246

Egypt. J. Chem. **Vol. 64,** No. 5 pp. 2685 - 2695 (2021)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Green Recycling Of Poly (Ethylene Terphthalate) Waste As Corrosion Inhibitor For Steel In Marine Environment

Reda. S. Abdel Hameed*[1,2] Mahmoud AlElaimi[1], M. T. Qureshi[1], M. F. H. Abd el-kader[1,3] Amr. M. Nassar[2,4] , Meshari M. Aljohani[5] , Enas I. Arafa[6]

[1]Basic Science Department, Preparatory Year, University of Ha'il, 1560, Hail, KSA.
[2]Faculty of Science, Department of Chemistry, Al-Azhar University,11884, Cairo, Egypt.
[3]Biophysics Department, Faculty of science, Cairo University, Egypt.
[4]Chemistry Department, College of Science, Al Jouf University, 2014, Aljouf, KSA.
[5]Department of Chemistry, Faculty of Science, University of Tabuk, Tabuk 71491, KSA.
[6]Egyptian Petroleum Research Institute, Department of Operations Development, 11727, Cairo, Egypt.

Abstract

Green recycling of poly(ethylene terephthalate) plastic waste, in this respect, **PET** waste was subjected to de polymerization process with tri methylene glycol (1,3-propandiol) in the presence of manganese acetate (1.0 % w/w to the total Wight of the reactants) as trans esterification catalyst, the product is Bis-(3-hydroxy-propyl)-terephthalate, **BHPT, as** a non-ionic surfactant was separated and characterized by FT-IR and ^{1}HNMR and evaluated as corrosion inhibitor for carbon steel alloy in artificial marine environment using chemical and electrochemical techniques. Effect of inhibitor concentrations and reaction temperature were studied. The chemical techniques used in this work are gravimetric, thermometric and atomic absorption spectroscopy(AAS), whereas the electrochemical techniques are open circuit potential, potentiodynamic polarization. The corrosion inhibition efficiency increases with increasing inhibitor concentrations and decreased by rising temperature. The maximum corrosion inhibition efficiency 96.5% was afforded using 300 ppm of the used inhibitor derived from plastic waste. Potentiodynamic polarization curves indicate that the used system act as mixed inhibitor. The data of AAS show that the iron(iii) ions Fe^{+3} concentrations were decreased by increasing inhibitor concentration. All the used techniques are in good agreement to each other (± 2 %) and shows that the used drug acts as green corrosion inhibitors for steel in marine environment.
Keywords: Poly (ethylene terephthalate); green recycling; waste; steel Corrosion; Potntiodynamic; gravimetric; thermometric; AAS.

1. Introduction

Poly (ethylene terephthalate) is a kind of thermoplastic polymer known as (PET), is the most common thermoplastic polymer resin of the polyester family and is used in fibers for clothing, containers for liquids and foods, and thermoforming for manufacturing, and in combination with glass fiber for engineering resins. PET is widely used thermoplastic that generates tones of wastes that may otherwise disrupt the balance of ecosystem due to its non-biodegradation in the environment. The chemical recycling of PET to useful materials is an accepted technique among recycling methods (mechanical, thermal, and chemical) that follows the rules of sustainable developments [1].

Converting of the plastic waste into useful product is of economical, technical, ethical, and environmental impact, especially with the increasing pressure of keeping the environmental clean the recycling of PET waste is an ecofriendly manner is the only solution, PET is not a hazardous product, but its waste quantity increases drastically. PET waste can be recycled by different methods like physical recycling and chemical recycling, chemical recycling is the reaction of PET with various reagents to obtain products that are used in the chemical industry [24]. There are different chemical depolymerization methods used for PET chain scission, such as methanolysis, glycolysis, hydrolysis, ammonolysis, aminolysis, and hydrogenation, which are based on the types of

chemical reagents [2]. During chemical recycling, PET waste can be depolymerized to base monomers or oligomers. With the use of solvent of depolymerization, generally called solvolysis of polymer, methanolysis and glycolysis [5-7] are the main possible routes. The PET bottle was patented in 1973 by Nathaniel Wyeth and began to be used popularly for the production of disposable soft drink bottles in the 1980s. in 1987, more than 700 million pounds of PET were consumed in their production [7]. The overall world production of polyester was about 30 million tons in 2000, this value increased to 55 million in 2012 and most consisted of PET. As a result of the diversity of its applications in a high volume of consumer products, large amount of PET waste is also generated, which includes polymer manufacturing waste as well as the products after the end of their useful life. PET is semi-crystalline, thermoplastic polyester of characteristic high strength, transparency, and not biodegradability [7]. PET is not a hazardous product, but its waste quantity increases drastically. With the increasing pressure of keeping the environmental clean. Recycling of PET waste is an ecofriendly manner is the only solution. PET waste can be recycled by different methods like physical recycling and chemical recycling. Steel is aback boon of heavy industries, Corrosion control of steel is of technical, economical, and environmental importance, corrosion inhibitors are commonly used to reduce the corrosion attack on the steel surface [7]. The presence of the inhibitors leads to decline in the rate of corrosion of steel and hence the lifetime increases [7]. Most of the effective acid inhibitors are organic compounds containing nitrogen, oxygen and /or sulfur and these compounds adsorb at the steel surface and hence slow down the rate of corrosion [8-12]. The strength of the adsorption depends on the several factors such as the chemical structure of the inhibitors, the presence of electro donating or electro repelling group, molecular weight of the inhibitor, temperature and electrochemical potential at the metal / solution interface [13,14]. surfactant inhibitor has many advantages such as high inhibition efficiency, low price, low toxicity and easy production [7,15]. The adsorption of the surfactant on the metal surface can markedly change the corrosion resisting property of the metal [16], and so the study of the relationship between the adsorption and corrosion inhibition is of great importance. In the previous works [16-24] de polymerization by aminolysis of PET, with mono ethanolamine, and ethylene di amine the products nonionic surfactants act as good corrosion inhibitors for steel in HCl. This work is one from the series aimed to alleviate the environmental pollution by accumulation of plastic waste by converting waste into modified products, and to evaluate the modified products as corrosion inhibitors for metals and alloys

in different aqueous media [16-24]. In the present work Propylene glycol was used to convert PET waste into Bis-(3-hydroxy-propyl)-terephthalate, BHPT, via solvent free green recycling, the product was evaluated as green corrosion inhibitor for carbon steel in 2.0 M sodium chloride solution as artificial sea water by chemical techniques namely, weight loss, thermometric and atomic absorption spectroscopy(AAS) also electrochemical techniques were used to evaluate to corrosion inhibition efficiency of the green inhibitor derived from PET waste.

