Available online at <u>www.pelagiaresearchlibrary.com</u>



Pelagia Research Library

Der Chemica Sinica, 2012, 3(1):236-248



New non ionic polymeric surfactants as corrosion inhibitors for the C- Steel alloy in hydrochloric acid corrosive medium

R.S.Abdel Hameed ^{a,b}; Omar.M.Ismail^e; Fayez M. Eissa ^{b,c}; and, Raed.Ghanem ^{b,d}

Faculty of Science, Department of Chemistry, Al-Azhar University, Cairo, Egypt^a Faculty of Science, Department of Chemistry, Hail University, Hail, KSA^b Aswan Faculty of Science, Aswan 81528 Aswan, Egypt^c Department of chemistry -Faculty of Science, Al-Al Bayte University, Mafraq, Jordan^d Jerash University, Science Faculty,Jerash,Jordon^e

ABSTRACT

Ethoxylation of N-(2-hydroxyethyl) oleiamides,(HA) using Polyethylene Glycol (PEG) in the presence of linking agent and catalyst to give the corresponding amido poly ethelene oxide (AP10000) which separated and characterized by FT-IR, ¹HNMR and ¹³CNMR the corrosion inhibition characteristics of amidopoly ethelene oxide (AP10000) as nonionic polymeric surfactants has been evaluated as a corrosion inhibitor for steel in aerated 2.0 M HCl by weight loss, open circuit potential and potentiodynamic polarization. Effect of temperatures and concentrations on the corrosion rate was also determined. It was found that the inhibition efficiency increased with inhibitor concentration and decrease with temperature. Adsorption was found to follow the Langmuir isotherm. Inhibition efficiency obtained from both polarization and weight loss measurements are in a good agreement. The obtained polarization curves indicate that these compounds act as mixed-type inhibitors. In fact addition of inhibitors molecules to the corrosive medium produces a negative shift in the open circuit potential due to the retardation of the cathodic reaction. Thermodynamics activation parameters were computed.

Keywords: Corrosion; Inhibition; Steel; surfactant, polarization.

INTRODUCTION

The highly corrosive nature of aqueous acid such as sulphuric acid or hydrochloric acid on most metal results on highly economical loose (i.e., it affects the operation of equipment minim loss and results on highly risk on the safety condition), therefore the inhibition of the corrosion of steel in aqueous solutions gains tremendous technological importance due to the increased industrial applications of this material. Use of inhibitor is one of the most practical methods for protection of steel against corrosion in acidic media.

Recently, the inhibition of the corrosion of iron and steel in acidic aqueous solutions by different organic compounds (called adsorption inhibitors) (i.e., such as amines,[1-5] aminothiols [6-8] thiols [9-11] acetylenic compounds [12-17] and azoles) [18-26] have been widely studied [1-14]. On the other hand, ionic surfactants [48, 49] (i.e., such as alkylbetaines [27] N-decylpyridinium [27-30] 2-(alkyldimethylammonio)butanol bromide) were

also reported as good inhibitors for iron corrosion in acidic media. However, very few studies have been devoted to nonionic surfactants as corrosion inhibitors for metals [31].

Surface active agents have been also used as corrosion inhibitors of metals [15–22] in different corroding media. Surfactant inhibitors show many advantages such as high inhibition efficiency, low price, low toxicity and easy production [23–28]. Adsorption of the surfactant on the metal surface can markedly change the corrosion-resisting property of the metal [29-33], therefore the study of the relationship between the adsorption and corrosion inhibition is of great importance. Surfactant adsorption could be attributed to electrostatic interaction, van der Waals interaction, hydrogen bonding and/or salvation and desolvation of adsorbate and adsorbent species [31, 32].

The aim of the present work is to evaluate the inhibition action of amidopolyethyleneoxide on the corrosion rate of mild steel in 2 M HCl corrosive media. in this respect monoethanol amine (EA) was used to convert ethyl oleate into water soluble hydroxyl amid, HA, followed by the reaction of the obtained amide with plolyethelene glycol, PEG, of molecular weight 10000 to gives amido polyethylene oxide non ionic polymeric surfactants. In this work, weight loss and various electrochemical techniques such as open circuit potential and potentiodynamic polarization measurements were carried out to determine the corrosion rates and mechanism from an electrochemical point of view. Also the effect of concentrations and temperature were studied.

