{R}$. The values of ΔH^* and ΔS^* are calculated from ML and HE and recorded in table (2).

From Table (2), it is clear that, E_a values are approximately agree with that obtained by a number of authors [17, 21-23]. But $(E_a)_{ML}$ is greater than $(E_a)_{HE}$, this attributed to that the hydrogen evolution reaction is easily than the dissolution reaction. As clear from Table (2), the values of E_a and ΔH^* are approximately equals, which indicate that the dissolution of aluminum will occur without changing in reaction mechanism at different temperatures.

3-1-2-Eletrochemical methods:

The electrochemical behavior of aluminum in 0.5 M HCl was studied using PDP and EIS measurements, Figure (5 a, b).

Figure (5a) represents the displacement in the anodic and cathodic Tafel lines and shift $E_{corr.}$ to more negative values when the temperature rise from 20° C to 60° C as a result to lowering the hydrogen evolution over potential. This means

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ISSN 1466-8858 Volume 14, Preprint 21 submitted 22 May 2011

that the corrosion rate of aluminum increase with rising temperature. Nyquist plots were illustrate in Figure (5b), it is clear that there are a gradual decrease in the diameters of the semicircles with rising temperature indicates that the increase in the corrosion rate of aluminum in 0.5 M HCl with rising temperature will occur. At 60 ^{o}C, Nyquist plots give semicircle with inductive loop due to pitting corrosion as a result of the presence of chloride ions within HCl solution which contain adsorbed layer on aluminum surface.

Table (3) gives the electrochemical parameters obtained from the polarization and impedance measurements. It is clear that corrosion current ($I_{corr.}$) and corrosion resistance ($R_{corr.}$) are increased and the charge transfer resistance ($R_{ct.}$) is decreased, which indicate increases in the corrosion rate with rising temperature.

Figures (6 a, b) give the relations: log $I_{corr.}$ vs. 1/T and log ($I_{corr.}$/T) vs.1/T from PDP method.

Activation energy (E_a), enthalpy (ΔH^*) and entropy (ΔS^*) were calculated and recorded in Table (4). It obvious that the values obtained from polarization is greater than that from chemical methods (ML and HE) (Table (2)), this attributed to that the electrochemical methods give instantaneous corrosion values, whereas the values obtained from chemical methods are intermediate values [24].

3-2-Effect of temperature on the corrosion of aluminum in the presence of constant concentration of Aloe extract:

The effect of temperature in the range (20-60)^{o} C on the corrosion rate of aluminum in 0.5 M HCl solution in the presence of (48%v/v) of Aloe extract was studied using electrochemical (PDP and EIS) measurements. Tafel plots and Nyquist diagrams are shown in Figures (7 a, b) and the electrochemical parameters are listed in Table (5), which exhibit that the corrosion current density ($I_{corr.}$) increase more rapidly with rising temperature, where it decrease in the presence of Aloe extract than that in absence (Table(3)). Figure (7a) shows displaces the cathodic and anodic curves and $E_{corr.}$ shifts to the negative direction with rising temperature, which indicates that thinning oxide film formed on aluminum surface and the increasing $I_{corr.}$values due to the decrease in hydrogen over potential with rising temperature and it obvious that the presence of inflection at the beginning of the cathodic polarization due to the accumulation of hydrogen gas which increase with rising temperature.

The presence of steady state in the anodic direction of polarization is due to the formation of protection layer adsorbed on aluminum surface.

As observed from Table (5) and Figure (7b), $R_{ct.}$ values and the diameters of semicircles decreases with rising temperature which indicates that Aloe extract acts as good inhibitor for aluminum corrosion at different temperatures. The increase in inhibition efficiency with increasing temperature can be explained due to: slowness the motion of Aloe extract molecules which have large size compared with that of adsorbed water molecules on aluminum surface. At high temperatures, the motion of Aloe molecules is less than that of

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water molecules which lead to desorption of water molecules from aluminum surface and adsorbed a lot of Aloe molecules which lead to increase the surface coverage and increasing inhibition efficiency [25,26].

Figure (8a) represents Arrhenius plot (log $I_{corr.}$vs.1/T) for aluminum in 0.5 M HCl containing 48%v/v of Aloe extract from polarization measurements. It was found that the value of activation energy (E_a) is equal to 13.69 $kJ.mol^{-1}$ which agrees with previous studies [27]. The decrease of the activation energy in the presence of Aloe extract indicate to chemisorption of the extract molecules on aluminum surface. Surface coverage (Θ) increase with rising temperature as a result of increases in the desorption process of H_2O molecules with rising temperature [28-30] which led to an increase in the adsorption process of the inhibitor. The results were in good agreement with those reported previously for aluminium [31, 32].

A plot log ($I_{corr.}$/T) vs. 1/T gives a straight lines (Figure 8b) with slope of ($-\Delta H^*/2.303R$) and an intercept of ($\log((R/Nh)+\Delta S^*/2.303R)$), from which the values of E_a, ΔH^* and ΔS^* were calculated and listed in Table (6). The data shows that the thermodynamic activation functions (E_a and ΔH^*) for the corrosion of aluminum in 0.5 M HCl in the presence of Aloe extract are less than those in acid solutions. The entropy of activation ΔS^* is large negative value, this indicates that the formation of activated complex is the rate determining step represents an association rather than dissolution step, this means, a decrease in disordering takes place on going from reactants to the activated complex [33].

3-3-Effect of temperature on the corrosion of aluminium in the presence of constant concentration of Aloe extract and constant concentration of iodide ions:

The electrochemical behaviour for aluminum in 0.5 M HCl in the presence of 48%v/v of Aloe extract and 0.01 M NaI at different temperatures (20-60)^{o} C was studied using polarization and impedance measurements, Figure (9 a, b) and Table (7).

It is clear that displaces the cathodic and anodic Tafel lines, shift $E_{corr.}$ to more negative values (Figure 9a) and a gradual decrease in the diameter of half circle (Figure 9b) with rising temperature from 20^{o} C to 60^{o} C, i.e., the corrosion rate of aluminium decrease and increase in resistance with rising temperature.

Table (7) shows the increase $I_{corr.}$ and $R_{corr.}$ values with rising temperature and also the inhibition efficiency in the presence of iodide ions is higher than that in the absence, this indicate to the synergistic effect between Aloe extract and iodide ions lead to increase the inhibition efficiency. This attributed to the formation of complex between iodide and Aloe molecules through the electrostatic attraction and it adsorb on aluminum surface and becomes more stable with rising temperature, the increase in temperature lead to high kinetic energy for molecules in solution with less weight and the large Aloe molecules moves far from aluminum surface and then, the formed complex becomes more stable which gives high inhibition efficiency.

Figure (10a) shows Arrhenius plot which illustrate the relation between log$I_{corr.}$ and 1/T for aluminum corrosion in 0.5 M HCl in the presence of constant concentration of Aloe

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extract and iodide ions. Also, a plot of log ($I_{corr.}$/T) vs. 1/T should give a straight line (Fig.10 b). The values of E_a, ΔH^* and ΔS^* were calculated and listed in Table (8). The data shows that the thermodynamic activation functions (E_a and ΔH^*) are higher than those in the presence of Aloe extract alone (Table (6)). This result shows that the uses of inhibitors in the presence of iodide ions for protection of metals from corrosion is linked to high adsorption on the surface [34], which include the formation of physical protective layer of stable (insoluble) complex between the metal and corrosive medium [35]. This layer will effect on the corrosion reaction.