2. Experimental
2.1. Materials
All chemicals used in this work were purchased from Sigma Aldrich chemicals Co. except poly (ethylene terephthalate) (PET) waste which was collected from beverage drinking water bottles. The bottle label and other polymers contaminate were removed and PET wastes were cut into small pieces $1mm^2$, washed with water and soap, dried, and subjected to green recycling process. The corrosive sodium chloride (NaCl Shinyo Pure Chemicals, 99.99%), The gravimetric composition of the used steel alloy materials employed in this study is given in **table 1**.

Table 1. Gravimetric composition of the used steel materials

Element	Mn	Si	S	P	C	Fe
Composition Weight (%)	0.517	0.201	0.009	0.007	0.157	About 99 %

2.2. Recycling Process of poly (ethylene terephthalate)

PET waste was depolymerized with 1,3-propandiol represented here as (PG), at weight ratio of PET to Glycol (PG) (1:3 wt. % of PET: wt.% of PG) using 1.0% of manganese acetate as transesterification catalyst (by weight based on weight of PET). The reaction mixtures were heated under vigorous stirring in nitrogen atmosphere at temperature about 170–190 ºC for 4 h and at 200 ºC for 3 h. The temperature of the reaction was then lowered to 100 ºC for 1 h. The mixture was allowed to cool to room temperature. at the end of the reaction, saline water was added to the reaction mixture with vigorous agitation followed by phase separation **[7,24]** the product, poly (bis (2-Hydroxy ethylene) terephthalate) **(BHPT)** was obtained in organic layer as a white viscous product, which have the chemical structure as showed in **Figure (1)**. The general diagram for the green synthesis procedure as presented in **Figure 2.**

2.3. Elemental and Spectroscopic Analysis
Elemental and spectroscopic analyses were carried out in the Micro Analytical Center of Cairo University. The fine chemicals were purchased from Aldrich Co.

The reactions were monitored using TLC and the resultant compounds were crystallized and then extra purified using a column chromatography technique.
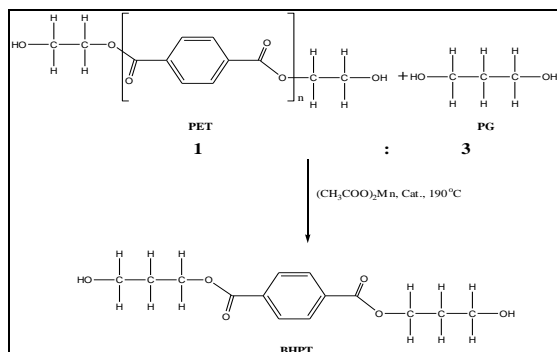

Figure.1. The chemical scheme of the green synthesis process for the Bis-(3-Hydroxy- Propyl) Terephthalate, **BHPT** inhibitor compound.

2.4. Infrared Spectroscopic Analysis
The purified synthesized compounds were analyzed using ATI Mattson Genesis Series FTIR spectrophotometer. The samples were investigated as thin film between two KBr discs.

2.5. Nuclear Magnetic Resonance Spectroscopic Analysis
The prepared surfactants were dissolved in DMSO and analyzed using Jeol NMR spectrometer model JNM-EX (270 MHz) as another spectroscopic technique for determining the chemical structure and the HLB by comparing integral trace of different peaks.

2.6. Gravimetric studies
The simplest and traditional techniques used for determinations of the corrosion rate and dissolution process of metals is the gravimetric method it has the advantage of being simple and does not require a complex equipment or procedures. In the present work, two types of gravimetric tests were used, namely the weight loss measurement and the dosing of the metal ions (iron(iii) Fe^{+3}) which passed in solution by atomic absorption spectroscopy.

2.6.1. Weight Loss measurement
Gravimetric determining the weight loss (WL) of a sample (coupon) of the surface (S) immersed for a time (t) in the aggressive solution. The tests are performed in 100 ml glass vials in non-aerated medium, at room temperature. The immersion time is 7 days, the metal surface was polished with different grades of emery papers, degreased with acetone, and rinsed with distilled water, pure sodium chloride was used for preparing the corrosive solution. The determination of the corrosion rate R_{corr} was made from the following relation (1) [25]:

$$R_{corr} = \frac{m_i - m_f}{At} \qquad (1)$$

where R_{corr} (mg.cm^{-2}.h^{-1}) is the corrosion rate, m_i (mg) and m_f (mg) are the mass before and after exposure to test solution, respectively, A (cm^2): is the surface of

area of specimen, t (days): is the immersion time. Regarding the inhibitory efficiency, I.E % and the surface coverage (θ), which represents the part of the metal surface covered by the inhibitors molecules, were calculated according to the following equations:

% I.E = ([W^o-W] /W^o) x 100 *(2)*
θ   = ([W^o-W] /W^o) *(3)*

where W^o and W represent the corrosion rates in the absence and presence of the inhibitors, respectively.

2.6.2. Atomic absorption Spectroscopy (AAS)
Quantitative determinations of iron(iii), Fe^{+3} ions contents in corrosive solutions in the absence and presence of the used inhibitor was determined by atomic absorption spectroscopy(AAS). Concentration of the iron(iii), Fe^{+3} that passed into solution has been performed by using Varian Spectra AA 220 atomic absorption spectroscopy. In order to determine the concentrations of iron ions within corrosive solution both when the inhibitor was absent and present, we dissolved the corrosive medium by aqua regia [26].