MATERIALS AND METHODS

2. Experimental

2.1. Materials

Mild steel specimens were used throughout experiments; mild steel specimens were composed from the following metal, Table 1

Table 1. Composition of the mild steel specimens

Element	С	Mn	Р	Mo	Al	Sn	V	Nb	Ni	Cu	Fe
Weight (%)	0.17	0.057	0.011	0.022	0.011	0.005	0.004	0.007	0.027	0.043	Balance

2.1.1. Aggressive solution.

The aggressive solution (2 M HCl) was prepared by appropriate dilution of analytical grade 36% HCl with double distilled water.

2.1.2. Synthesis

Elemental and spectroscopic analyses were carried out in the Micro Analytical Center of Cairo University. The fine chemicals were purchased from Aldrich Co. and the organic solvents were of spectroscopic grades. The reactions were monitored using TLC and all the resultant compounds were crystallized and then extra purified using a column chromatography technique.

Synthesis of N-(-2-hydroxyethyl)-octadec-10-enamide (3)

Ethyl-octadec-10-enoate (1) (0.01 mol) and an equimolar ratio of 2-aminoethanol (2) were refluxed in ethanolic solution of sodium ethoxide for 2 hours at 100 C°. The reaction mixture was cooled and ethanol was evaporated. The residue was extracted via ethyl acetate and washed three times with bi distilled water. The organic layer was separated, dried over anhydrous sodium sulfate, filtered off to remove sodium sulfate and ethyl acetate was evaporated to obtain oily viscous products **3**. This compound was extra purified using column chromatography, silica gel, eluting with ethyl acetate/hexanes (20/80).

3: (*Y*: 69%); *Mol. F.:* C20H39NO₂; *Mol. Wt.:* 325.53; *m/z* (*FABMS*): 326.3; *Elemental analysis:* (*Calculated %*) C: 73.79, H: 12.08, N: 4.30, O: 9.83 (*Found %*) C: 73.83, H: 13.00, N: 4.25, O: 9.81; *HNMR* (400 MHz, DMSO-d6):0.89 (t, 3H-CH₃), 1.11-1.37 (m, 20H-10CH₂), 1.54 (p, 2H-CH₂), 1.91 (q, 4H-2CH₂), 2.08 (t, 2H-CH₂-CO), 3.29 (t, 2H-CH₂-NH), 3.76 (t, 2H-CH₂-CO), 4.16 (s, OH), 5.42 (q, 2H-CH=), 6.93 (s, NH). *CNMR* (400 MHz, DMSO): 11.90 (CH₃), 22.19 (CH₂), 25.63 (CH₂), 28.40 (CH₂), 29.45 (CH₂), 30.14 (6CH₂), 31.80 (CH₂), 33.70 (2CH₂-CH=), 36.44 (CH₂-CO), 41.32 (CH₂-NH), 61.14 (CH₂OH), 130.50 (2CH=), 172.66 (C=O).

Synthesis of N-(-2-hydroxyethyl)-octadec-10-enamido-polyethylene oxide (4)(AP10000)

In a 250 ml three neck round bottomed flask, fitted with condenser, mechanical stirrer and thermometer, 0.01 mole of N-(-2-hydroxyethyl)-octadec-10-enamide 3, equimolar ratio of poly ethylene glycol 10000 (PEG10000), bimolar ratio of β , β '-dichlorodiethyl ether (DCDEE), and bimolar ratio of sodium hydroxide, in 30 mL xylene as solvent, were agitated and heated at 170 C°. At this temperature, the reaction mixture was maintained for 5 hours and the reaction course could be monitored by depositing of sodium chloride **[34]**. The reaction mixture was cooled and xylene was evaporated. The residue was extracted via ethyl acetate and washed three times with bi distilled water. The organic layer was separated, dried over anhydrous sodium sulfate, filtered off to remove sodium sulfate and ethyl acetate was evaporated to obtain oily viscous product **4**. This compound was extra purified using column chromatography, silica gel, eluting with ethyl acetate/hexanes (15/85).