3-4-Effect of temperature on the corrosion of aluminuim in the presence of constant concentration of Azadirachta Indica (AZI) extract:

The corrosion of aluminum in 0.5 M HCl containing 24% v/v of AZI extract has been studied over the temperature range (20-60)^o C using PDP and EIS measurements.

Figures (11a, b)) show the effect of temperature on the polarization Tafel lines and Nyquist plots for aluminum in 0.5 M HCl in the presence of 24% v/v of AZI extract. A general trend was observed in this Figure, as the temperature increases the cathodic and anodic Tafel lines are shifted towards high current and $E_{corr.}$ values. The values of the inhibition efficiency and the electrochemical parameters are listed in Table (9). It was noted that:

- the values of $I_{corr.}$ and $R_{corr.}$ increase with rising temperature and then decrease indicate to decrease the corrosion rate with rising temperature.
- $E_{corr.}$ shift to more negative values indicate to the formation of thin layer on aluminum surface.
- gradual decrease in the diameter of half circles with rising temperature in the presence of constant concentration of AZI extract, while in the absence of AZI extract, it obvious gradual increase in the diameter of the circles and decrease the values of charge transfer resistance ($R_{ct.}$).

These results are attributed to the increase in the thickness of passive oxide layer which lead to increase in the inhibition efficiency as a result of adsorption of AZI extract molecules on aluminum surface, which attributed to desorption of water molecules and replacement with the large AZI molecules with rising temperature.

The apparent activation energy E_a was calculated from the relation between log $I_{corr.}$vs. 1/T (Figure (12a)). It was found that E_a value equal to 28.15 kJmol^{-1}, this result agrees with previous study [3], ΔH^* and ΔS^* values obtained from the relation between log $I_{corr.}$/T vs. 1/T, Figure (12b) and recorded in Table (10).

The results show that the less E_a value in the presence of AZI extract attributed to chemisorption of AZI molecules on aluminum surface with rising temperature and form the adsorbed layer at the interface between aluminum/HCl solution which lead to increase Inh.%. The values of E_a and ΔH^* for the corrosion of aluminum in 0.5 M HCl in the presence of AZI extract less than those in 0.5 M HCl alone and higher than those in the presence of Aloe extract, this attributed to the concentration which chosen from the

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extract and to the large size of AZI molecules. Also, it was found that the value of ΔS^* in the presence of AZI extract have high negative value, this indicate to the activated complex formed in the determination step was accumulation rather than dissolution which lead to lower the disruption [33]. This is agrees with that obtained in the case of Aloe extract.

3-5-Effect of temperature on the corrosion of aluminum in the presence of constant concentration of AZI extract and constant concentration of iodide ions:

Figure (13a) shows polarization curves , for aluminum in 0.5 M HCl in the presence of 24% v/v AZI extract and 0.01M NaI at different temperatures, it is clear that, shift in the cathodic and anodic Tafel lines and $E_{corr.}$values to more negative values with rising temperature from 20° C to 60° C, i.e., the corrosion rate decrease. Figure (13b) shows a gradual decrease in the diameter of half circles which indicate to decrease in corrosion rate and the resistance with rising temperature.

Table (11) shows the electrochemical parameters obtained from polarization and impedance measurements.

$I_{corr.}$ and $R_{corr.}$ values increase with rising temperature and, the adsorption of AZI extract and iodide ions through the chemisorption of $Ex_{И}I$ complex. It obvious that the inhibition efficiency in the absence iodide ions (i.e., in presence of AZI extract alone) decrease which indicate that the addition of iodide lead to decrease the inhibition efficiency of AZI extract, but at 30° C, the Inh.% decrease comparing with that at 20° C and 40° C, this can interpret as, at 20° C the molecules will adsorb on aluminum surface by physical adsorption and it change to chemisorption at 40° C, which produce with rise the temperature from 20° C to 30° C desorption of AZI molecules lead large area of aluminum surface to corrosion media [9], after that the physical adsorption change to chemisorption and increase the inhibition efficiency with rising temperature, but it will be less in the range (40-60)° C. This can be interpreted to that the active complex formed at the aluminum/HCl interface will be able to soluble at low temperatures, and with rising temperature the adsorbed layer become insoluble, which it is the result to the reaction occur between the complex and aluminum surface and then the chemical adsorption of AZI molecules and iodide ions which occur with constant rate.

The activation energy E_a for the corrosion process was calculated from Arrhenius equation and it is equal to 35.61 kJmol^{-1}. Figure (14 (a, b)) illustrates the relation between $\log I_{corr.}$vs.1/T and the relation $\log(I_{corr.}/T)$ vs.1/T, respectively for aluminum in 0.5 M HCl. Values of E_a, ΔH^* and ΔS^* are recorded in Table (12).

The results show that the values of E_a and ΔH^* for the corrosion of aluminum in 0.5 M HCl in the presence of AZI and iodide ions are higher than that in the presence of AZI extract alone, and ΔS^* value have large positive value indicate to the formation of stable adsorbed layer on aluminum surface at high temperatures.

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From pervious results it obvious that the Inh.% of Aloe plant extract increase in presence of I^- ions, and AZI extract have high Inh.% with rising temperature in absence of I^- ions, this make it good inhibitors at high temperatures.

It will be noted that the Aloe plant extract and AZI plant extract are good inhibitors for aluminum corrosion at high temperatures.

CONCLUSION:

1- The corrosion rate ofaluminum sample in 0.5 M HCl solution increase with rising temperature.
2- The inhibition efficiency of Aloe extract and AZI extract for aluminum sample in 0.5 M HCl solution increase with rising temperature , this indicates that Aloe and AZI extracts are good inhibitors in acidic solutions at higher temperatures.
3- Aloe and AZI extracts molecules adsorb on aluminum surface by chemical adsorption.
4- The addition of iodide ions on the corrosive medium containing Aloe extract and/or AZI extract give inhibition efficiency greater than that in the absence, which indicate to the synergistic effect between I^- and Aloe and / or AZI extract molecules.

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Table (1): Corrosion rates (R' and R) of alumnium in 0.5 M HCl at different temperatures.

t°C	20	30	40	50	60
R'	4.433×10^{-6}	2.380×10^{-5}	3.360×10^{-5}	5.469×10^{-5}	9.230×10^{-5}
R	-	7.917×10^{-3}	6.907×10^{-2}	1.628×10^{-1}	2.782×10^{-1}

Table (2): Thermodynamic parameters of aluminum in 0.5 M HCl at different temperatures from ML and HE methods.

Method	**E_a kJ.mol.$^{-1}$**	**$\Delta H^{\#}$ kJ.mol.$^{-1}$**	**$\Delta S^{\#}$ J.mol.$^{-1}$K^{-1}**
ML	56.48	53.80	-160.04
HE	36.38	33.50	-155.95

Table (3): Electrochemical parameters and inhibition efficiency for Al corrosion in 0.5 M HCl at different temperatures.