2.7. Thermometric measurements
The carbon steel sheet was press cut 2 x2 x 0..1 cm with chemical composition as mentioned in table 1. The measurements were carried out in a Dolvacpyrex flask cover with sheet of aluminum foil. The reaction vessel consists of 50 ml of the test solution put into the flask covered with sheets of aluminum foil, corked with a Check temp digital thermometer in place. The metal coupon was introduced into the corrosive solution and quickly covered. The variation of temperature of the system was monitored with time and the reaction number (RN) is defined as [26]

RN (^{0}C/min.) = (T_m – T_i) / t_m   *(4)*

Where T_m and T_i are the maximum and initial temperature respectively, t_m is the time in minutes taken to attain the maximum temperature.

2.8. Open circuit potential
The potential of the carbon steel electrode was measured against saturated calomel electrode (SCE) in 2.0 M NaCl solution in absence and presence of different concentrations of used inhibitor at 30°C. All measurements were carried out using Multi-tester until the steady-state potentials are reached.

2.9. Potentiodynamic polarization measurement
The working electrode was made from carbon steel rod that has the same composition as mentioned in point 2.1. The rod was axially embedded in araldite holder to offer an active flat disc shaped surface of an area 1 cm^{-2}. Prior to each experiment, the working electrode was polished successively with fine emery paper, rinsed with acetone, washed with double distilled water and finally dried before dipping into the electrolytic cell. A platinum wire was used as a counter electrode and a saturated calomel electrode (SCE) as the reference electrode to which all potentials are referred.   The electrochemical experiments are performed using radiometer analytical, Volta master

(PGZ301, DYNAMIC ELS VOLTAMMETRY). Under stirring with scan rate 1 mV/s and potential was scanned in the range of -1800 to 0 mV. Three compartment cell with a saturated calomel reference electrode (SCE) and a platinum foil auxiliary electrode was used.

3. RESULTS AND DISCUSSION

3.1. Chemistry: Synthesis of Bis-(3-hydroxy-propyl)-terephthalate, BHPT

PET (1 %w/w) and an tri molecular ratio of 1,3-dihydroxy propane (3 %w/w) were refluxed in the presence of manganese acetate (1.0 % wt. %) as a transesterification catalyst for 6 hours at temperature (190-200 C°) as mentioned before Part 2.2. **[7,24].** The reaction mixture was cooled to 100 ^{O}C, then to room temperature, saline water was added to remove glycol the product residue is a white viscous product, this compound was extra purified using column chromatography. figure 1 show the chemical structure of the product and scheme of the synthesis process, the obtained compound has the elemental analysis as given in **table 2**.

Table 2. Elemental analysis of the prepared compound from **PET** waste.

Analysis	*(Mol.F)*	*(Mol.wt.)*	*C %*	*H %*	*O %*
Calculated	$C_{14}H_{18}O_6$	*282.3*	*59.5*	*6.4*	*33.98*
Found		*281.6*	*59.1*	*5.3*	*32.6*

The structure of the obtained compound, **BHPT** was verified form their **IR** spectra. The spectra of **BHPT** shows the presence of strong band at 3420 cm^{-1}, in the spectra, indicates the termination of the products with hydroxyl groups. On the other hand, the band observed at 810 cm^{-1} for all depolymerized PET is assigned to –CH out-of-plane bending of p-substituted phenyl. This band confirms the presence of phenyl rings in depolymerized products. The presence of strong peaks at 1745 cm^{-1} and 1150 cm^{-1}, which were assigned for C=O stretching and C-O stretching of ester groups, indicates the incorporation of ester groups in all depolymerized **PET** products. A further confirmation for the products of PET with Propylene glycol (1,3-dihydroxy propane) is given by **^{1}HNMR**. In this respect the spectra of **BHPT** show the signals at chemical shifts 8 ppm, and 4.5 ppm, represent p-substituted phenyl group, and COOCH$_2$CH$_2$CH$_2$O-H of produced PET respectively, were observed in the spectra. The signal observed at 2.6 ppm in the spectra of **BHPT**, which represent OH group of PG, indicate

the presence of terminal OH in the obtained **BHPT** sample.

3.2 Gravimetric (weight loss) Measurements
3.2.1. Effect of Concentrations

Gravimetric techniques were used in determination of the corrosion rate and corrosion inhibition efficiency %I.E. of the used inhibitor which derived from **PET** plastic waste for the various concentrations the inhibitor after 7 days of immersion of steel coupon in 2.0 M NaCl corrosive environment. The values of corrosion rate (W) and corrosion inhibition efficiency %IE are given in **table 3**. And **figures 3**. According to gravimetric results the weight loss and consequently the corrosion rate decreases and inhibition efficiency increases by adding the **BHPT** green inhibitor and this behavior was increased by increasing the **BHPT** inhibitor concentrations. It's clear that the inhibition efficiency increase as the inhibitor concentration increases to attain 96.5 % at 300 ppm. The inhibitory efficiency % I.E. and the surface coverage (θ), which represents the part of the metal surface covered by the inhibitors molecules, were calculated according to equations 2 and 3 mentioned in experimental part. Inspection of **table 3** reveals that; the values of inhibition efficiency increase with increasing inhibitor concentration. **Figure 3** reveals that by increasing the concentrations of **BHPT** inhibitor, the weight loss of carbon steel samples are reduced, this clarified that the occurrence of these compounds lowered the dissolution of steel in 2.0 M NaCl solution indicating that these compound acts as inhibitors. The relation between weight loss with time in uninhibited and inhibited 2.0 M NaCl is linear This illustrates that the absence of insoluble surface films during corrosion. In this case, the inhibitors are first adsorbed onto the metal surface and thereafter impede corrosion either by merely blocking the reaction sites (anodic and cathodic) or by altering the mechanism of the anodic and cathodic partial processes, **[24]**. The maximum inhibition efficiency obtained using 300 ppm of **BHPT** inhibitor is 96.5 % within the range when it compared by the obtained efficiency in the cited references (previous works) **[15-24]**.