4: *HNMR* (400 MHz, DMSO-d6):0.99 (t, 3H-CH₃), 1.29-1.41 (m, 20H-10CH₂), 1.59 (p, 2H-CH₂), 2.15 (q, 4H-2CH₂), 2.37 (t, 2H-CH₂-NH), 3.51-3.76 (m, 6H-3CH₂), 4.37 (s, H-OH), 5.37 (q, 2H-2CH=), 7.02 (s, H-NH),



Fig. 1. Chemical structure of AP10000(4) inhibitor and Scheme of the synthesis

2.2. Weight loss technique

Coupons of steel of 2 x 2 x 0.1cm dimensions were used as test specimens, the specimens were polished by 410 and 610 emery papers, respectively, degreased with acetone, washed with distilled water and finally dried using two filter papers. The described treatment was carried out immediately before each measurement. The specimen of the given metal was immersed in 100 ml of the test solution (i.e., 2 M HCl) with different inhibitor concentration (AP10000), samples maintained in test solution up to 10 hours. Experiments were carried out under different temperature 25, 30, 35, 40 and 45° C

2.3. Open circuit potential

The potential of steel electrode was measured against saturated calomel electrode (SCE) in 2 M HCl solution in absence and presence of different concentrations of the inhibitor at 25 °C. All measurements were carried out using Multi-tester until the steady-state potentials are reached. Temperature effect was also studied using concentration of 1000 ppm of inhibitor.

2. 4. Polarization measurements

Platinum electrode and a saturated calomel (SCE) electrode were used as auxiliary and reference electrodes, respectively. The samples of steel, 1 cm², were first immersed into the solution for 30 minutes to establish a steady state open circuit potential. The effect of inhibitor on steel corrosion was determined by measuring corrosion rate in different concentration of AP10000. For the evaluation of inhibitor concentration effects on inhibition efficiency (the protection of corrosion) experiments were carried out in 2 M HCl in the absence and presence of various concentrations of inhibitors. The cell was left open to air at room temperature (25 C). All potential values were reported in millivolt (SCE). The electrochemical polarization was also done after 30 min immersion in inhibited solution.

The effect of temperature on corrosion inhibition of AP10000 was investigated at five different temperatures.

RESULTS AND DISCUSSION

3.1. Weight loss measurements

Effects of inhibitor concentration on inhibition efficiency

Effects of the inhibitor concentrations (AP10000) on the steel corrosion rate were summarized on **Table 1**, and graphically represented in **Figure 2**.



Fig. 2. Weight loss-time curves of steel in 2.0 M HCl in absence and presence of different concentrations of AP10000 inhibitor.

Figure 2 shows the results of the Weight-loss time curves of steel in 2.0M HCl in presence of different concentration of AP10000 inhibitor

In general, a decrease in the weight loss of steel occurred in the presence of a different concentration of additive compared to the blank was observed.

Data in **Table 2** used to calculate the values of surface coverage area(θ), efficiency of inhibitor (P) were calculated using equations 1 and 2 [**35-39**]

$$\theta = \frac{W^{\circ} - W}{W^{\circ}}$$
(1)
$$P(\%) = \frac{W^{\circ} - W}{W^{\circ}} \times 100$$
(2)

Where W° and W are the weight loss in the absence and presence of inhibitor, respectively. W is the loss of weight after corrosion (mg), A the total area of the specimen (cm²), t the corrosion time (hr), d the specimen density (g/cm³).

Corrosion rates (CR) of steel (equation 3) were calculated by considering the total affected sample area and immersion times.

$$CR(mpy) = \frac{3445.15W}{A.d.t} \tag{3}$$

As we can see from table 2, the addition of AP10000 inhibitors results in a remarkable decrease of the corrosion rate of steel. In fact these results support the inhibitive effect of the added AP10000 on steel corrosion in the acidic solution. Moreover, as we can see from **Table 2**, increasing the concentration surfactant increases surface coverage area (θ) and inhibition efficiency (P%).

Table 2. Effect of AP10000 concentrations on steel corrosion in 2.0 M HCl at 25°C

	polarization							
Conc (ppm)	$W (mg/cm^2)$	θ	P(%)	CR (mpy)	i_{corr} (mA/cm ²)	θ	P(%)	CR (mpy)
Blank	0.4681			185.35	0.374			175.54
100	0.1652	0.58	58	75.75	0.1025	0.71	71	52.86
300	0.1372	0.66	66	63.57	0.0835	0.75	75	40.84
500	0.1263	0.68	68	56.68	0.0794	0.81	81	30.45
700	0.0998	0.75	75	47.46	0.0632	0.86	86	21.81
1000	0.0673	0.84	84	31.92	0.0428	0.90	90	17.31

Temperature effects on inhibition efficiency were also investigated, **Table 3** summarize the results of surface coverage area (θ), inhibition efficiencies (P%), and corrosion rates (CR) of AP10000 for the corrosion of steel at different temperature. Results of the effect of AP10000 surfactant on the corrosion behavior of steel in 2.0M HCl solution at different temperatures using weight loss technique are shown in **Figure 3**. It has been found that the weight loss of steel increased with increasing temperature, and the corrosion rate of steel increases with increasing temperature, and the corrosion rate of steel increases with increasing temperature.

