Poly (m-aminophenol) as a Corrosion Inhibitor for Low Carbon Steel (AISI C1010)

A. Gad[a], A. Abd-EL- Fattah[b], H. EL-Nagar[c].

[a&b]Department of Materials Science, Institute of Graduate Studies and Research, Alexandria University, 163 Horrye Avenue, EL-Shatby, P.O.Box 832, Alexandria ,Egypt.

[c]Alexandria National Refining and Petrochemicals Co. (ANRPC). Alexandria, Egypt.

Abstract

This study involves a preparation of poly (m-aminophenol) by chemical oxidative polymerization of m-aminophenol (m-AP) using ammonium persulfate (APS) or potassiumdichromate ($K_2Cr_2O_7$) as oxidative initiators and sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) as dopants with polymer yield 98%. It is found that poly (m- aminophenol) is insoluble in common organic solvents, aqueous NaOH and partially soluble in conc. HCl and H_2SO_4. The prepared polymer was characterized by FTIR, TGA, XRD, and SEM. The anti-corrosion behavior of poly (m- aminophenol) (30, 60,120 ppm) at room temperature in low carbon steel (AISI C1010) has been investigated in aqueous HCl (1.5 M) and NaCl (3.4 M) solutions using electrochemical impedance spectroscopy (EIS) and weight loss measurements.

From weight loss measurements it was found that the corrosion inhibitor efficiencies (%IE) of PmAP of 30, 60,120 ppm in aqueous HCl solution (1.5 M) are (86.5, 88.6, 85.7 %) respectively and it is in aqueous solution of NaCl (3.4 M) are (93.1, 93.9, 92.1 %) respectively. From electrochemical impedance spectroscopy (EIS) it was found that the corrosion inhibitor efficiency (%IE) of PmAP (30, 60,120 ppm) in aqueous HCl solution (1.5 M) is (91.4, 94.0, 90.4 %) respectively. From economic comparison between poly (m- aminophenol) with other inhibitors it can be seen that the poly (m- aminophenol) inhibitor has lower economic cost and higher saving (52 – 74 %) compared to the other inhibitors which are used in the Egyptian market.

Keywords: Chemical synthesis and characterization of poly (m-aminophenol), Corrosion inhibitor, Low carbon steel, EIS

1. Introduction

Polymers provide one of the most versatile groups of materials and find widespread use as plastics, rubbers, fibers, adhesives and coatings. The advantages of these materials, especially their ease of fabrication and low density, for use in an ever widening range of products have become more appreciated by designers and engineers. However, some inherent deficiencies in these materials have prevented their employment in certain areas of application. Polymers show extreme sensitivity to temperature. Most importantly, owing to the intrinsic flexibility of their molecular chains, they exhibit very low softening points. A further restriction to their use at high temperature is their susceptibility to atmospheric oxidation when used at elevated temperatures. This oxidation usually leads to polymer chain scission by way of a free radical chain reaction.

Among all of the electrically conductive polymers, polyaniline (PANI) is a particularly attractive material because it has moderately high conductivity upon doping with acids. It is easily synthesized by chemical or electrochemical oxidation of aniline, and has good thermal and oxidative stability [1]. Polyaniline, which has wide applicability as an intrinsically conducting polymer shows poor processability [2]. Much effort has been made for chemical and electrochemical polymerization of aniline with various substituted groups [3-6] to improve its processability. Common derivatives include ortho and meta substituted aniline with –OCH$_3$,-CH$_3$, -SO$_3$H, -Cl, -F, -I and –CH$_2$-CH$_3$ groups. The polymers of substituted aniline have less conductivity than polyaniline due to repulsion factor. Recently, polymers have been synthesized chemically or electrochemically using ortho -NH$_2$ [7- 10] and –OH [11 - 14] groups substituted anilines. Unlike other derivatives of aniline, both the amine and hydroxyl substituents in these two monomers can be oxidized.The monomer m-AP was reported to be electrochemically polymerized in acid medium. In chemical polymerization, various redox reagents were used in acidic medium, e.g., cupric

chloride, barium manganate, ammonium persulfate and sodium dichromate. Only a few reports are available for the chemical polymerization of m-AP and o-AP in acid medium [15-18].

The conducting polymers based on aromatic or heterocyclic monomers like aniline, pyrrole, thiophene, and their derivatives have attracted a great attention in recent years .The polyaminophenol used as corrosion inhibitors for iron alloys will have a desirable impact an environmental and health protection [19-٢1].

Electrochemical impedance spectroscopy (EIS) has become a well established tool for the study of corrosion and degradation of metallic materials through electrochemical reactions. EIS is now the method of choice for characterizing any system in which the electrical behavior is dependent on several different physic-chemical processes occurring on materials surfaces at different rates. It also has the advantage of allowing the rapid determination of the corrosion rate of a sample without requiring long-term testing.

An electrode interface undergoing an electrochemical reaction is typically analogous to an electronic circuit consisting of a specific combination of resistors, capacitors, and inductors. In a galvanic cell, the initial corrosion current is defined by

$$\mathbf{I_{initial}} \quad = \quad \mathbf{E^{o}_{c}} \quad - \quad \mathbf{E^{o}_{a}/R} \quad = \quad \mathbf{\Delta V^{o}/R}$$
…………………………………………………………...…..………….(1)

Where $\mathbf{E^{o}_{c}}$ and E^{o}_{a} are the open circuit cathode and anode potentials respectively. R is the total resistance which in corrosion is made up mainly of polarization resistance, solution resistance, and charge transfer resistance to current flow. The corrosion current can be obtained from the polarization resistance via the stern-geary equation given as:

$$\mathbf{I_{corr}=1/R_{P}\ [\beta_{a}\ \beta_{c}/2.3(\beta_{a}\ \beta_{c})]}\ …………… \ ……………...….………(2)$$

Where $\mathbf{I_{corr}}$ is the corrosion current density in A/cm2, β_{a} is the anodic tafel coefficient; β_{c} is the cathodic tafel coefficient and $\mathbf{R_{P}}$ is the polarization resistance (ohm.cm2). The tafel coefficient is generated from the anodic and cathodic branches of the potential current diagrams generally known as the tafel plots.