Table 3. Effect of increasing concentration of the **BHPT** inhibitor on the corrosion parameters of steel in 2.0 M NaCl solution data obtained from the weight loss measurements at 303 k.

Compound	Conc. ppm	Corrosion rate (W) mg cm^{-2} day^{-1}	θ	I.E. %
Blank	Free	**7.8**	-	-
BHPT	50	0.84	0.897	89.7
	100	0.71	0.91	91
	150	0.56	0.935	93.5
	200	0.47	0.945	94.5

	250	0.39	0.95	95
	300	0.27	0.965	96.5

3.2.2. Effect of temperature

To elucidate the mechanism of inhibition and to determine the kinetic parameters of the corrosion process gravimetric (weight loss) measurements was performed at different temperatures e.g., 303,313,323,333K. The effect of temperature on the percentage inhibition efficiency of steel in the presence of the inhibitor is graphically represented in **Figure 4**. It is obvious that the values of %I.E. decreased with increase in temperature, leading to the conclusion that the protective film of these compounds formed on the steel surface is less stable at higher temperature; which may be due to the desorption of some adsorbed molecules from the surface of the steel at higher temperature due to which greater area of the metal is exposed to the acidic environment. All the experiments were done three times and the recorded data was taken to the medium value with (± 0.1) error.

3.3. Atomic Absorption Spectroscopy(AAS)

Iron corrosion is a complex process that occurs when iron is exposed to oxygen and humidity and is exacerbated by the presence of chloride ions. The deterioration of iron structures or other components can be costly to society and can be evaluated by following the properties of the corroding material [26,27]. The iron(iii) Fe^{+3} ions released into solution due to corrosion were detected directly by atomic absorption spectroscopy and their concentration was determined using a calibration curve. The corrosion of the iron samples in solution was accelerated by high salinity, lowering pH, the presence of chloride ions, and temperatures [26,27]. In the present study the ferric ions (iron(iii) Fe^{+3}) concentrations result due to corrosion of iron by the corrosive environment after 7 days, were determined by atomic absorption spectroscopy(AAS). The concentrations of the ions passed into solution has been performed by using AAS and in order to determine the concentrations of iron(iii) Fe^{+3} within corrosive solution both when the green inhibitor was absent and present. The data of AAS are listed in **table 4**. Which show that the iron(iii) $[Fe^{+3}]$ concentrations in the corrosive medium were decreased by increasing inhibitor concentration. Here ferric ions concentration taken as a function of corrosion rate consequently as the $[Fe^{+3}]$ ions in the solution increases the corrosion rate increases and vice versa. All process is influenced by adding inhibitor. The data in **table 4** agree well with results obtained by gravimetric (weight loss) method so the tow gravimetric techniques are in good agreement to each other to indicate that, the addition of **BHPT** compound inhibit the corrosion of iron in artificial marine environment and decrease the iron dissolution process iron(iii) $[Fe^{+3}]$ in this environment.

Table 4. Effect inhibitor concentrations on ferric ions concentrations as result of AAS technique.

Sample	Inhibitor Concentration	Iron(iii) ions concentrations $[Fe^{+3}]$, ppm
Blank	Free	123
BHPT	50 ppm	33
	100 ppm	25
	150 ppm	17
	200 ppm	13
	250 ppm	11
	300 ppm	9

3.4. Thermometric Measurements

Reaction number (RN) values are known as a relative measure of retardation of the dissolution process [26,28]. The extent of corrosion inhibition can have expressed in terms of the percentage reduction in reaction number (% RR) given by the following equation [26,28].

$$\%RR = \frac{RN\ uninhibited - RN\ inhibited}{RN\ uninhibited} \times 100$$
(5)

The thermometric parameters and inhibition efficiency are summarized in **table 5.** The inhibition efficiency and t_m increase by increasing inhibitor concentrations. This order similar that obtained from both weight loss and AAS techniques.

Table 5. Thermometric parameters for the steel corrosion in 2.0 M NaCl solution in presence of 300 ppm of the **BHPT** inhibitor compound derived from PET waste.

Thermometric Parameters	BHPT
T_m, ^0C	36
t_m, min.	380
RN, ^0C/min.	0.029
% RR	90
Δt_m	335

3.5. Open circuit Potential Measurements

The potential time curves of the carbon steel electrode in the absence and presence of different concentration of the used inhibitor at 30 ^0C was measured against SCE reference electrode for 50 min the obtained data are presented in **Figure 5.** As seen from **Figure 5.** in uninhibited 2.0M NaCl solution, the E value of steel tends towards more negative potentials then slightly shifted to positive direction. After that, it was kept at a nearly stable value. The same behavior appears at

_____

addition of the inhibitors but a steady state potential, which produced from addition of inhibitors shifted to more noble values with inhibitors. This shift increase with increasing inhibitor concentrations. The inhibitors raise the free corrosion potential of steel (shifted it to more noble values) compared to the blank solution. This initially indicates that the studied inhibitors act as anodic inhibitor [29-33]. In all curves the steady-state values are always more negative than the immersion potential suggesting that before the steady state condition is achieved the steel oxide film has to dissolve [29-33].

3.2. Potentiodynamic Polarization Measurements

Potentiodynamic polarization studies have been used to evaluate the corrosion inhibition efficiency of the used inhibitors by study the formation of protective film on the metal surface. The potentiodynamic polarization curves of carbon steel immersed in the test solutions are shown in **figure 5.** The Tafel corrosion parameters and inhibition efficiency are given in **table 6.** As shown from the table the inhibitors shifts the corrosion potential to less negative values versus SCE. This indicates that the anodic current reaction is controlled predominantly. The corrosion current potential values for carbon steel in 2.0 M NaCl solution decreases in the presence of inhibitors and the corrosion resistant values has increased . this indicates that a protective film formed on the metal surface. From the **table 6** the addition of inhibitors enhance the corrosion inhibition efficiency.   The shift in anodic Tafel slope (β_a) is greater than the shift in cathodic Tafel slope (β_c) in case of inhibitors system indicating that the inhibitors   act as mixed inhibitors mainly anodic [30]. The inhibition efficiency and surface coverage is given by the following equations [34-38]:

$$\%I.E = 1- (I_{inh} / I_{uninh}) \times 100 \quad (6)$$

$$\theta = 1- (I_{inh} / I_{uninh}) \quad (7)$$

Where: I_{uninh} and I_{inh} are the corrosion current densities in the absence and presence of inhibitor respectively.