Temp. °C	***Polarization***					***Impedance***		
	$-E_{corr.}$ *(mV)*	b_a *(V dec^{-1})*	$-b_c$ *(V dec^{-1})*	$I_{corr.}$ *(mA. cm^{-2})*	$R_{corr.}$ *(mm day^{-1})*	$R_{sol.}$ *(Ω cm^2)*	$R_{ct.}$ *(Ω cm^2)*	$C_{dl.}$ *(μF)*
20	694.21	30.647	118.37	3.32	45.60	2.098	109.9	29.55
30	726. 57	44.550	131.22	7.28	79.30	0.584	42.52	102.5
40	722.09	76.615	10896	25.90	282.66	2.227	11.89	24.51
50	713.13	72.270	139.151	26.71	290.92	2.272	6.421	30.77
60	719.12	83.171	84.540	31.82	346.53	1.065	1.101	38.22

Table (4): Thermodynamic Parameters for aluminum in 0.5 M HCl from polarization method.

Method	**E_a kJ.mol.$^{-1}$**	**$\Delta H^{\#}$ kJ.mol.$^{-1}$**	**$\Delta S^{\#}$ J.mol.$^{-1}$K^{-1}**
Polarization	48.06	45.38	-77.98

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Table (5): Electrochemical parameters and inhibition efficiency for Al corrosion in 0.5M HCl in presence of 48% v/v of Aloe Vera extract at different temperatures.

Temp. ***°C***	***Polarization***						***Impedance***			
	$-E_{corr.}$ *(mV)*	b_a *($V\ dec^{-1}$)*	$-b_c$ *($V\ dec^{-1}$)*	$I_{corr.}$ *($mA.\ cm^{-2}$)*	$R_{corr.}$ *($mm\ day^{-1}$)*	*Inh.%*	$R_{sol.}$ *($\Omega\ cm^2$)*	$R_{ct.}$ *($\Omega\ cm^2$)*	$C_{dl.}$ *(μF)*	*Inh.%*
20	705.60	30.04	86.40	1.33	14.43	**59.94**	1.775	324.00	33.26	**66.08**
30	728.81	45.69	75.44	2.16	23.49	**70.34**	1.198	200.40	50.55	**75.05**
40	729.70	97.31	71.82	3.00	32.60	**88.42**	1.710	93.93	55.02	**87.33**
50	747.42	33.40	71.00	3.08	33.56	**88.47**	2.949	64.00	39.31	**89.98**
60	759.46	44.77	21.77	3.08	33.49	**90.32**	1.310	15.50	13.82	**92.91**

Table (6): Thermodynamic parameters of Al sample in 0.5 M HCl in presence of 48% of Aloe Vera extract at different temperatures from polarization method.

Method	**E_a** **$kJ.mol.^{-1}$**	**$\Delta H^{\#}$** **$kJ.mol.^{-1}$**	**$\Delta S^{\#}$** **$J.mol.^{-1}K^{-1}$**
Polarization	13.69	11.36	-179.88

Table (7): Electrochemical parameters and inhibition efficiency for corrosion of Al in 0.5 M HCl in the presence of 48% of Aloe Vera extract + 1×10^{-2} M NaI at different temperatures.

Temp. ***°C***	***Polarization***						***Impedance***			
	$-E_{corr.}$ *(mV)*	b_a *($V\ dec^{-1}$)*	$-b_c$ *($V\ dec^{-1}$)*	$I_{corr.}$ *($mA.\ cm^{-2}$)*	$R_{corr.}$ *($mm\ day^{-1}$)*	*Inh.%*	$R_{sol.}$ *($\Omega\ cm^2$)*	$R_{ct.}$ *($\Omega\ cm^2$)*	$C_{dl.}$ *(μF)*	*Inh.%*
20	695.70	87.55	95.00	2.13	23.15	**35.84**	1.133	147.10	4.964×10^{-5}	**25.29**
30	732.05	71.89	15.14	2.68	29.16	**63.20**	0.525	87.23	57.80	**52.23**
40	707.75	103.71	113.79	3.90	42.46	**84.94**	2.051	44.26	6.821×10^{-5}	**73.10**
50	761.55	32.14	39.80	3.64	39.61	**86.37**	1.449	27.04	1.024×10^{-4}	**76.11**
60	735.40	33.23	25.87	3.41	37.11	**89.28**	1.813	10.68	2.988×10^{-5}	**89.71**

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Table (8): Thermodynamic parameters of Al in 0.5 M HCl in presence of 48% of Aloe Vera + 1.0×10^{-2} M NaI at different temperatures from polarization method.

Method	E_a kJ.mol.$^{-1}$	$\Delta H^{\#}$ kJ.mol.$^{-1}$	$\Delta S^{\#}$ J.mol.$^{-1}$K^{-1}
Polarization	17.23	14.36	-172.28
Impedance	58.02	60.50	6.53

Table (9): Electrochemical parameters and inhibition efficiency for Al corrosion in 0.5M HCl in the presence of 24% of Azadirachta Indica extract at different temperatures.

Conc. V/V	***Polarization***						***Impedance***			
	$-E_{corr.}$ *(mV)*	b_a *(V dec^{-1})*	$-b_c$ *(V dec^{-1})*	$I_{corr.}$ *(mA. cm^{-2})*	$R_{corr.}$ *(mm day^{-1})*	*Inh.%*	$R_{sol.}$ *(Ω cm^2)*	$R_{ct.}$ *(Ω cm^2)*	$C_{dl.}$ *(μF)*	*Inh.%*
20	727.51	40.82	85.49	2.60	28.23	**21.69**	1.595	147.10	65.59	**25.29**
30	732.82	56.04	105.58	4.00	43.63	**45.07**	2.898	139.40	55.31	**70.13**
40	756.58	48.20	68.24	6.34	69.05	**75.52**	1.505	45.45	82.48	**73.93**
50	733.81	79.33	104.49	4.02	43.73	**84.50**	1.612	41.13	93.59	**84.45**
60	750.89	83.99	56.31	3.46	37.68	**89.13**	2.849	10.84	36.90	**89.86**

Table (10): Thermodynamic parameters of Al in 0.5 M HCl in presence of 24% of AZI extract at different temperatures from polarization method.

Method	E_a kJ.mol.$^{-1}$	$\Delta H^{\#}$ kJ.mol.$^{-1}$	$\Delta S^{\#}$ J.mol.$^{-1}$K^{-1}
Polarization	28.15	25.08	-150.88

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Table (11): *Electrochemical parameters and inhibition efficiency for Al corrosion in 0.5 M HCl in the presence of 24% of AZI extract + 1×10^{-2} M of NaI at different temperatures.*

Conc. V/V	***Polarization***						***Impedance***			
	$-E_{corr.}$ *(mV)*	b_a *(V dec^{-1})*	$-b_c$ *(V dec^{-1})*	$I_{corr.}$ *(mA. cm^{-2})*	$R_{corr.}$ *(mm day^{-1})*	*Inh.%*	$R_{sol.}$ *(Ω cm^2)*	$R_{ct.}$ *(Ω cm^2)*	$C_{dl.}$ *(µF)*	*Inh.%*
20	721.00	23.85	64.02	2.28	24.82	**31.33**	6.263	203.9	42.79	**46.10**
30	734.64	25.86	16.56	5.10	56.16	**29.18**	25.75	69.60	121.2	**41.67**
40	723.12	65.49	186.95	8.60	93.55	**66.80**	1.904	25.90	87.73	**54.04**
50	735.84	63.49	141.59	8.83	96.11	**66.94**	1.707	14.42	106.0	**55.55**
60	754.22	125.45	144.84	9.03	98.36	**71.62**	4.008	9.106	137.7	**87.94**