$$\mathbf{C_{rate}\ (mill/year) = K_{r}.I_{corr}\ \epsilon}\ …………………..………………....……..….(3)$$

Where C_{rate} is the corrosion rate in milli-inches or mills per year (mpy).When a small potential is applied, electrochemical impedance spectroscopy (EIS) uses the impedance frequency response of a corroding system, to generate a plot of the

magnitude of the real impedance against the imaginary impedance component. This is known as a complex plane plot or nyquist plot. The impedance is generated in real and imaginary format according to the equation

$$Z=R-jX……………………….…………………..………(4)$$

Where Z is the impedance response, R is the real impedance, X is the magnitude of the imaginary component, and j is a complex number equivalent to the square root of-1. Data from the nyquist and tafel plots are used by EIS software to generate the equivalent electrical circuits (EEC) which approximates the physical phenomena occurring on the working electrode surface during corrosion [22].

First aim of this study is the preparation of poly (m-aminophenol) by chemical oxidative polymerization of m-aminophenol (m-AP) using ammonium persulfate (APS) or potassium dichromate ($K_2Cr_2O_7$) as oxidative initiators and sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) as dopants. And second aim was to investigate the corrosion behavior of a PmAP deposited on low carbon steel (AISI C1010) in NaCl solution (3.5 M) and HCl (1.5 M) using electrochemical impedance spectroscopy (EIS) and weight loss measurements. And finally a comparison of poly (m-aminophenol) with other inhibitors which used in the Egyptian market.

II. Materials & Methods

II.1. Materials

m-aminophenol (m-AP) from Loba Chemicals, India, Mumbai was used without further purification. Hydrochloric acid extra pure (Riedel-Dellen), sulphuric acid (Adwic), toluene (Adwic) and ethanol absolute, iso propyl alcohol, iso butyl alcohol, ammonium peroxodisulphate (APS) and cyclohexane from BDH (England) were used as received. Methanol absolute, sodium hydroxide and 2, 2, 4 trimethyl pentane were purchased from Panreac (Spain). Potassium dichromate (Merck), carbon tetrachloride (Prolabo) and chloroform (Prolabo) were used. Dimethylsulfoxide (DMSO) was purchased from "El-Gomhoria" Chemical Company (Egypt). Low carbon steel (AISI C1010). The chemical composition of low carbon steel (AISI C1010 in Table (1).

Table 1: Chemical composition of low carbon steel specimens (AISI C1010)

% C	% Mn	% Si	% P	% Cu	% Ni	% Cr	% S	% V	% Fe
0.05- 0.35	1.21	0.23	0.02	0.016	0.02	0.02	0.02	0.003	Balance

II.2. Preparation of poly (m – aminophenol) with different dopants and initiators

Oxidative chemical polymerization of m-aminophenol (m-AP) monomer was carried out at room temperature by addition of 0.4 M of m-AP to 100 ml of water contained 0.5 , 1.0 , 1.5 , 2.0 or 4.0 M of hydrochloric acid or 0.5 , 1.0 , 1.5 , 2.0 or 3.0 M of sulphuric acid with continuous stirring for one hour. Ammonium peroxodisulphate (APS) (0.06 , 0.1 , 0.4 or 0.8 M) or potassium dichromate (0.06 , 0.1 , 0.14 or 0.3 M) as oxidant dissolved in 25 ml of aqueous acidic medium was slowly poured into the polymerization bath and the solution was left for 2 h with continuous stirring. The solution changed to black color, and left for 10 h at room temperature with constant stirring. A black precipitate of poly (m-aminophenol) was obtained. The precipitate was filtered and washed with excess amount of deionized water and methanol to remove the excess of dopant and oxidant. PmAP powder was then dried at 60° C in a vacuum oven for about 24 h.

II.3. Solubility

The solubility of poly (m-aminophenol) (PmAP) was carried out using methanol absolute, ethanol absolute, isopropyl alcohol , isobutyl alcohol , carbon tetrachloride , chloroform, cyclohexane , toluene , dimethylsulfoxide (DMSO), 2,2,4 trimethylpentane , aqueous NaOH, conc.HCl and conc. H_2SO_4 .

II.4. Techniques of polymers characterization and measurements

II.4.1. FTIR spectra

Polymeric samples were prepared as potassium bromide (KBr) disks and examined by Perkin-Elmer BX II FTIR spectrophotometer. The spectra were recorded in the wavenumbers range of 4000-400 cm^{-1}.

II.4.2. X-ray diffraction

X-Ray diffraction scans were carried out using X-ray 7000 Shimadzu at room temperature in the range of 10 to 80 degree to determine the degree of crystallinity in the polymers. Bragg angle was (2 Ө). The X-Ray source utilized was Cu target with settings of 30 kV, 30 mA, and scan speed 4 deg/min.

II.4.3. Scanning electron microscope (SEM)

High-resolution SEM "JEOL JSM 6360 LA", Japan was used to get the morphology and microstructure of the polymer samples.

I.4.4. Thermal analysis measurements

Thermogravimetric analysis (TGA) measurements were carried out using TA-SDT Q600 thermal analysis system. (5 -7) mg of a sample was placed in a platinum pan and heated from 25 to 700°C with a heating rate 10 °C / min. in air 100 ml/min.

II.4.5. Electrical measurements

Disks of thickness $((0.5 - 1.5) *10^{-4} cm)$ and diameter (1.3 cm) were obtained from fine powder compressed at 80 KN for electrical conductivity measurements. The electrical conductivity (σ) $(\Omega^{-1} cm^{-1})$ was calculated from the following equation:

$$\sigma = 1/\rho = L/(R*A) \quad \text{(5)}$$

Where L is the thickness (cm) of the sample, ρ (Ω cm) is the electrical resistivity of the sample, R is the resistance (Ω) of the sample and A (cm^2) is the area of the sample.