Table 6. Polarization data for steel electrode in 2.0 M NaCl solution with various concentrations of the **BHPT** inhibitor compound derived from PET waste. at room temperature.

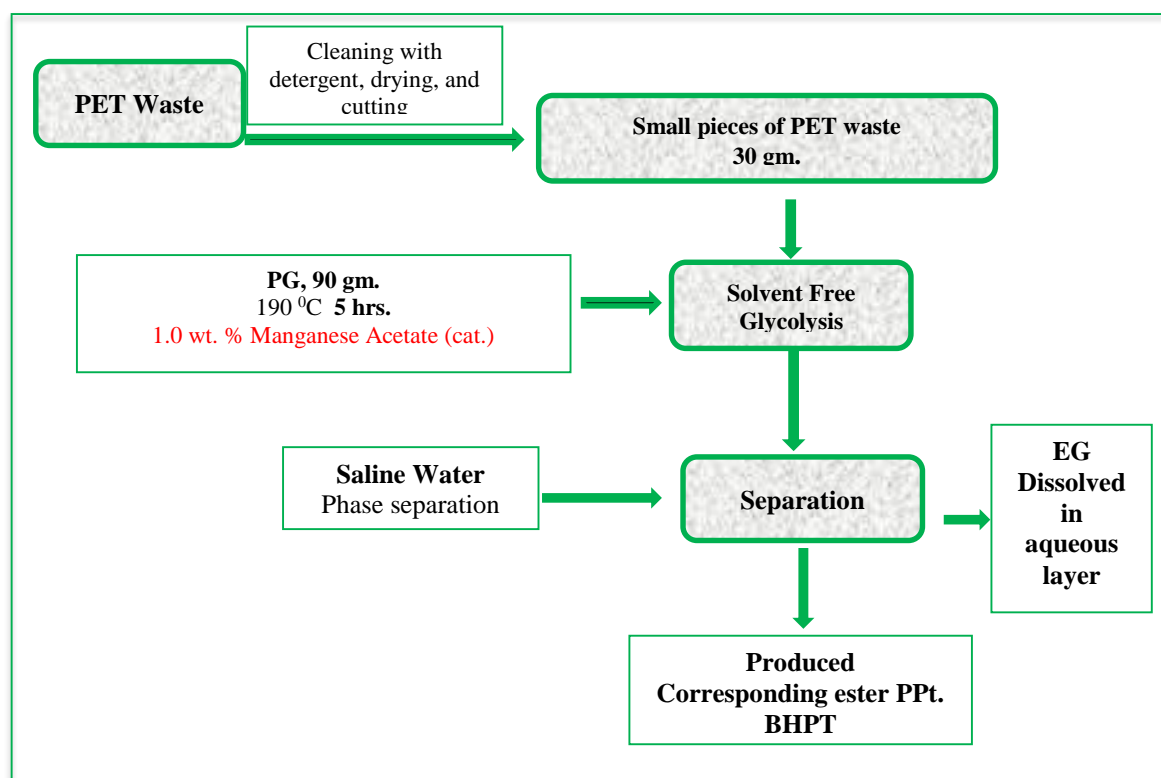| Inhibitors	Conc., ppm	-E_{corr} mV (SCE)	I_{corr} mA cm^{-2}	β_c mVdec^{-1}	β_a mVdec^{-1}	% IE
Blank	-	478	1.2	101	97	------
BHPT	50	510	0.21	118	103	82.5
	100	519	0.19	122	112	84.2
	150	525	0.12	128	118	90.0
	200	537	0.10	135	126	91.6
	250	539	0.098	140	132	91.8
	300	542	0.096	146	139	92.0

_____

Figure. 2. *The* flow diagram of the solvent free green synthesis processes
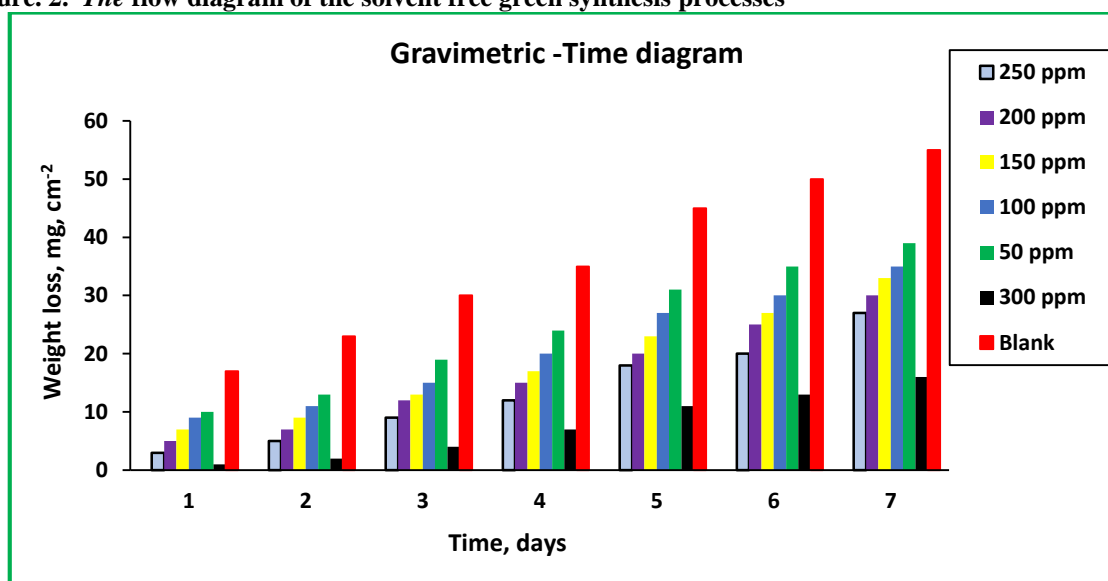