Table (12): Thermodynamic parameters of Al sample in 0.5 M HCl in presence of 24% of AZI extract+ 1.0×10^{-2} M NaI at different temperatures from polarization method

Method	**E_a kJ.mol.$^{-1}$**	**$\Delta H^{\#}$ kJ.mol.$^{-1}$**	**$\Delta S^{\#}$ J.mol.$^{-1}$K^{-1}**
Polarization	35.61	33.89	-120.82

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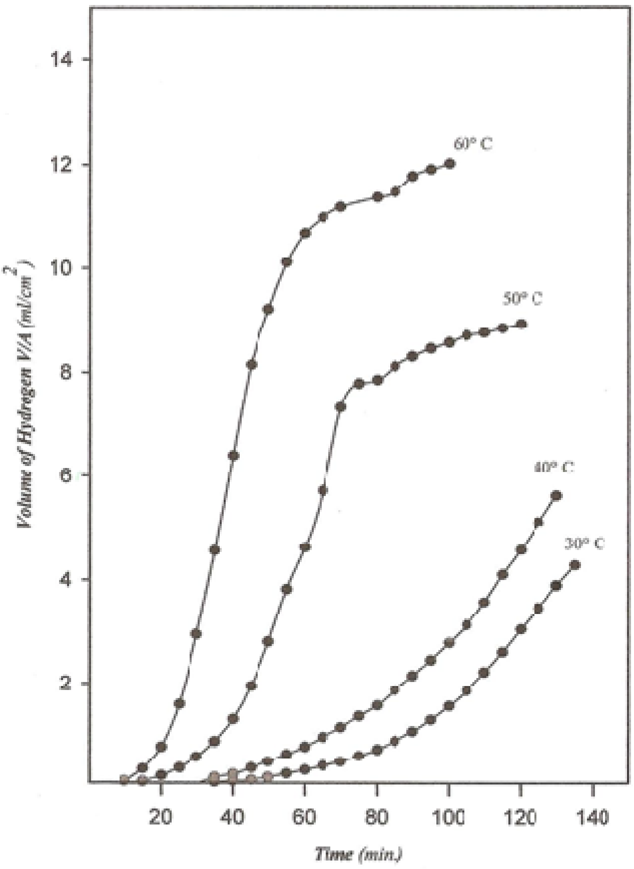

Fig(1): The relation between hydrogen volume and time for the corrosion of Al in 0.5M HCl at different temperatures.

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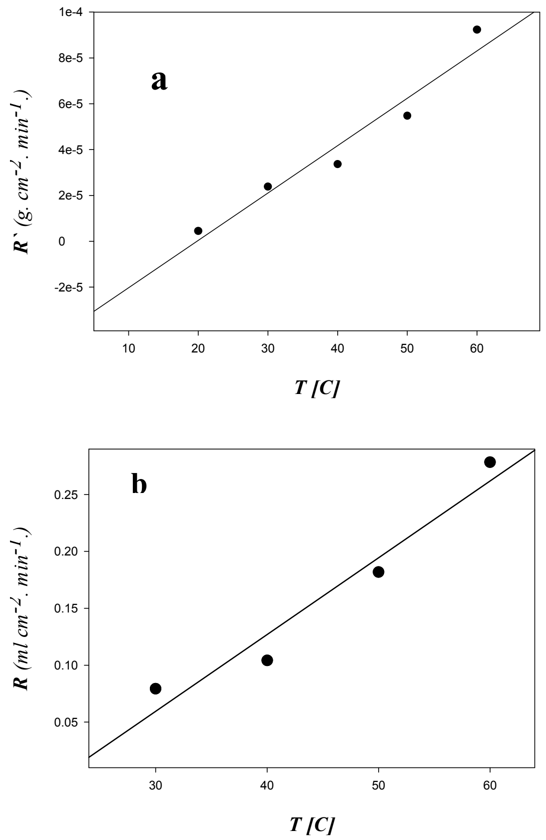

Fig.(2): The relationship between corrosion rates **(a)R`**, **(b)R** of Al corrosion in 0.5M HCl at different temperatures.

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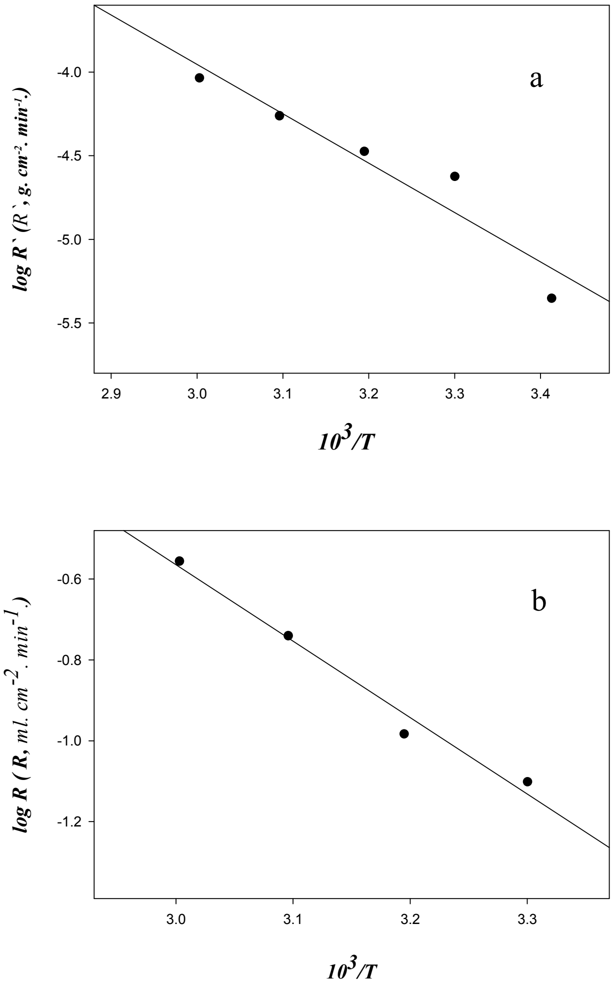

Fig.(3): Arrhenius plots for the corrosion rate **a)** (R`) **b)** (R) of Al in 0.5M HCl solution.