The electrical conductivity of PmAP samples was measured at room temperatures by a digital electrometer (Keithley 616).

II.4.6. Corrosion measurements

II.4.6.1.Weight loss method measurements

The corrosion performance of PmAP in low carbon steel (AISI C1010) was studied in aqueous HCl (1.5 M) and NaCl (3.4 M) solutions using weight loss measurements. The corrosion rate were calculated by using the following equation

$$\text{Corrosion rate (MPY)} = [143.7*10^3*W*24] / [D*T*A] \quad \text{(6)}$$

Where W= final weight loss (gm), D= density (7.87 gm/cm^3), A= surface area (20.9 cm^2), T= total hours exposed.

$$IE\% = 100*(W_0 - W_I/W_0) \quad \text{(7)}$$

Where W_0 and W_1 values of the weight loss (gm) of the carbon steel in absence and presence of inhibitor respectively.

II.4.6.2. Electrochemical impedance spectroscopy (EIS)

A three –electrode cell assembly consisting of working electrode (the mild steel to be tested with cross section area is 1.77 cm^2), (figure 1), counter electrode (a platinum mesh of negligible impedance) and reference electrode (saturated calomel electrode). The temperature of the electrolyte at room temperature. The corrosion inhibitor efficiency (%IE) was calculated by using the following equations [23, 24].

$$\text{IE\%} = 100*(\text{Rct}_{(Blank)} - \text{Rct}_{(PmAP)} / \text{Rct}_{(Blank)} \ldots\ldots\ldots \ldots\ldots \text{ (8)}$$

Where Rct $_{(Blank)}$ and Rct $_{(PmAP)}$ are the charge transfer resistance of steel in the absence and the presence of certain concentration of the inhibitors respectively.

$$\text{IE\%} = 100*(\text{Icorr}_{(Blank)} - \text{Icorr}_{(PmAP)} / \text{Icorr}_{(Blank)} \ldots\ldots\ldots\ldots\ldots \text{(9)}$$

Where Icorr $_{(Blank)}$ and Icorr $_{(PmAP)}$ are the corrosion current of steel in the absence and the presence of certain concentration of the inhibitors respectively.

III. Results and discussions

III.1. Solubility of PmAP

PmAP with different dopants is insoluble in organic solvents (methanol absolute, ethanol absolute, iso propyl alcohol, iso butyl alcohol, carbon tetrachloride, chloroform, cyclohexane, toluene, dimethylsulfoxide , 2,2,4 trimethyl pentane) , aqueous NaOH, and partially soluble in conc.HCl and conc. H_2SO_4. This is attributed to the ladder structure of the polymers [1,2].

III.2. FTIR Spectra of PmAP

FTIR spectrum of PmAP prepared from m-AP (0.4 M), H_2SO_4 (1 M) and $K_2Cr_2O_7$ (0.14 M) is shown in (Figure 1) and the characteristic bands data are collected in Table (2). The peak appeared at 3377 cm^{-1} is due to –O-H (hydrogen bonded) stretching. The peak at 1620 cm^{-1} is due to -C=N (in polymer chain) stretching and -NH bending. The bands at 1482, 1298 and 1037 cm^{-1} are attributed to -C=C aromatic, –CN stretching and C-O (C-O-H bond) bending respectively. The band observed at 840 cm^{-1} is attributed to C-H aromatic (out –of -plane bending) [1, 2] .
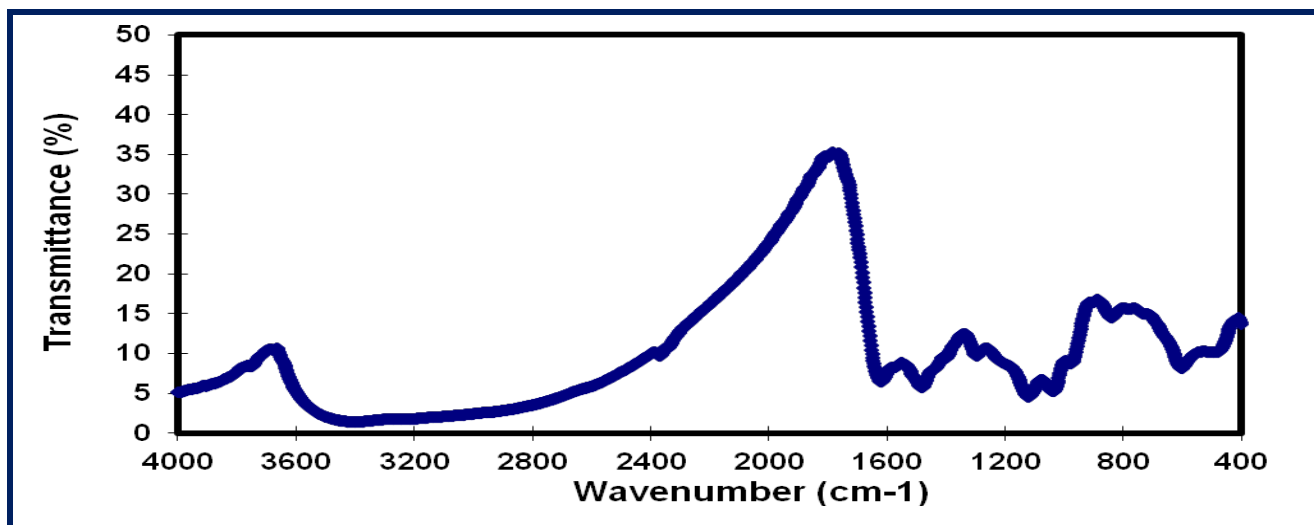
Figure 1: FTIR Spectrum of PmAP prepared from m-AP (0.4 M), H₂SO₄ (1 M) and K₂Cr₂O₇ (0.14M).

Table 2: Characteristic FTIR bands of PmAP prepared from m-AP (0.4 M), H₂SO₄ (1 M) and K₂Cr₂O₇ (0.14 M).