Wt. loss						Polarization			
	Temp. (°C)	$W (mg/cm^2)$	θ	P (%)	CR (mpy)	i_{corr} (mA/cm ²)	θ	P (%)	CR (mpy)
	25	0.4681			185.35	0.374			175.54
Å	30	0.4823			189.45	0.468			208.64
lan	35	0.4972			203.35	0.527			240.28
В	40	0.5042			209.88	0.592			262.23
	45	0.5234			218.67	0.665			293.64
_	25	0.0673	0.84	84	31.92	0.0428	0.90	90	17.31
00	30	0.1054	0.75	75	48.85	0.0501	0.89	89	24.25
10	35	0.1282	0.69	69	61.75	0.0589	0.87	87	25.83
AP	40	0.1635	0.65	65	77.48	0.0646	0.86	86	32.21
	45	0.2187	0.58	63	99.56	0.0794	0.84	85	38.13

Table 3.	Effect of tem	perature on steel	corrosion in	absence and	presence of 1000	00000 ppm of AP10000



Fig. 3. Weight loss-time curves of steel in 2.0 M HCl in presence of 1000 ppm of AP10000 inhibitor at different temperatures.

3.2. Open circuit measurements

Open Circuit Corrosion Potential (OCP) measurements were carried out in a separate cell with steel coupon as a working electrode and saturated calomel (SCE) as reference electrode. OCP of steel were recorded in 2.0M hydrochloric acid in the absence and presence of different concentration of AP10000 inhibitor at 25°C. **Figure 4**. Show the potential-time curves of steel in 2.0 M HCl in absence and presence of different concentrations of AP10000 inhibitor at 25 °C. The corrosion potential of steel electrode in 2.0M hydrochloric acid solution for the blank sample (blank curve) tends towards more negative value firstly, giving rise to short step. This behavior represents the breakdown of the pre-immersion, air formed oxide film present on the surface. This is followed by the growth of a new oxide film inside the solution, so that the potential was shifted again to more noble direction until steady state potential is established. Addition of the inhibitor molecules produce a positive shift in the potential and as the concentration of the inhibitor increases, the corrosion potential was shifted to more noble direction. In fact, it is important to mention that the addition of inhibitors molecules to the corrosive medium produces a negative shift

in the open circuit potential due to the retardation of the cathodic reaction. Moreover the steady-state values are always more negative than the immersion potential, which suggests that, before the steady state condition is, achieved the steel oxide film has to dissolve.



Fig. 4. Potential-time curves of steel in 2.0 M HCl in absence and presence of different concentrations of AP10000 inhibitor at 25 C.



Fig . 5. Potential-time curves of steel in 2.0 M HCl in presence of 1000 ppm of AP10000 inhibitor at different temperatures.

Figure 5 show typical potential time versus open circuit potential plots for steel in 2.0M HCl and presence of 1000 ppm AP10000 inhibitor at different temperatures against (SCE). The steady state potentials of steel shifted to more noble values with decreasing in temperature, this behavior may be due to the decreasing amount of adsorbed inhibitor on the surface of steel when the temperatures increased.

3.3. Polarization measurements

Figure 6. Shows the anodic and cathodic polarization curves of steel in 2.0 M HCl solutions in presence and absence of AP10000. Values of the surface coverage area (\Box), efficiency of inhibitor (P%) and corrosion rate (CR) were calculated according equations (4-6), respectively [40,41]

$$\theta = \frac{i_{corr}^{\circ} - i_{corr}}{i_{corr}^{\circ}} \tag{4}$$

$$P\% = \frac{i_{corr}^{\circ} - i_{corr}}{i_{corr}^{\circ}} \times 100$$
⁽⁵⁾

$$CR(mpy) = \frac{0.1288i_{corr}.Eq.wt}{d}$$
(6)

Where i_{corr} is the corrosion current density (μ A/cm²), *d* the specimen density (g/cm³)

The corrosion currents (i_{corr}) at different concentration of AP10000 were tabulated in **Table 2**, as it could be expected the inhibition. Results of the inhibition efficiencies revealed the good inhibiting action of AP10000 at high concentration.