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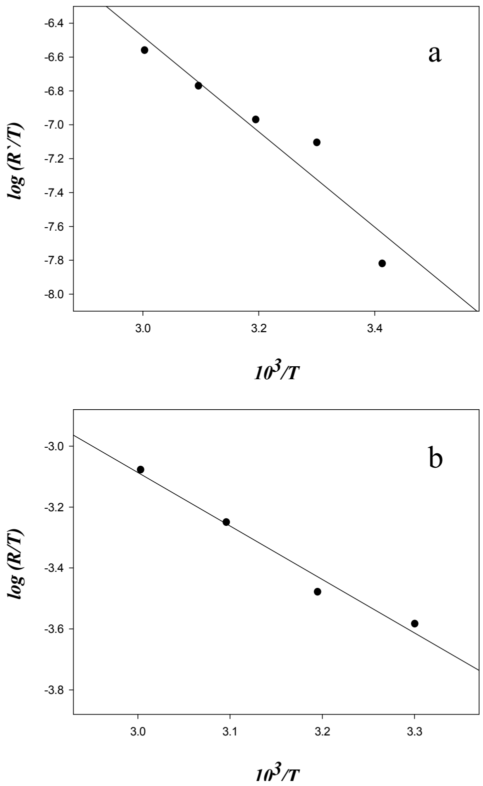

Fig (4): Plots of (a) log (R`/T) (b) log (R/T) Vs. (10^3/T) for the corrosion of Al in 0.5 M HCl solution.

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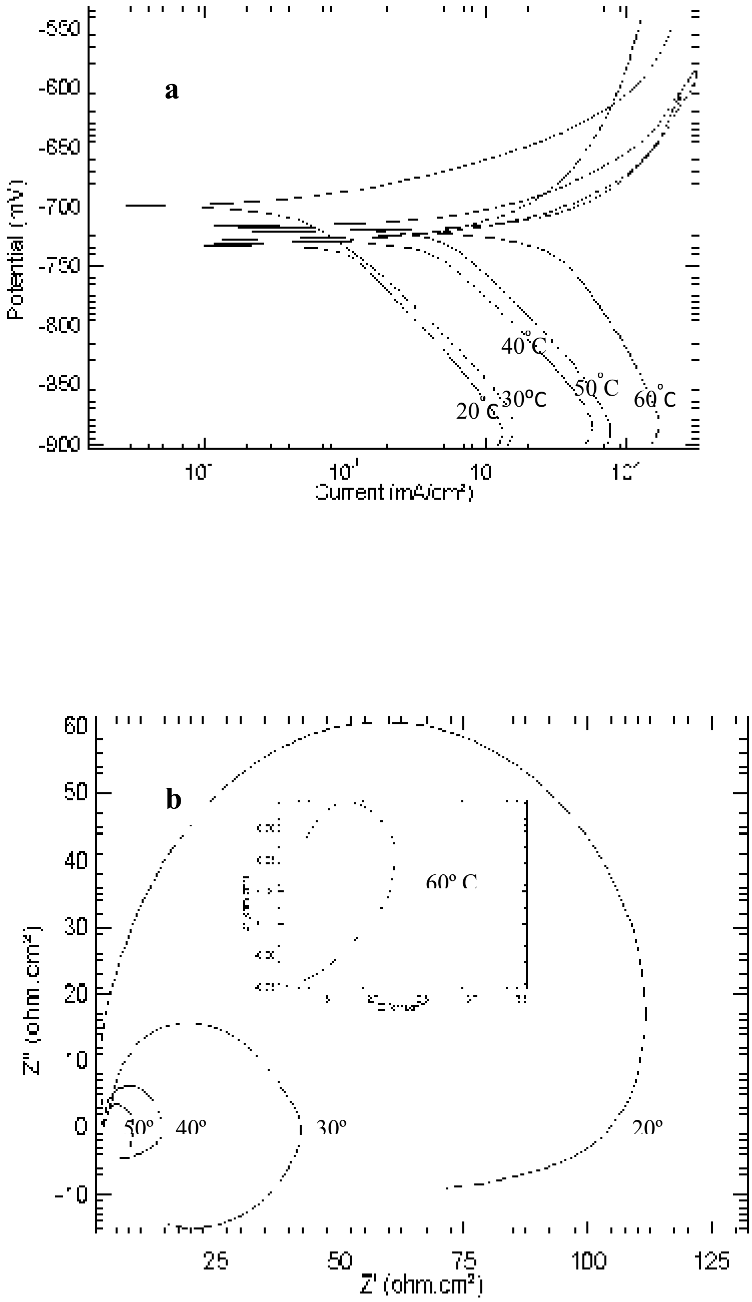

Fig.(5): Electrochemical behavior of Al corrosion in 0.5M HCl at different temperatures from **(a)** Polarization, **(b)** Impedance

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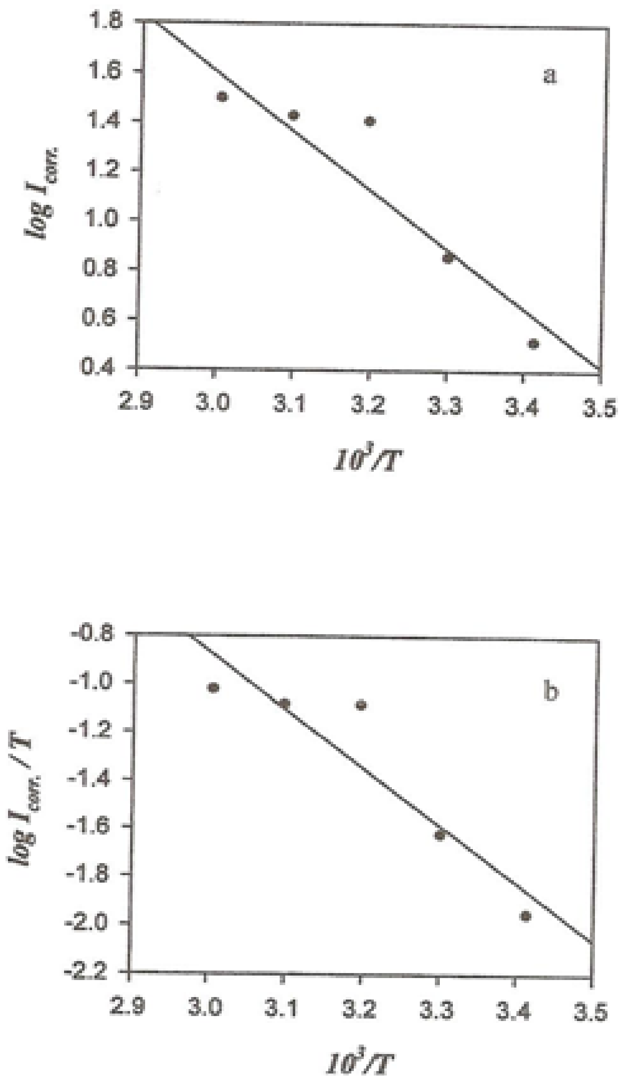

Fig.(6): Plots of **a)** log $I_{corr.}$ **b)** log $_{Icorr./T}$ Vs. (10^3/T) for the corrosion of Al in 0.5 M HCl solution.