Wavenumber (cm⁻¹)	Assignment
3377	–O-H (hydrogen bonded) stretching
1620	–C=N (in polymer chain) stretching -NH (in polymer chain) bending C-C (aromatic)
1482	-C=C aromatic
1298	–CN (in polymer chain) stretching
1037	C-O (C-O-H bond) bending
840	C-H aromatic (out –of -plane bending)

The molecular structure of poly (m-aminophenol) is suggested as follows [3] .
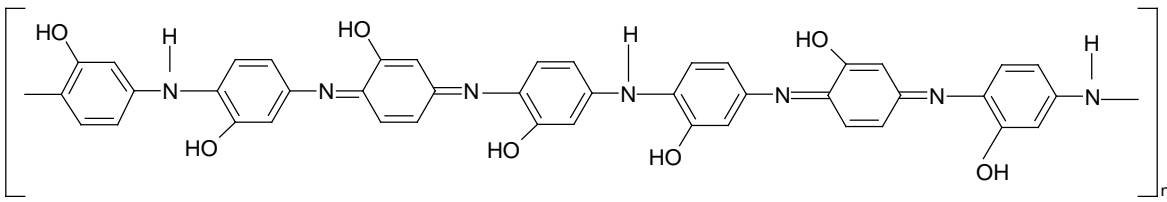
III.3. X-ray diffraction

(Figure 2) shows X-ray diffraction analysis of PmAP prepared from m-AP (0.4 M), H_2SO_4 (1.5 M) and $K_2Cr_2O_7$ (0.1 M). There are three prominent crystalline peaks at $2\theta = 44$, 64.39 and 77.51 degree and a broad amorphous region from 20 to 30 degree [3].
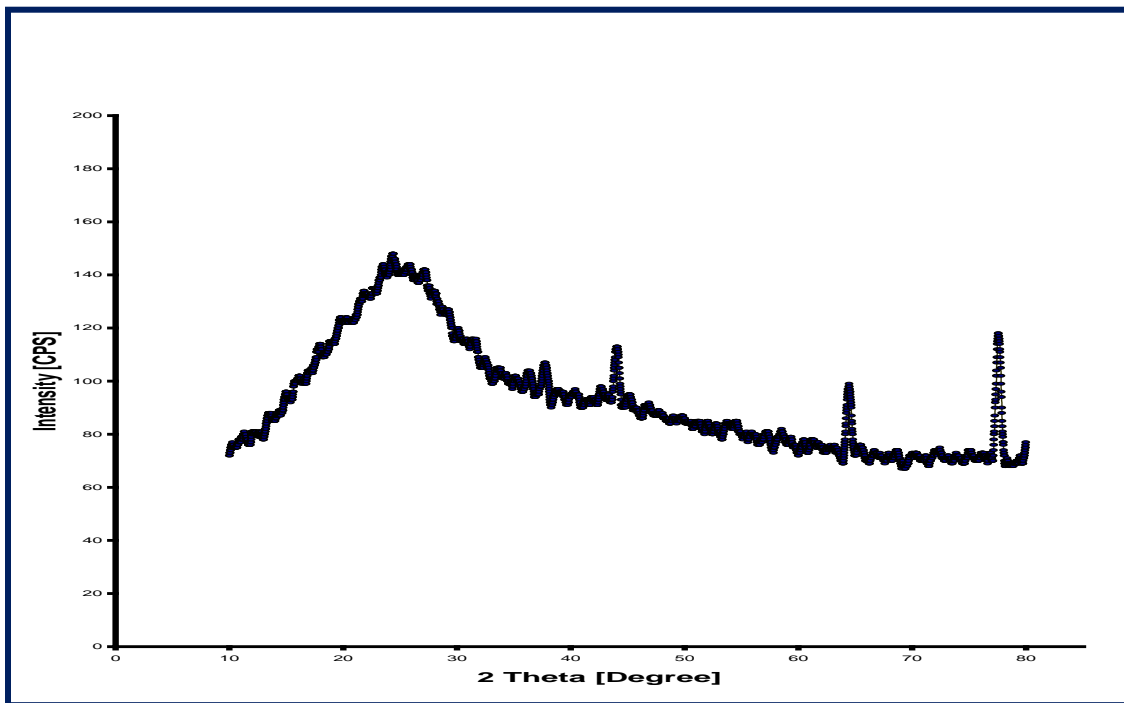
Figure 2: XRD analysis of PmAP prepared from-AP (0.4 M), H_2SO_4 (1.5 M) and $K_2Cr_2O_7$ (0.1)

III.4. Scanning electron microscope (SEM)