Fig.6. Polarization curves of steel in 2.0 M HCl in presence of different concentration of AP10000.

Also **Figure 7** Shows the Anodic and cathodic polarization curves for electrodes in 2.0 M HCl acid in the presence 1000 ppm of AP10000 inhibitor at various temperatures. Results of the corrosion current, corrosion rate and inhibition efficiencies at different temperatures are listed in **Table 3**. The values of corrosion current density and corrosion rate were found to increases with temperature. Moreover, the inhibition efficiency decreases with an increase in experimental temperature, this is attributed to the dissolution of the metal surface and decreasing of the inhibitors layer on the surface, the highest inhibition efficiency obtained at 25 °C.



Figure 7. Polarization curves of steel (in 2.0 M HCl) in presence of 1000 ppm of AP10000 at different temperatures.

3.4. Adsorption isotherms

Corrosion inhibition could be attributed to the adsorption of the AP10000 inhibitor on the surface of steel, results of surface coverage at different concentration of AP10000 obtained from the two different techniques (weight loss and polarization measurements) were used to study the type of adsorption isotherm, Adsorption isotherms such as Langmuir, Frumkin, Freundlich, Temkin, Florry-Huggins, and El-awardy could be used to elucidate the inhibition mechanism of the inhibitors. The correlation coefficient was used to choose the adsorption isotherm that best fits the experimental data [42-44]. Results here were completely fit with Lagmuir isotherm (i.e., data fit straight line (r^2 >0.98) with a slope nearly equal unity, this result is corresponds to Langmuir equation, Figure 8.



Fig. 8. Curves fitting of the corrosion data of steel in 2.0 M HCl in the presence of AP10000 to Langmuir isotherm.



Fig. 9. Variation of the prediction efficiency with temperature

3.5. Activation Energy of corrosion

Corrosion is an electrochemical phenomenon and consequently follows the laws in chemical kinetics. The corrosion rate increases with temperature as a result of decreasing the apparent activation energy, Ea, of the charge transfer reactions. The increase of temperature enhances the rate of H^+ ion diffusion to the metal surface beside the ionic mobility, which increases the conductivity of the electrolyte. The effect of temperature on the inhibition efficiency of corrosion inhibitors is important in elucidation of the mechanism and kinetics of their action. **[45]**. Analysis of the effect of temperature on the protection efficiencies (P%)(**Figure9** and **Table2**) shows that the inhibition efficiency decreases with an increase in temperature.

This is due to decreasing surfactant adsorption at higher temperatures. This suggests that physical adsorption may be the type of adsorption of the inhibitor on the metal surface. **Figure10** shows the relation between corrosion rate (CR) of mild steel and temperature in both acid solutions added with surfactants. According to Arrhenius plot

$$Log CR = (E_a/2.303RT) + A$$

Where E_a is the apparent activation energy and A is a constant. **Table 4** shows the apparent activation energies (E_a) of steel in HCl are 32.41 and 29.87 for weight loss and polarization respectively in the presence of AP10000 molecules higher activation energies is observed. **Table 4** shows that the apparent activation energies (E_a) increase by increasing the concentrations of the used inhibitor.



Fig .10. Arrhenius plots of the corrosion of C-steel in 2M HCl in absence and presence of 1000 ppm of the used inhibitor.

An alternative form of Arrhenius equation is the transition state equation.

Corrosion rate = $(RT/Nh) \exp(\Delta S^0/R) \exp(-\Delta H^0/RT)$

Where R is the ideal gas constant, h the Plank's constant, N the Avogadro's number, ΔS^0 and ΔH^0 are respectively the entropy and the enthalpy of activation.

The plots of logCR/T versus 1/T for different concentrations of the used inhibitor shows linear variation **Figure 11** with a slope of $(-\Delta H^0/2.303R)$ and the intersection of $(\log R/Nh + (\Delta S^0/2.303R))$. The values of ΔH^0 and ΔS^0 were calculated and tabulated in **Table 4**. This table indicates that the addition of AP10000 to the corrosive medium leads to an increase in the ΔH^0 values; so these molecules increase the height of energy barrier for the corrosion process.