Figure 3. Weight loss of steel as a function in time in 2.0 M NaCl in absence and presence of the **BHPT** inhibitor compound derived from **PET** waste.
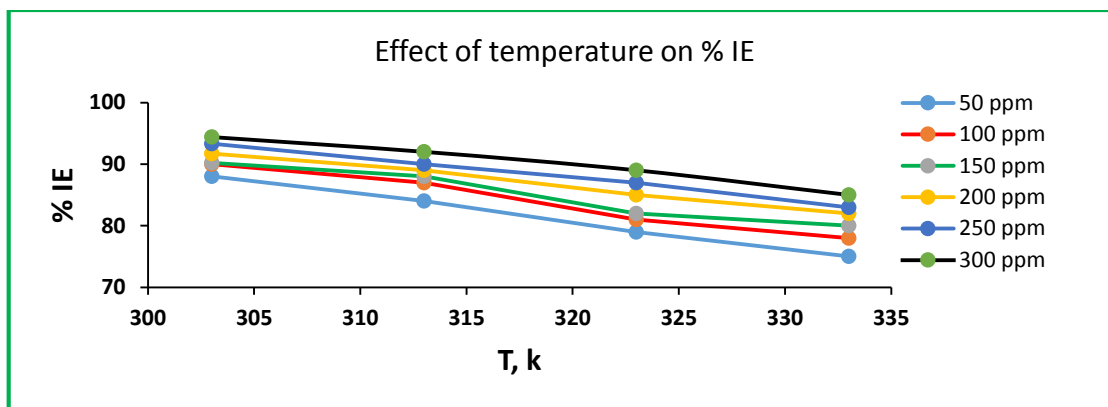
Figure 4. Effect of temperature on % I.E for carbon steel in 2.0 M NaCl in the presence of different concentrations of the **BHPT** inhibitor compound derived from **PET** waste.
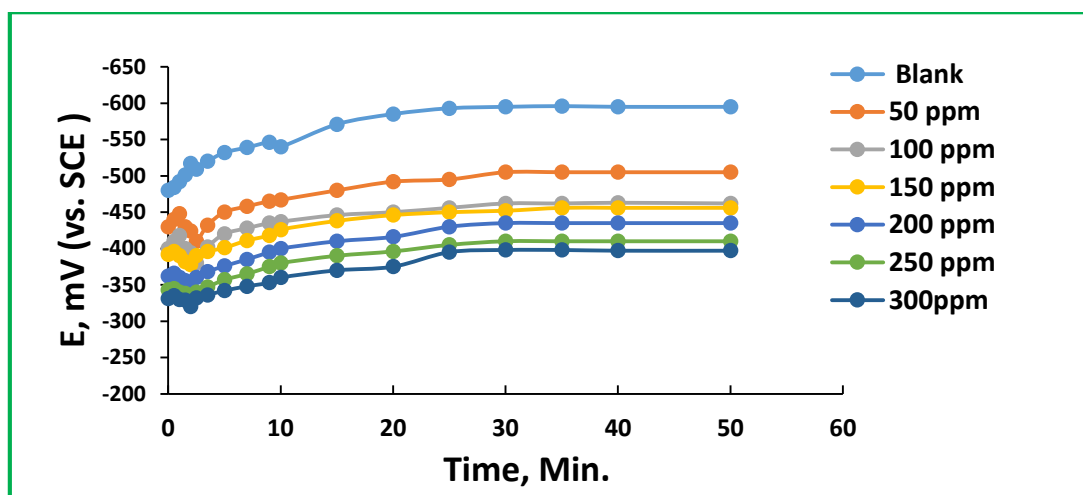

Figure. 5. Potential–time curves for carbon steel immersed in 2.0 M NaCl solution in the absence and presence of the **BHPT** inhibitor compound derived from PET waste at room temperature.
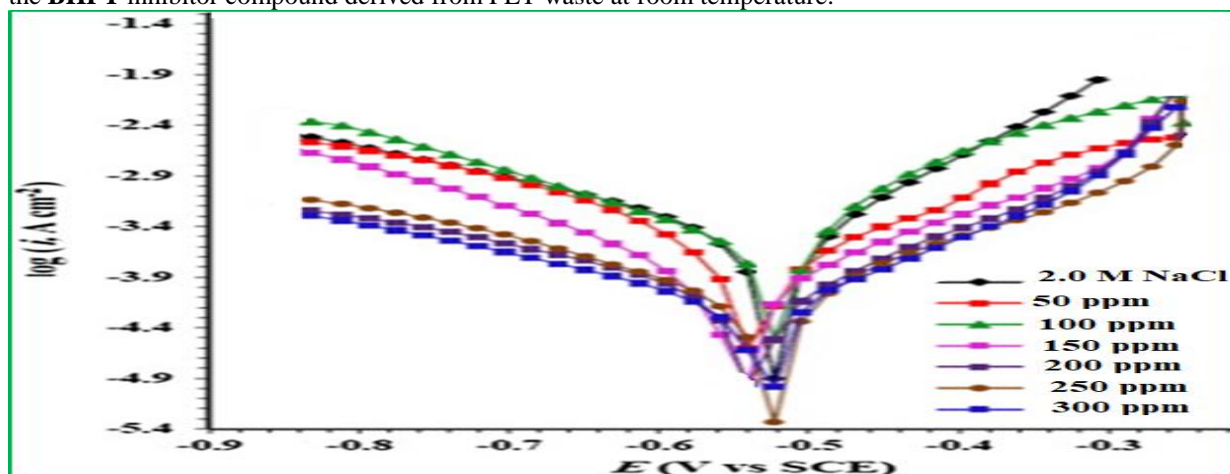

Figure 6. Potentidynamic polarization curves of iron in 2.0 M NaCl solution containing different concentrations of the **BHPT** inhibitor compound derived from **PET** waste at room temperature.