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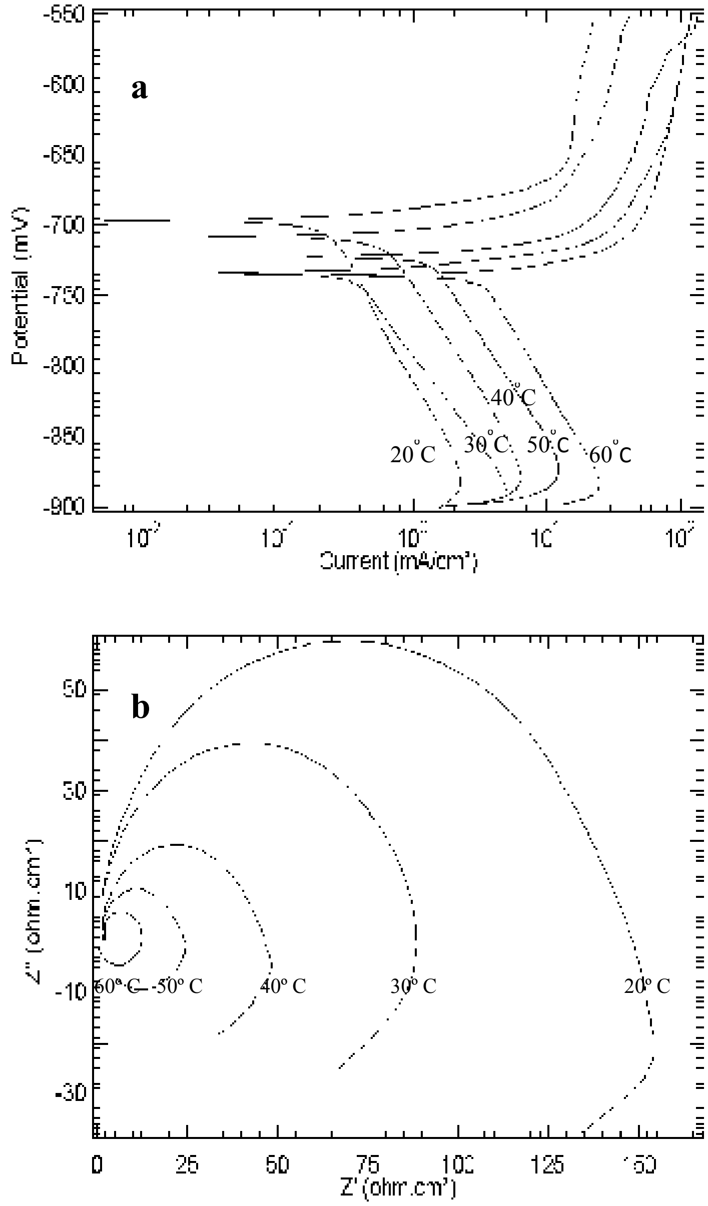

Fig.(7): Electrochemical behavior of aluminum samAl corrosion in 0.5 M HCl in presence of 48% of Aloe Vera extract at different temperatures from **(a)** Polarization, **(b)** Impedance.

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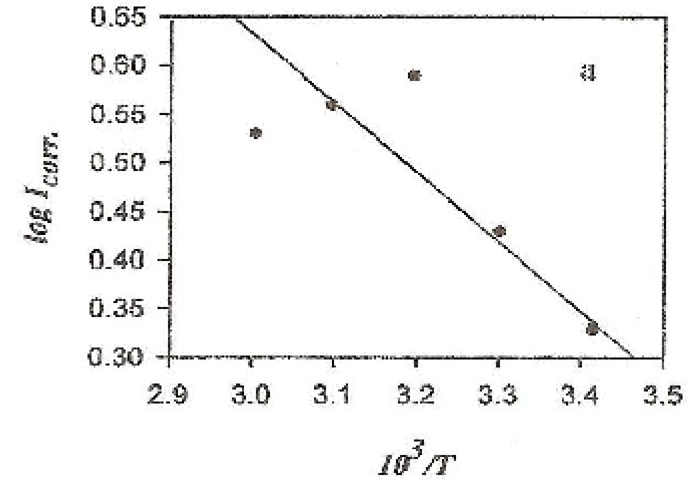

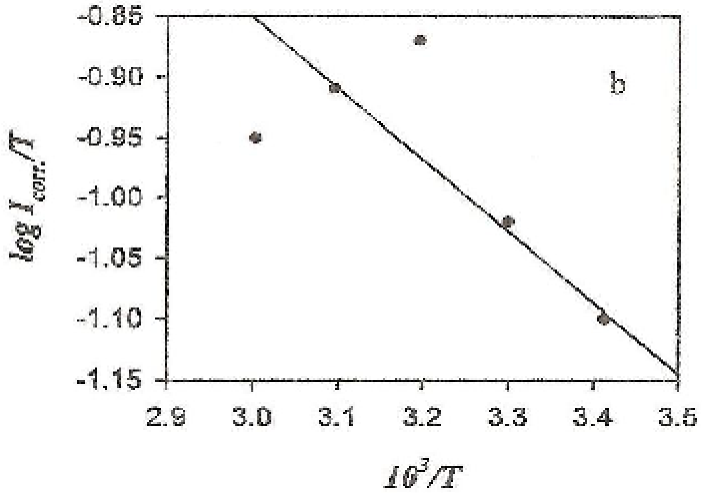

Fig.(8): Plots of **a)** log $I_{corr.}$ **b)** log $_{Icorr./T}$ Vs. $(10^3/T)$ for the corrosion of Al in 0.5 M HCl solution HCl in presence of 48% of Aloe Vera extract.

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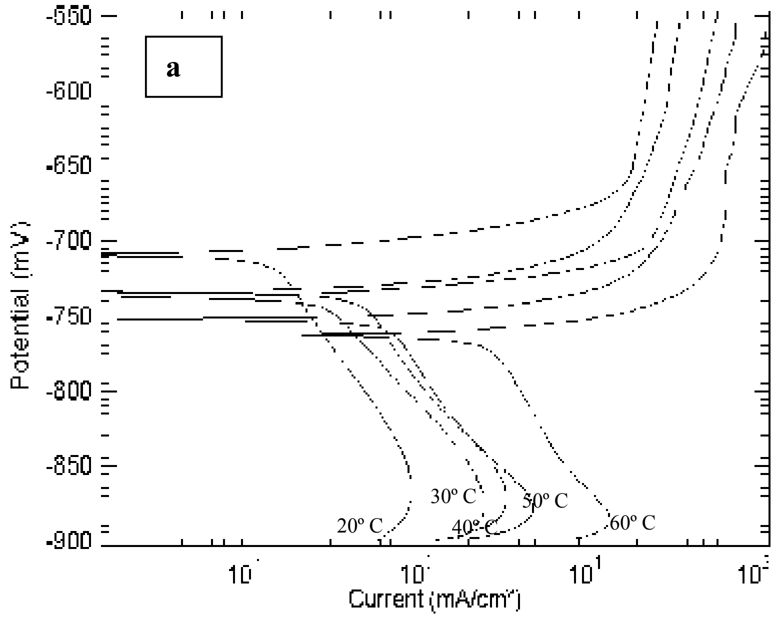