In addition, the values of entropy of activation ΔS^0 are large and negative. This implies that the activated complex in the rate determining step represent association rather than dissociation meaning that the decrease in a disordering takes place on going from reactants to activated complex [46,47].



Fig.11. Transition state plots of the corrosion of C-steel in 2M HCl in the absence and presence of 1000 ppm of the used inhibitor

Fable 4. The values of activation parameters $E_a, \Delta S^0, \Delta H^0$ for mild steel in 2 M HCl in the absence a	nd
presence of different concentrations of Amido poly(ethylene oxide)(AP10000)	

Tachniques	Concentration	Ea	ΔH^0	ΔS^0	
Techniques	(ppm)	(KJmol ⁻¹)	(KJmol ⁻¹)	(KJmol ⁻¹)	
	blank	32.41	26.53	- 213.54	
	100	48.23	29.42	-196.54	
	300	51.47	33.74	-182.43	
Weight loss	500	56.86	37.42	-175.86	
weight loss	700	62.14	39.84	-162.46	
	1000	68.75	41.31	-153.42	
	blank	29.87	24.73	-198.24	
	100	46.75	27.46	-175.42	
	300	49.84	31.54	-163.24	
Polarization	500	53.93	34.32	-154.63	
	700	58.21	34.86	-146.75	
	1000	61.78	37.64	-142.86	

CONCLUSION

In this paper we studied the inhibition of the steel corrosion by AP10000 in 2.0M hydrochloric acid corrosive medium. Three techniques were used (i.e. open circut, polarization and f weight loss measurements). Inhibition efficiency obtained from both of them is in a good agreement. In fact, the polarization curves indicate that these compounds act as mixed-type inhibitors.

Results obtained from the experimental data shows that AP10000 acts as inhibitor for the corrosion of steel in 2.0 M HCl. Its inhibition efficiency directly dependent on the concentration of AP10000 inhibitor, on the other hand it is inversely temperature dependent. Corrosion inhibition behavior of AP10000 is attributed to the adsorption of AP10000 on steel surface from 2.0 M HCl, the adsorption isotherm mechanism was found to obeys the Langmuir

adsorption isotherm. the apparent activation energies (E_a) increase by increasing the concentrations of the used inhibitor.