(Figures 3) shows SEM micrograph of PmAP prepared from m-AP (0.4M), H_2SO_4 (1.5M) and $K_2Cr_2O_7$ (0.1M). The structure morphology of PmAP is spherical and plate with particle diameter (10 µm at 20 kV and X = 1000) , (2 µm at 20 kV and X = 5500) and (1 µm at 20 kV and X = 10000).
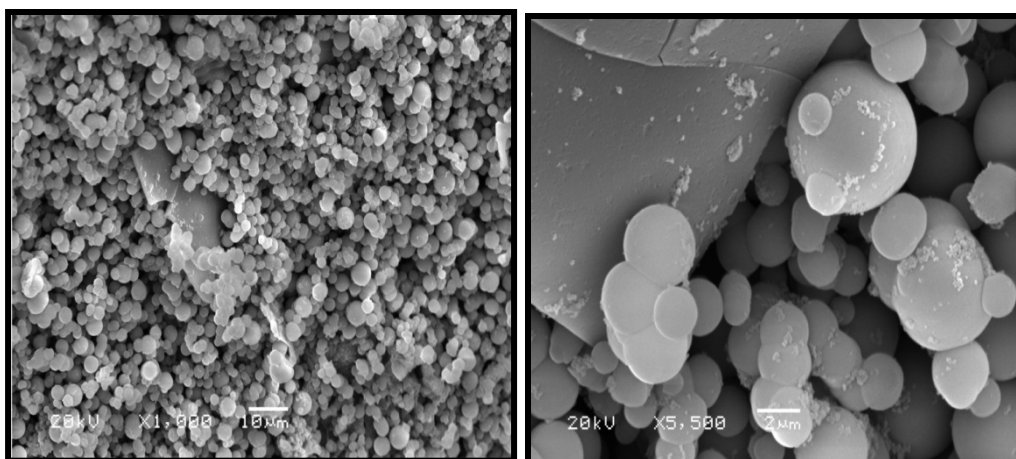
(A)   X = 1000   (B) X = 5500
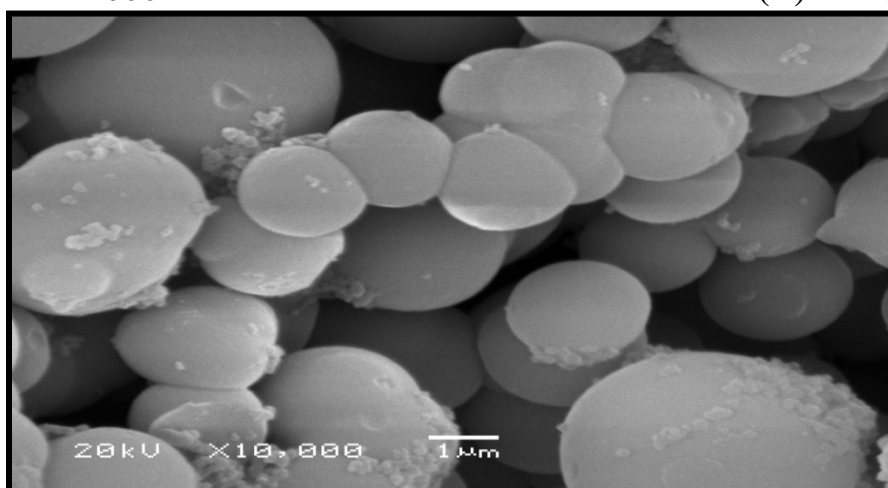
(C) X = 10000

Figure 3: SEM micrographs of PmAP prepared from m-AP (0.4M), H_2SO_4 (1.5M) and $K_2Cr_2O_7$ (0.1M)

III.5. Thermal analysis of PmAP

The thermal stabilities of the prepared homopolymers PmAP are studied by TGA technique. (Figure 4) show TGA curve and thermoanalytical results of PmAP prepared from m-AP (0.4 M), H_2SO_4 (1 M) and $K_2Cr_2O_7$ (0.14 M). PmAP decomposes in two stages. The first stage shows 13.7 % weight loss in the temperature range 25-240 $^\circ$C. This is due to the release of bound water and solvent molecules [4, 5]. The second stage occurs in the temperature range 240 -680 $^\circ$C with 44.1 % weight loss and is attributed to the degradation of polymer. The remaining residue is 42.2 % wt.

From thermogravimetric analysis (TGA) results, it is concluded that the presence of (OH) group in meta position has no effect on the thermal stability of the polymer.
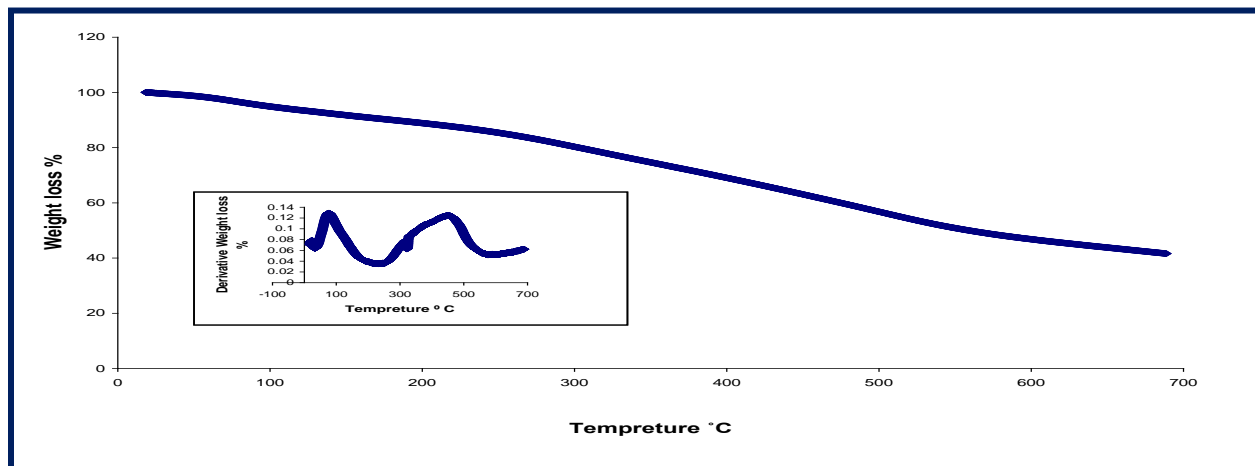
Figure 4: TGA of PmAP prepared from m-AP (0.4 M), H_2SO_4 (1 M) and $K_2Cr_2O_7$ (0.14 M)

III.6. Electrical conductivity of PmAP

Table (3) shows the electrical conductivity of PmAP prepared from monomer (m-AP), HCl, and APS. It is found that the electrical conductivity of PmAP prepared from m-AP (0.4 M), HCl (1 M) as dopant and APS (0.4 M) as oxidant   is $(1.28 * 10^{-11}$ S/cm). By increasing HCl concentration from 2 M to 4 M, the electrical conductivity of PmAP increases from $(1.48 * 10^{-12}$ S/cm) to $(4.65 * 10^{-12}$ S/cm).

Table (4) shows the electrical conductivity of PmAP prepared from monomer (m-AP) ,H_2SO_4 and $K_2Cr_2O_7$ .It is found that the electrical conductivity of PmAP prepared from   m-AP (0.4 M) ,H_2SO_4 (1 M) as dopant and $K_2Cr_2O_7$ (0.14 M) as oxidant is $(0.486 * 10^{-7}$ S/cm). By increasing the concentration of H_2SO_4 to 1.5 M, the electrical conductivity of PmAP is $(2.61 * 10^{-7}$ S/cm). Decreasing H_2SO_4 concentration to 0.5 M at the same conditions, the electrical conductivity increases from $(0.486 * 10^{-7}$ S/cm) to $(5.98 * 10^{-7}$ S/cm).