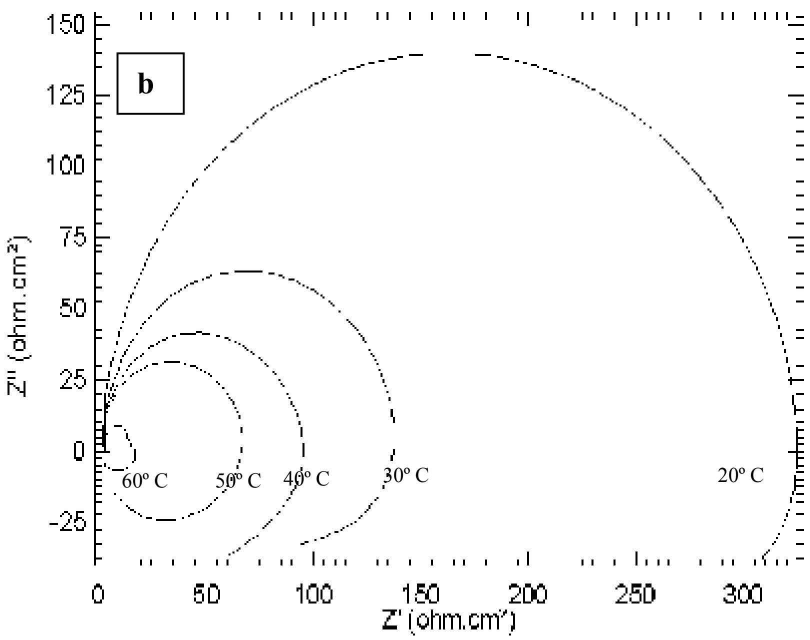

Fig.(9): Electrochemical behavior of Al corrosion in
0.5 M HCl in presence of 48% of Aloe Vera extract + $1x10^{-2}$M NaI
at different temperatures from **(a)** Polarization, **(b)** Impedance.

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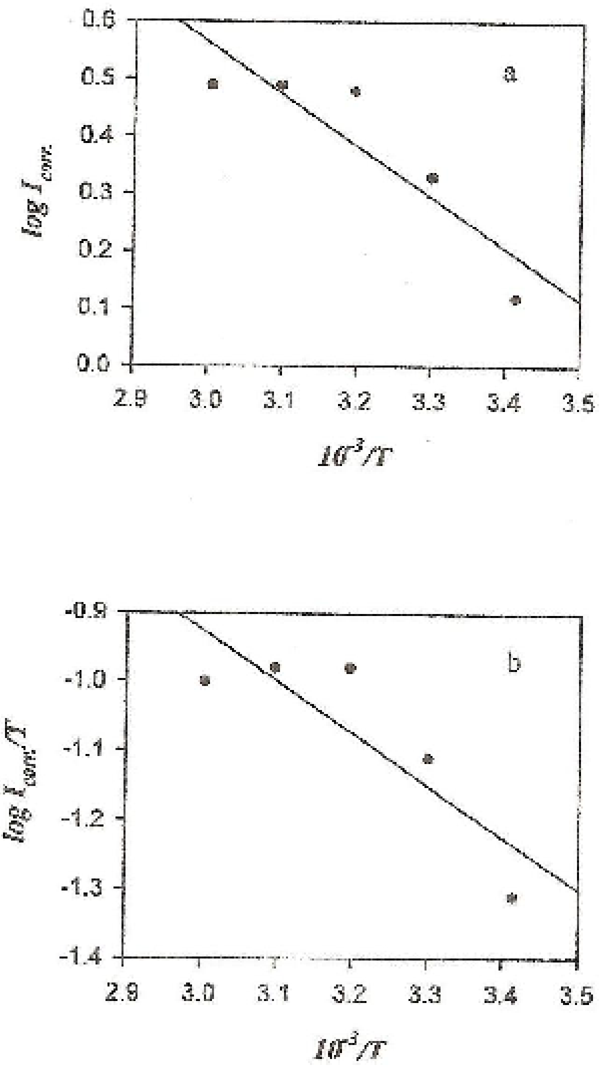

Fig.(10): Plots of **a)** log $I_{corr.}$ **b)** log $_{Icorr./T}$ Vs. (10^3/T) for the corrosion of Al in 0.5M HCl in presence of 48% of Aloe Vera extract+ $1x10^{-2}$M NaI.

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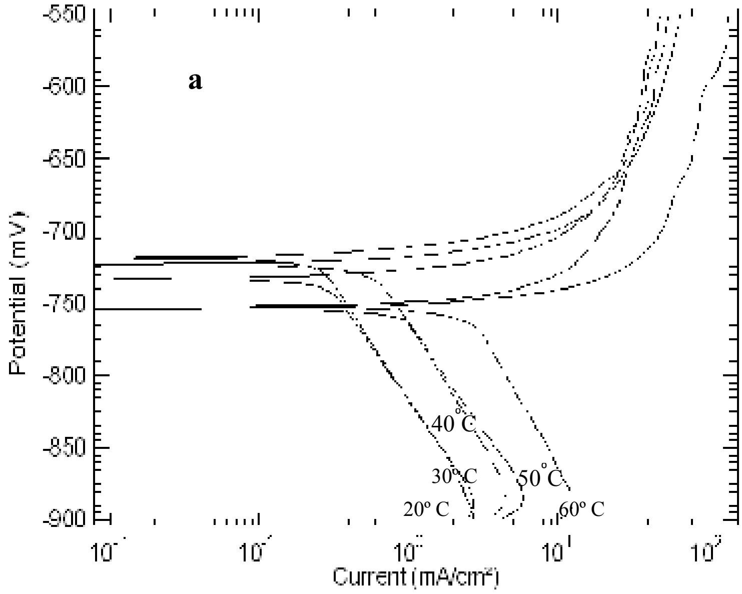

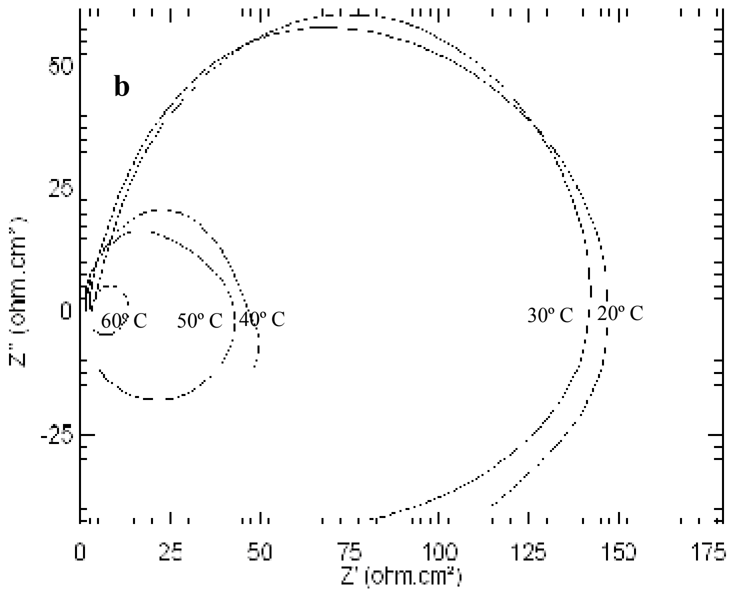

Fig.(11): Electrochemical behavior of Al corrosion in 0.5 M HCl in presence of 24% of AZI extract at different temperatures from **(a)** Polarization, **(b)**Impedance.