CONCLUSIONS

From the obtained results we can conclude the following points:

1- PET waste could be depolymerized using propylene glycol in the presence of manganese dioxide catalyst to give Bis (Hydroxy Propylene) terephthalate, BHPT, the process is solvent free efficient green process.

_____

2- BHPT compound act as mixed inhibitor for carbon steel in 2.0 M NaCl medium as artificial sea water.

3- The corrosion inhibition efficiency increase with inhibitor concentration and decrease with temperatures.

4- The corrosion inhibition efficiency increase by increasing OMP inhibitor concentrations reach to 96 .5 % at 300 ppm. As soon as the iron(iii) ions [Fe^{+3}] decreases.

5- The data of AAS show that the iron(iii) ions [Fe^{+3}] concentrations were decreased by increasing inhibitor concentrations.

6- Potentodynamic measurements results indicate that the values of $E_{corr.}$ change slowly to negative values indicating that used inhibitors are of mixed type inhibitors.

7- All the used techniques are in good agreement to each other (±2 %) and shows that the **BHPT** inhibitor compound derived from PET plastic waste acts as green corrosion inhibitors for steel in artificial marine environment.

References

1- Achilias, D.; Karayannidis, G. The chemical recycling of PET in the framework of sustainable development. *Water Air Soil Pollut. Focus,*4 (**2004**) 385–396.

2- George, N.; Kurian, T. Recent developments in the chemical recycling of postconsumer poly (ethylene terephthalate) waste. *Ind. Eng. Chem. Res.* 53(**2014**) 14185–14198.

3- Atta, A.M.; El-Kafrawy, A.F.; Aly, M.H.; Abdel-Azim, A.-A.A. New epoxy resins based on recycled poly (ethylene terephthalate) as organic coatings. *Prog. Org. Coat.* 58(**2007**)13–22.

4- Spychaj, T.; Fabrycy, E.; Spychaj, S.; Kacperski, M. Aminolysis and aminoglycolysis of waste poly (ethylene terephthalate). *J. Mater. Cycles Waste Manag*.3 (**2001**) 24–31.

5- G. Colomines,J.Robin, G. Tersac, *Polymer* 46 (**2005**)3230-2246.

6- Ayman M. Atta , Hamad A. Al-Lohedan, Abdelrahman O. Ezzat and Nourah I. Sabeela, New Imidazolium Ionic Liquids from Recycled Polyethylene Terephthalate Waste for Curing Epoxy Resins as Organic Coatings of Steel, *Coatings*, 10(**2020**) 1139; doi:10.3390/coatings10111139

7- Reda S. Abdel Hameed, Solvent Free Glycolysis of Plastic Waste as Green Corrosion Inhibitor for Carbon Steel in Sulfuric Acid, *Journal of New Materials for Electrochemical Systems,* 20,1 (**2017**) 141-149.

8- Abdel Hameed R. S., Abd-Alhakeem H Abu-Nawwas, HA Shehata. Nano-composite as Corrosion Inhibitors for Steel Alloys in different corrosive media: Review Article. *Advances in Applied Science Research*, 4,3 (**2013**) 126-129.

9- M. Abdallah, H.M. Al –Tass, B. A. AL Jahdaly, A. S. Fouda, Inhibition properties and adsorption behavior of 5-arylazothiazole derivatives on 1018 carbon steel in 0.5M H_2SO_4 solution *J.Mol. Liq.* ,216 (**2016**)590-597.

10- R. S. Abdelhameed , Recycling of the Used Cooking Oils as Corrosion Inhibitors for Carbon Steel in Hydrochloric acid Corrosive Medium, *Adv. Appl. Sci. Res.,* 7,2,(**2016**)92-102.

11- H. Hanane,T. Douadi ,M. Al-Noaimi,S.Issaadi, D. Daoud ,S. Chafaa Electrochemical and quantum chemical studies of some azomethine compounds as corrosion inhibitors for mild steel in 1M hydrochloric acid, *Corros.Sci.,*88(**2014**)234-245.

12- M. Abdallah,B. H. Asghar, I. Zaafarany, M. Sobhi, Synthesis of some aromatic nitro compounds and its applications as inhibitors for corrosion of carbon steel in hydrochloric acid solution , *Prot.Met.Phys. Chem. Surf.,*49,4(**2013**)485–491.

13- Abdel Hameed R. S. , HI Al Shafey, AH Abu-Nawwas, Expired Voltaren Drugs as Corrosion Inhibitor for Aluminium in Hydrochloric Acid. *Int. J. Electrochem Sci.,* 10 (**2015**)2098 – 2109.

14- Reda. S. Abdel Hameed, A. H. Al-Bagawi , Hassan A. Shehata, Ahmed H. Shamroukh , M. Abdallah, Corrosion Inhibition and Adsorption Properties of Some Heterocyclic Derivatives on C- Steel Surface in HCl, *j. of bio- tribio corrosion,* 516 (**2020**) 1-11.

15- M. Sobhi ,R. El-Sayed, M. Abdallah ,Synthesis, surface properties and inhibiting action of novel nonionic surfactants on C-steel corrosion in 1M hydrochloric acid solution. *Chem.Eng. Comm..* 203, 6 (**2016**)758-768.

16- R. S. Abdel Hameed, Aminolysis of polyethylene terephthalate waste as corrosion inhibitor for carbon steel in HCl corrosive medium. *Advances in Applied Science Research*, 2,3**(2011)**483-499.

17- R. S. Abdel Hameed, Naser S.Elmetery, Nawaf F.Alshemary, Hassan A.Shehata, Recycling of some plastic waste as green corrosion inhibitors for steel in 1 M phosphoric acid, *Materials Science Journal,* 14, 11**(2016)** 417-4250.