The different values of   electrical conductivities of PmAP are probably due to the difference in polymer chain lengths. Substituted polyanilines have lower electrical conductivity than that of polyaniline due to the repulsion factor. The electrical conductivity of PmAP using $K_2Cr_2O_7$ as oxidant is higher than the electrical conductivity of PmAP when APS is used as oxidant [2, 5] .

Table 3: Electrical conductivity of PmAP prepared from m-AP, HCl and APS

	Dopant	Oxidant	
m-AP	HCl	APS	Electrical conductivity (S/cm)
0.4 M	1 M	0.06M	$1.55 * 10^{-11}$
0.4 M	1 M	0.10M	$1.43 * 10^{-11}$
0.4 M	1 M	0.40M	$1.28 * 10^{-11}$
0.4 M	1 M	0.80M	$1.85 * 10^{-11}$
0.20M	0.5 M	0.40M	$2.58 * 10^{-13}$
0.4 M	2 M	0.80M	$1.48 * 10^{-12}$
0.4 M	4 M	0.80M	$4.65 * 10^{-12}$

Table 4: Electrical conductivity of PmAP prepared from m-AP, H_2SO_4 and $K_2Cr_2O_7$

m-AP	Dopant H_2SO_4	Oxidant $K_2Cr_2O_7$	Electrical conductivity (S/cm)
0.40 M	1 M	0.06M	$1.33 * 10^{-7}$
0.40 M	1 M	0.1 M	$0.486 * 10^{-7}$
0.40 M	1 M	0.14M	$2.407 * 10^{-7}$
0.40 M	1 M	0.3 M	$0.493 * 10^{-7}$
0.40 M	0.5 M	0.1 M	$5.98 * 10^{-7}$
0.40 M	1.5 M	0.1 M	$2.61 * 10^{-7}$

III.7. Corrosion behavior

III.7.1. Study of the corrosion inhibitor efficiency of PmAP on low carbon steel (AISI C1010) at different concentration of HCl and NaCl by weight loss method.

III.7.1.1. In case HCl (1.5 M), PmAP (30, 60 and 120 ppm) and AISI C1010 alloy.

Tables (5, 6 and 7) show corrosion inhibitor efficiency of PmAP for the solution with and without HCl 1.5 M after 24 and 144 h exposure. From demonstrated results in tables (5, 6 and 7) it is obvious the corrosion inhibitor efficiency of PmAP increased in the order 60 ppm > 30 ppm and at least a few in 120 ppm. It was found that the rate of corrosion AISI C1010 alloy without PmAP is 88.58 MPY during 24 hour exposure; with PmAP the corrosion inhibitor efficiency is 86.5, 88.6 and 85.7 % in case 30, 60 and 120 ppm respectively. The results confirmed the corrosion protection effect of PmAP on AISI C1010 alloy in HCl (1.5 M).

Table 5: Corrosion inhibitor efficiency of PmAP (30 ppm) in HCl (1.5 M) solution after exposure time

Sample	W1 (gm)	W2 (gm)	Time (hour)	Wt. Loss(gm)	MPY	% IE
Blank HCl(1.5M)	10.6014	10.5000	24	0.1014	88.58	-
HCl(1.5M)& PmAP(30 ppm)	10.743	10.661	144	0.082	11.93	86.5

Table 6: Corrosion inhibitor efficiency of PmAP (60 ppm) in HCl (1.5 M) solution after exposure time

Sample	W1 (gm)	W2 (gm)	Time (hour)	Wt. Loss(gm)	MPY	% IE
Blank HCl(1.5M)	10.6014	10.5000	24	0.1014	88.58	-
HCl(1.5 M) & PmAP(60 ppm)	11.7821	11.7125	144	0.0696	10.13	88.6

Table 7: Corrosion inhibitor efficiency of PmAP (120 ppm) in HCl (1.5 M) solution after exposure time

Sample	W1 (gm)	W2 (gm)	Time (hour)	Wt. Loss(gm)	MPY	% IE
Blank HCl(1.5M)	10.6014	10.5000	24	0.1014	88.58	-
HCl(1.5 M) & PmAP(120 ppm)	10.1290	10.042	144	0.0870	12.66	85.7

III.7.1.2. In case NaCl (3.4 M), PmAP (30, 60 and 120 ppm) and AISI C1010 alloy

Tables (8, 9 and 10) show corrosion inhibitor efficiency of PmAP for the solution with and without NaCl 3.4 M after 24 and 144 h exposure. From demonstrated results in tables (8, 9 and 10) it is obvious the corrosion inhibitor efficiency of PmAP increased in the order 60 ppm > 30 ppm and at least a few in 120 ppm. It was found that the rate of corrosion of AISI C1010 alloy without PmAP is 164.4 MPY during 24 h exposure; with PmAP the corrosion inhibitor efficiency is 93.1, 93.9 and 92.1 % in case 30, 60 and 120 ppm respectively. The results confirmed the corrosion protection effect of PmAP on AISI C1010 alloy in NaCl (3.4 M).