REFERENCES

- [1] E.E. Foad El Sherbini, Mater. Chem. Phys., 1999, 60, 286
- [2] J.M. Bastidas, P. Pinilla, E. Cano, J.L. Polo, S. Miguel. Corros. Sci., 2003, 45, 427
- [3] M.A. Migahed, E.M.S. Azzam, A.M. Al-Sabagh, Mater. Chem. Phys., 2004, 85, 273
- [4] C. Jeyaprabha, S. Sathiyanarayanan, G. Venkatachari, J. Electr. analytical Chem, 2005, 583 232
- [5] Mahmoud M. Saleh, Mater. Chem. Phys., 2006, 98, 83
- [6] M. Kissi, M. Bouklah, B. Hammouti, M. Benkaddour, App. Surf. Sci., 2006, 252, 4190
- [7] R. Fuchs-Godec, Colloids and Surfaces A: Physicocheml. Eng. Aspects, 2006, 280 130
- [8] S.A. Ali, H.A. Al-Muallem, M.T. Saeed, S.U. Rahman, Corros. Sci., 2008, 50, 664
- [9] Xianghong Li, Shuduan Deng, Hui Fu, Guannan Mu, Ning Zhao, App. Surf. Sci., 2008, 254, 5574
- [10] Ling-Guang Qiu, Yun Wu, Yi-Min Wang, Xia Jiang, Corros. Sci., 2008, 50, 576
- [11] I.B. Obot, N.O. Obi-Egbedi, Corros. Sci., 2010, 52, 198
- [12] Yongming Tang, Xiaoyuan Yang, Wenzhong Yang, Yizhong Chen, Rong Wan, Corros. Sci., 2010, 52, 242
- [13] I.B. Obot, N.O. Obi-Egbedi, Corros. Sci., 2010, 52, 282
- [14] B. Sanyal, Organic compounds as corrosion inhibitors in different environments a review, Prog. Org. Coat., **1981**, 9, 165.
- [15] H. Luo, Y.C. Guan, K.N. Han, Corros. Sci., 1998, 54, 619.
- [16] M.N. Shalaby, M.M. Osman, Anti-Corros. Methods Mater, 2001, 48, 309.
- [17] A.K. Maayta, M.B. Bitar, M.M. Al-Abdallah, Br. Corros. J., 2001, 36, 133.
- [18] M. El Achouri, M.R. Infante, F. Izquierdo, S. Kertit, H.M. Gouttaya, B. Nciri, Corros. Sci., 2001, 43, 19.
- [19] R. Guo, T. Liu, X. Wei, Colloids Surf., A Physicochem. Eng. Asp., 2002, 209, 37.
- [20] V. Branzoi, F. Golgovici, F. Branzoi, Mater. Chem. Phys., 2002, 78, 122.
- [21] M.M. Osman, R.A. El-Ghazawy, A.M. Al-Sabagh, Mater. Chem. Phys., 2003, 80, 55.
- [22] M.A. Migahed, E.M.S. Azzam, A.M. Al-Sabagh, Mater. Chem. Phys., 2004, 85, 273.
- [23] D.N. Singh, A.K. Dey, Corrosion, 1993, 49, 594.
- [24] G. Banerjee, S.N. Malhotra, Corrosion, 1992, 48, 10.
- [25] S.T. Arab, E.A. Noor, Corrosion, 1993, 49, 122.
- [26] B.S.Shylesha, T.V.Venkatesha, B.M.Praveen, advances in applied Science Research, 2011, 2 (2) 333
- [27] Y. Chen, Y. Wang, G. Zhang, Daily Chem. Ind., 1986, 2, 56.
- [28] L. Shi, H. Song, Daily Chem. Ind., 1987, 1, 9.
- [29] F. Bentiss, M. Traisnel, M. Lagrene'e, Corros. Sci., 2000, 42, 127.
- [30] M.A.B. Christopher, A.R.G. Isabel, P.S.M. Jenny, Corros. Sci., 1994, 36, 15.
- [31] T.J. Haley, J. Pharm. Sci., 1965, 54, 633.
- [32] M.Z.A. Rafiquee, Nidhi Saxena, Sadaf Khan, M.A. Quraishi, Mater. Chem. Phys., 2008, 107, 528
- [33] N.O.Shaker, E.E.Badr, E.M.Kandeel, Der Chemica Sinica, 2011, 2, 4, 26
- [34] Reda Abd El Hameed, Ph.D., Thesis, Al Azhar Uni., (Cairo, Egypt, 2006)
- [35] Nguyen Dang Nam, Min Jun Kim, Young Wook Jang, Jung Gu Kim, Corros. Sci, 2010, 52, 14
- [36] C.M. Dacres, R. A. Sutula, and B. F. Larrick, J. Electrochem. Soc, 1983, 130, 981.
- [37] S.A. Umoren, E.E. Ebenso, Mater. Chem. Phys, 2007, 106, 387.
- [38] R.O. Rihan, S. Nešić, Corros. Sci, 2006, 48, 2633.
- [39] P.C. Okafor, M.E. Ikpi, I.E. Uwah, E.E. Ebenso, U.J. Ekpe, S.A. Umoren, Corros. Sci, 2008, 50, 2310.
- [40] W. H. Ailor, "Handbook of Corrosion Testing and Evaluation" John Wiley & Sons, Inc., New York, **1971**, pp. 173.
- [41] C. M. Dacres, R. A. Sutula, and B. F. Larrick, J. Electrochem. Soc, 1983, 130, 981.
- [42] R.S.Abdel Hameed, Advances in Applied Science Research, 2011, 2, 3, 483.
- [43] R.S.Abdel Hameed, H.I.Alshafy, O. Farghaly, Research & Reviews in Electrochemistry, Accepted , May, 2011.
- [44] Sayed S. Abd El Rehim, Mohammed A. Amin, Hesham T.M. Abdel-Fatah, *Corrosion Science*, 2009, 51, 882.
- [45] E.E.Foad El- Sherbini, S.M.Abdel Wahaab, M.Deyab, Mater Chem. Phys., 2005, 89, 183.
- [46] G.K.Gomma, M.H.Wahdan, Mater Chem. Phys., 1995, 30, 209.
- [47] L. S. L, Y. G. Wang, S. H. Chen, *Corros. Sci.*, **1999**, 41, 1769.
- [48] A.A.El Maghraby, T.Y.Soror, Advances in Applied Science Research, 2010, 1, 2, 143.
- [49] A.A.El Maghraby, T.Y.Soror, Advances in Applied Science Research, 2010, 1, 2, 156.