18- R. S. Abdel Hameed, "Evaluation of some water -based surfactants derived from plastic waste as Corrosion inhibitors, for carbon steel alloy", Ph.D., Thesis, Al Azhar Uni**., (2006).**

19- R. S. Abdel Hameed, H. A.Shehata, H.M.Abdelbary ,S.A.Soliman, A.M.Salem, A. M. Atta, , Evaluation of Nonionic Surfactants from Plastic Wasteas Corrosion Inhibitors of Carbon steel in 1M HCl, *Materials Science,* 8,7**(2012)**289-302.

20- R. S. Abd El-Hameed, H. I. AL-Shafey and O. A. Farghaly , "Corrosion of Mild Steel in NaCl solutions and Effect of Recycled Plastic Waste Inhibitors", *Research and reviews in Electrochemistry, 3,2*(*2012)41-49.*

21- R. S. Abdel Hameed; H. I. Al-Shafey; E. A. Ismail; Abd-Alhakeem H. Abu-Nawwas, and O.E. El Azabawy; Poly(oxyethylene)terphthylamine as corrosion inhibitors for carbon steel in methanoic acid; *Int. Journal of Engineering Research and Applications ;* 3, 6 **(2013)** 1094-1103.

22- Reda S. Abdel Hameed, Muhammad Tauseef Qureshi, M. Abdallah, Application of Solid Waste for Corrosion Inhibition of Steel in Different Media- *A Review, Int. J. Corros. Scale Inhib.,* 10,6 **(2021)**68-79.

23- R. S. Abdel Hameed, HI Al Shafey, AH Abu-Nawwas. *International Journal of Electrochemical Science*, 9 **(2014)** 6006-6019.

24- Reda S. Abdel Hameed, M.F. H. Abd el-kader, M. T. Qureshi, M. Al Elaimi, O. A. Farghaly, Green Synthesis for Nonionic Surfactants from Poly(etheleneterphthalate) Plastic Waste, *Egyptian Journal of Chemistry*, 64, 2 **(2021)**773 – 780.

25- M.Abdallah, F.H. Al-abdali, E.M.Kamar, R.El-Sayed, R.S.Abdel Hameed, Corrosion inhibition of aluminum in 1.0M HCl solution by some nonionic surfactant compounds containing five membered heterocyclic

26- Reda. S. Abdel Hameed, Enas H Aljuhani, Rasha Felaly, Alaa M. Munshi, Effect of Expired Paracetamol-Zn^{+2} System and its Synergistic Effect Towards Iron Dissolution inhibition and Green Inhibition Performance, *journal of Adhesion science and Technology*, 34,201**(2020)** 1-27.

27- Esteban Malel and Deborah E. Shalev Determining the Effect of Environmental Conditions on Iron Corrosion by Atomic Absorption, *Journal of Chemical Education* 90,4**(2013)**490-494.

28- Reda S. Abdel Hamee, Meshari M. Aljohani, Ayham Bani Essa, Azaa Khaled, Amr. M. Nassar, Magd M. Badr , Saedah R. Al-Mhyawi, Mahmoud S. Soliman, Electrochemical Techniques for Evaluation of Expired Megavit Drugs as Corrosion Inhibitor for Steel in Hydrochloric Acid, *Int. J. Electrochem. Sci.,* 16 **(2021)**1-13.

29- R. S. Abdel Hameed**,** Hussin I. Al-Shafey, Ismail E.A., Abd-Alhakeem H Abu-Nawwas. Expired Voltaren Drugs as Corrosion Inhibitor for Aluminium in Hydrochloric Acid. *Int. J. Electrochem Sci.* 10 **(2015)**: 2098 – 2109.

30- R. S. Abdel Hameed, Aminolysis of polyethylene terephthalate waste as corrosion inhibitor for carbon steel in HCl corrosive medium. *Advances in Applied Science Research*, **2011**, 2(3): 483-499.

31- R.S. Abdel Hameed, M. Abdallah, Corrosion Inhibition of Carbon Steel in 1M Hydrochloric Acid using some Pyrazolo[*3,4-d*]Pyrimidnone Derivatives, *Protection of metals and physical chemistry of Surface*, 54,1**(2018)** 113-121.

32- Reda Abdel Hameed, M. Abdallah Inhibiting Properties of Some Heterocyclic Amide Derivatives as Potential Nontoxic Corrosion Inhibitors for Carbon Steel in 1.0 M Sulfuric Acid. *Surface Engineering and Applied Electrochemistry Journal,* 54,6 **(2018)** 599-606.

33- Reda S. Abdel Hameed, Cationic Surfactant-Zn^{+2} System as Mixed Corrosion Inhibitors for Carbon Steel in Sodium Chloride Corrosive Medium, *Portugaliae Electrochimica Acta*, 36,4 **(2018)** 1-19.

34- Reda S. Abdel Hameed, Schiff' Bases as Corrosion Inhibitor for Aluminum Alloy in Hydrochloric Acid Medium. *Tenside Surfactants Detergents,* 56,3 **(2019)** 209-215.

35- R. S. Abdel-Hameed, Expired Drugs as Corrosion Inhibitors for Metals and Alloys,

_____

Journal of Physical Chemistry, 8,4*(***2013***)*146-149.

36- R. S. Abdel Hameed, Expired Ranitidine drugs as corrosion inhibitor for aluminum in 1M Hydrochloric acid, *Al-Azhar Bull. Sci.,*20,1*(***2009***)* 151-163.

37- R. S. Abdel Hameed, Ranitidine Drugs as Non-Toxic Corrosion Inhibitor for Mild Steel in Hydrochloric Acid Medium, *Portogalie Electro chemica acta,* 29, 4 (**2011)** 273-285.

38- Abdel Hameed R. S., HI Al Shafey, AH Abu-Nawwas. 2-(2, 6-dichloranilino) phenyl acetic acid Drugs as Eco-Friendly Corrosion Inhibitors for Mild Steel in 1M HCl. *Int. J. Electrochem. Sci.*, 9 (**2014**) 6006-6019.

_____