Table 8: Corrosion inhibitor efficiency of PmAP (30 ppm) in NaCl (3.4 M) solution after exposure time

Sample	W1 (gm)	W2 (gm)	Time (hour)	Wt. Loss(gm)	MPY	% IE
Blank NaCl(3.4 M)	9.7321	9.5439	24	0.1882	164.4	-
NaCl(3.4 M) & PmAP(30 ppm)	10.0546	9.9770	144	0.0776	11.29	93.1

Table 9: Corrosion inhibitor efficiency of PmAP (60 ppm) in NaCl (3.4 M) solution after exposure time

Sample	W1 (gm)	W2 (gm)	Time (hour)	Wt. Loss(gm)	MPY	% IE
Blank NaCl(3.4 M)	9.7321	9.5439	24	0.1882	164.4	-
NaCl(3.4 M) & PmAP(60 ppm)	11.8496	11.7811	144	0.0685	9.97	93.9

Table 10: Corrosion inhibitor efficiency of PmAP (120 ppm) in NaCl (3.4 M) solution after exposure time

Sample	W1 (gm)	W2 (gm)	Time (hour)	Wt. Loss(gm)	MPY	% IE
Blank NaCl(3.4 M)	9.7321	9.5439	24	0.1882	164.4	-
HCl(3.4 M) & PmAP(120 ppm)	10.2091	10.1200	144	0.0891	12.97	92.1

III.7.2. Study of the corrosion inhibitor efficiency of PmAP by using electrochemical impedance spectroscopy (EIS)
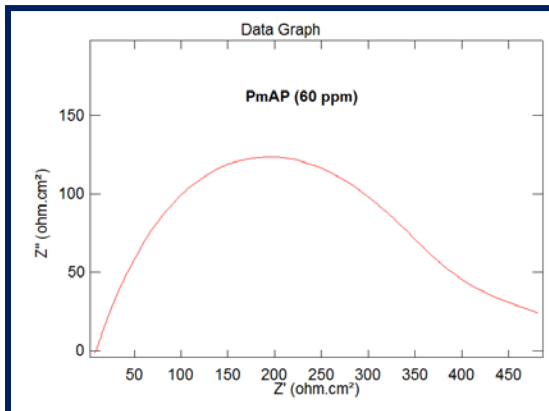
The Nyquist diagrams obtained for low carbon steel in HCl (1.5 M) are given in   Figure 5 (A, B, C, D). It was found that the charge transfer resistance (R_{ct}) increased with PmAP concentration in case (30, 60 ppm). But in case PmAP (120 ppm) the charge transfer resistance (R_{ct}) decreased as a result of the saturation of porous water film with water and such case could be related to break down of oxide layer [6]. The corrosion inhibitor efficiency (%IE) of PmAP (30, 60,120 ppm) in aqueous HCl solution (1.5 M) is shown in Table (11).
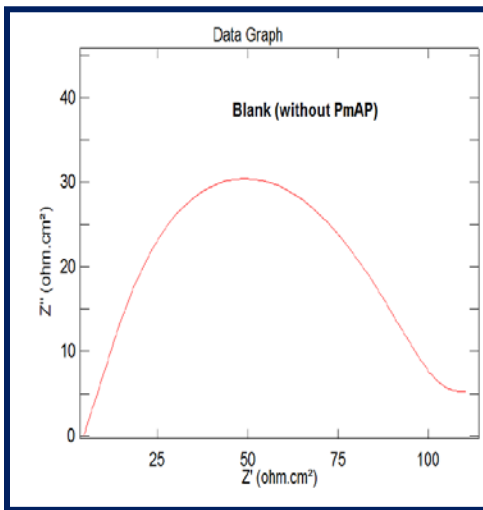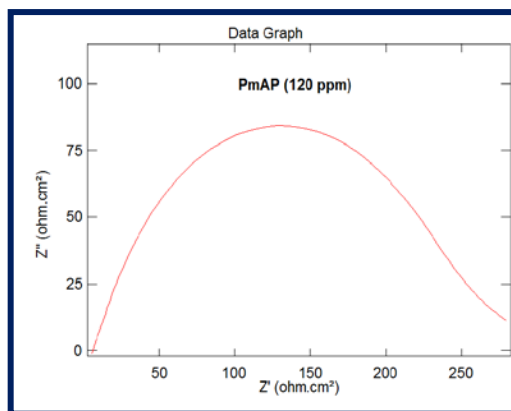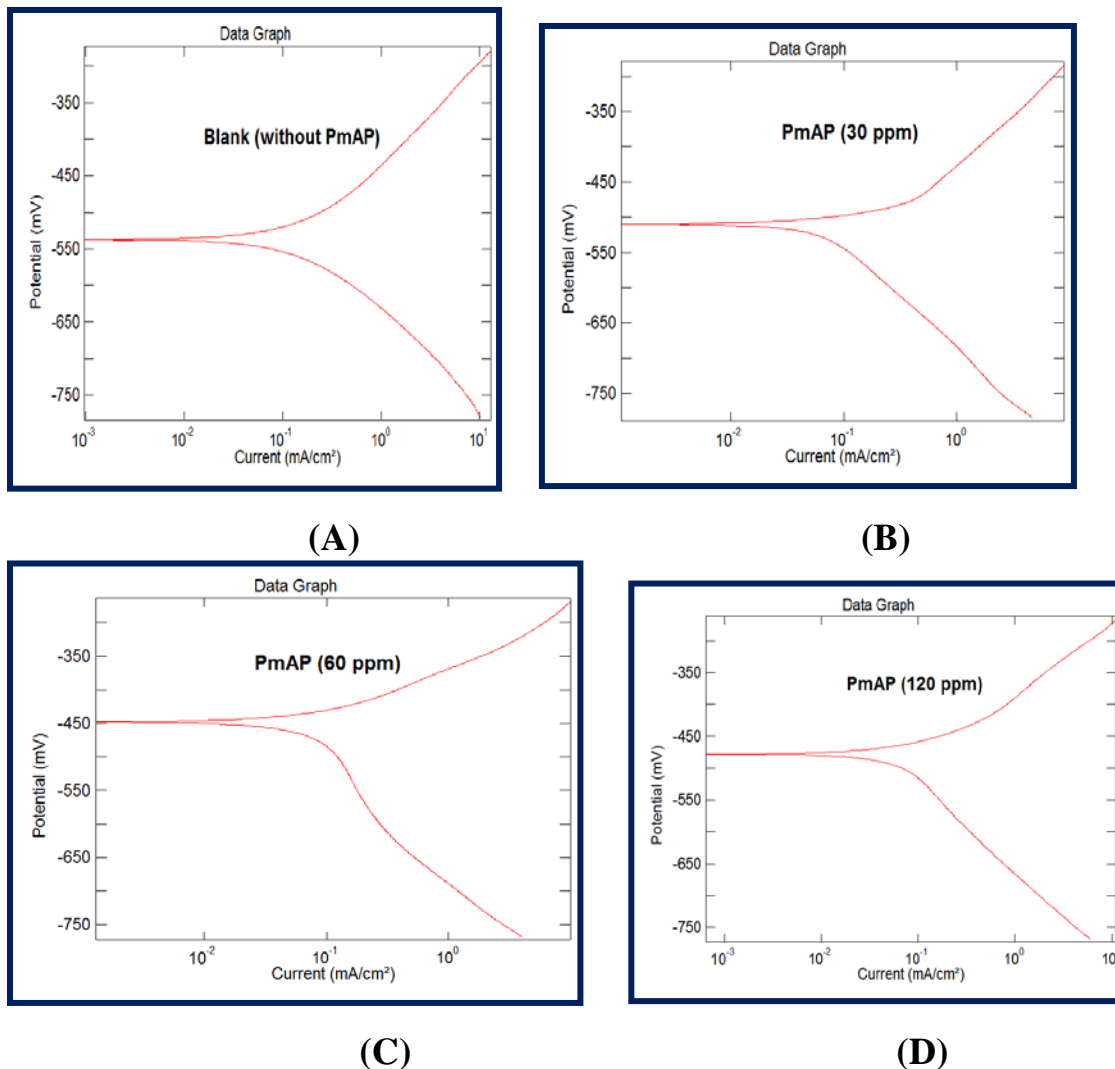
(A)
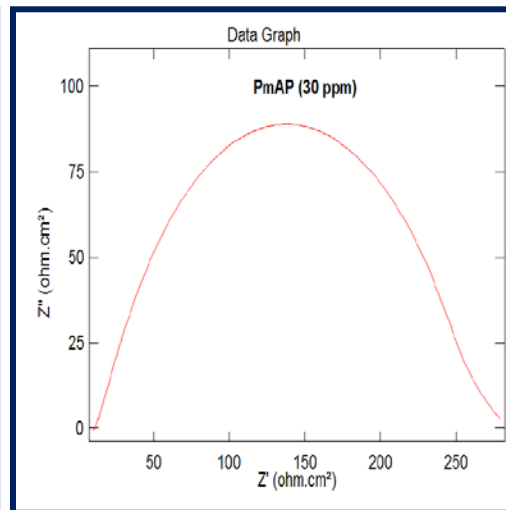
(B)