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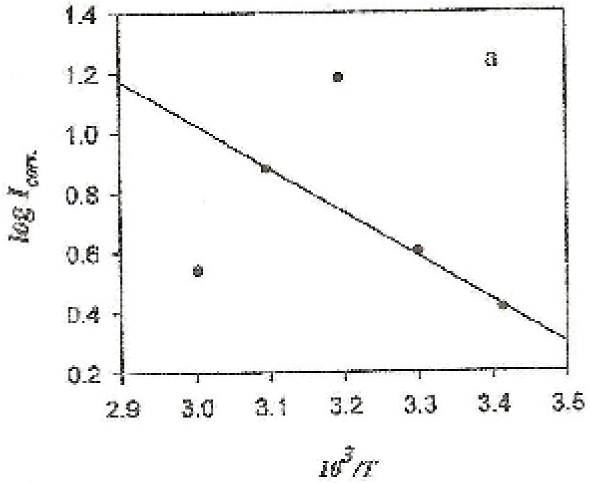

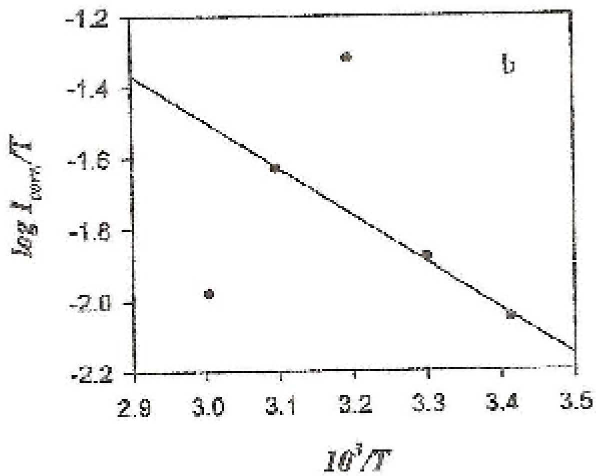

Fig.(12): Plots of **a)** log $I_{corr.}$ **b)** log $_{Icorr./T}$ Vs. (10^3/T) for the corrosion of Al in 0.5 M HCl solution HCl in presence of 24% AZI extract.

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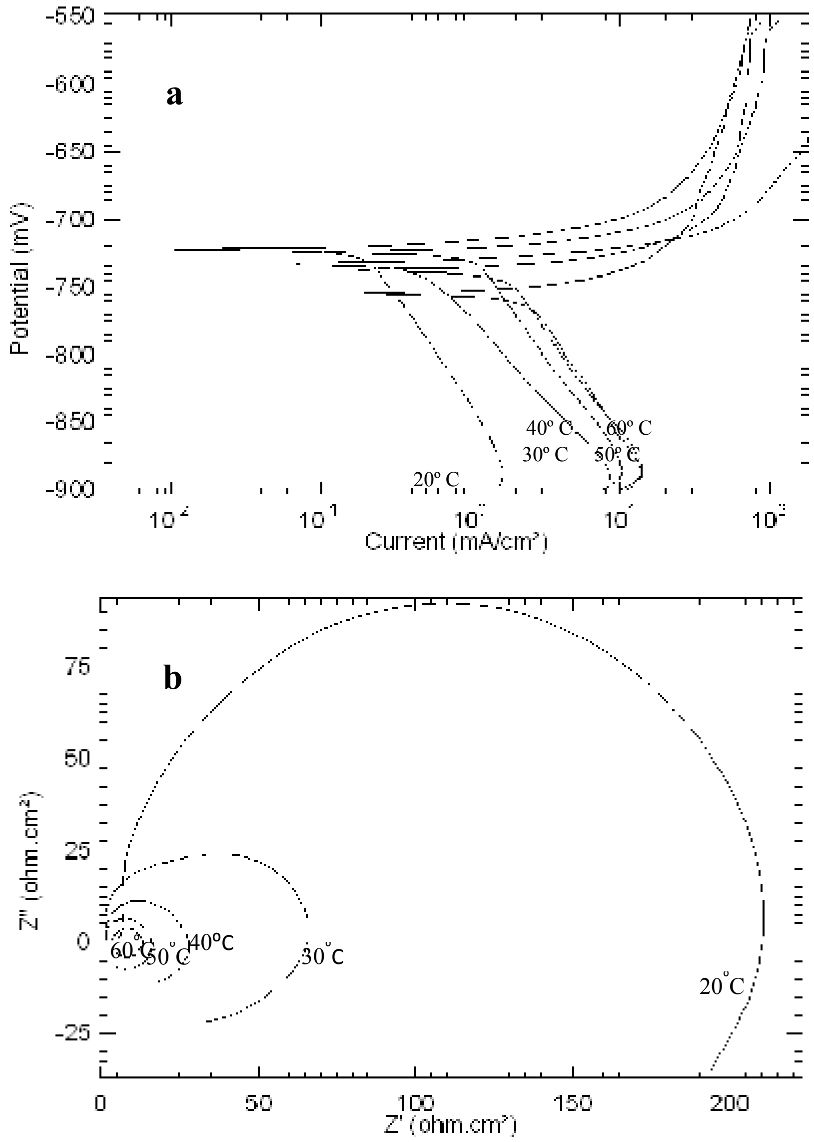

Fig.(13): Electrochemical behavior of Al corrosion 0.5 M HCl in presence of 24% of AZI extract $+1\times10^{-2}$ M NaI at different temperatures from **(a)** Polarization, **(b)**Iimpedance.

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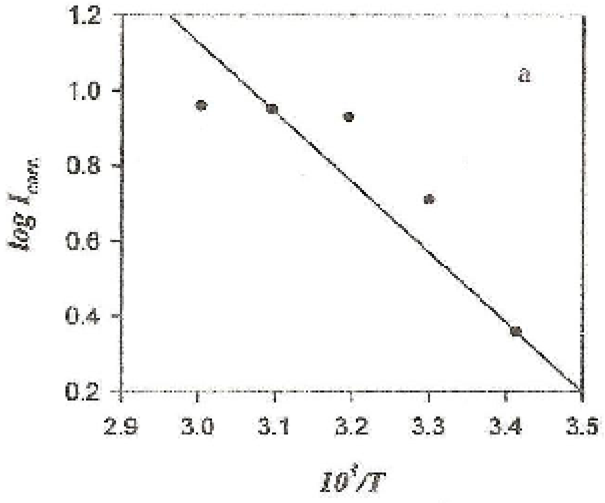

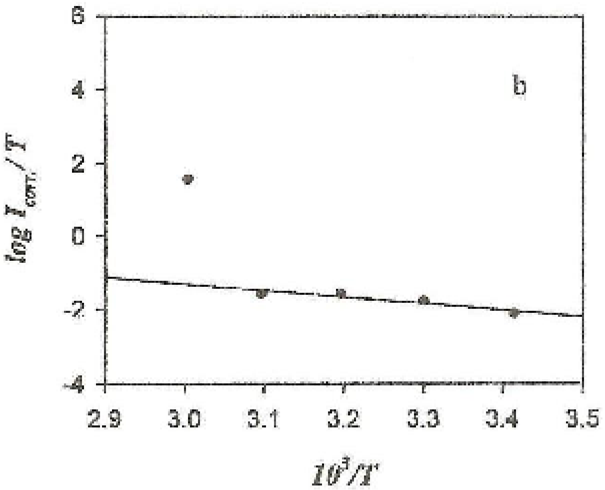

Fig.(14): Plots of **a)** log $I_{corr.}$ **b)** log $_{Icorr.}$/T Vs. (10^3/T) for the corrosion of Al in 0.5M HCl in presence of 24% AZI extract+1×10^{-2} M NaI.

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