(C)

(D)

Figure 5: The Nyquist diagrams obtained for low carbon steel in HCl (1.5 M) (A) Blank (without PmAP), (B) PmAP (30 ppm) (C) PmAP (60 ppm), (D) PmAP (120 ppm).

Tafel plots for low carbon steel in HCl (1.5 M) are given in Figure 6 (A, B, C, D). The corrosion current in the blank (without PmAP) is higher than corrosion current in case 30, 60 and 120 ppm. And the passivation from -520 to -550 Mv in case 30 ppm , -450 to -550 Mv in case 60 ppm and -475 to -550 mV in case 120 ppm where increasing potential does not lead to a significant increase in current flow. This is attributed to the well known formation of a passive oxide film on the low carbon steel surface [7].

(A)

(B)

(C)

(D)

Figure 6: Tafel plots for low carbon steel in HCl (1.5 M) (A) Blank (without PmAP), (B) PmAP (30 ppm) (C) PmAP (60 ppm), (D) PmAP (120 ppm).

Table 11: Corrosion inhibitor efficiency of PmAP from charge transfer resistance (Rct)

Concentrations	Rsol	Cdl	Rct	Efficiency %
Blank (HCl 1.5 M)	4.75E+00	3.47E-04	2.40E+01	
PmAP 30 ppm	1.07E+01	1.03E-04	2.78E+02	91.4
PmAP 60 ppm	8.63E+00	1.51E-04	3.98E+02	94.0
PmAP 120 ppm	5.62E+00	2.03E+05	2.51E+02	90.4
IE% = 100*(Rct (Blank) - Rct (PmAP) / Rct (Blank)				

IV. Cost of preparation one ton from poly (m-aminophenol) (PmAP)

Polymer was prepared from the following materials and it is shown in Tables (12).

Table 12: Cost of preparation one ton from poly (m-aminophenol) (PmAP)

Material	Concentration	Quantity to prepare One ton	Price per kg	Cost per Ton
m-AP (Monomer)	0.4 M	44 Kg	8.8 USD	389. USD
H_2SO_4 (dopant)	1.0 M	1000 Liter	1.7 USD	170 USD
$K_2Cr_2O_7$ (Initiator)	0.29 M	86 Kg	2.65 USD	228 USD

Where summation cost in case preparation one ton from poly (m-aminophenol) (polymer yield = 98%) = 787 USD /Ton

V. Conclusions

Poly(m-aminophenol) (PmAP) was prepared by chemical oxidative polymerization of m-aminophenol (m-AP) using ammonium persulfate (APS) or potassium dichromate ($K_2Cr_2O_7$) as an oxidative initiator and sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) as a dopant with polymer yield 98%. The prepared polymer was insoluble in organic solvents, aqueous NaOH and partially soluble in conc. HCl and H_2SO_4. The thermal stability PmAP is independent on the type of dopant or initiator. The electrical conductivity showed that the prepared polymer is insulator when ammonium peroxodisulfate (oxidative initiator) and sulfuric acid or hydrochloric acid (dopant) are used. The polymers are semiconductors when potassium dichromate as an oxidative initiator and sulfuric acid or hydrochloric acid as a dopant are used.

The anticorrosion behavior of PmAP at room temperature in low carbon steel (AISI C1010) has been investigated in aqueous HCl and NaCl solutions using weight loss measurements and electrochemical impedance spectroscopy (EIS). Protection effect of the Poly (m-aminophenol) is due to a barrier effect for oxygen diffusion

VI. References

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