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To cite this article: Asia Mishaal Salim *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **987** 012019

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Pomegranate Peel Plant Extract as Potential Corrosion Inhibitor for Mild Carbon Steel in a 1 M HCl Solution

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Abstract Herein, *Pomegranate Peel* plant extract was assessed as a low-cost, green and efficient corrosion inhibitor for mild carbon steel in 1 M hydrochloric acid solution using weight loss, potentiodynamic polarisation, an atomic absorption Spectroscopy test, surface roughness test and surface studies by optical microscopy (LOM). Increasing *Pomegranate Peel* extract concentration increases the charge transfer resistance as a result of the adsorption of *Pomegranate Peel* extract on the mild carbon steel surface. The polarisation results showed the mixed-type inhibition behaviour of the studied extract with an inhibition efficiency (%IE) of 90.193% achieved with the addition of 4% vol. of *Pomegranate Peel* plant extract. The adsorption isotherm model of *Pomegranate Peel* plant extract on a mild carbon steel surface followed the Langmuir adsorption isotherm in a HCl solution. The inhibition mechanism of *Pomegranate Peel* plant extract was explained according to the increase in the IE% with concentration and the activation parameters which suggested significant chemisorption of the *Pomegranate Peel* plant extract on the mild carbon steel surface. LOM studies confirmed the formation of a protective layer of *Pomegranate Peel* plant extract on a mild carbon steel surface. Results obtained by different techniques showed good agreement that confirm the potential use of Pomegranate Peel plant extract as a corrosion inhibitor for mild carbon steel in an acidic media.

Keywords: Pomegranate Peel extract · Corrosion inhibition · mild-carbon steel · HCl · LOM

1.0. Introduction

Corrosion is still a significant problem for many industrial systems that use water or acids in their applications, such as cooling systems, condensers, heat exchangers and engines, all of which need water more than any other purpose. Moreover, acids play a big role in pickling processes or acid-cleaning processes in oil refining or manufacturing industries [1]. The maintenance of these systems is very expensive unless the water or acid is treated to protect the systems from erosion, sediment or biological growth. One of the most important and widely used techniques for reducing or preventing metal corrosion is the use of inhibitors, which are chemical compounds that, when added in small amounts to a medium (usually a liquid phase) in which the metal corrodes, impede or eliminate this corrosion. Organic inhibitors are a good method widely used to protect iron and steel from corrosion in acidic media. At present, modern organic inhibitors that have been experimentally discovered have shown remarkable superiority in neutral solutions or salt solutions [2].

Organic compounds, especially adsorbent ones, reduce the rate of corrosion, either by interfering with the corrosion reaction or by forming an adsorbent uniform layer that impedes the effective sites on the metal surface and acts as a protective layer [3]. The toxic nature and high costs of many of the existing organic inhibitors have prompted researchers to develop corrosion inhibitors that are more acceptable and less expensive; natural products can be considered a good source for this purpose. Natural products of plant origin contain many organic compounds such as pigments, tannins, alkaloids and, finally, organic and amino acids. Most of these substances possess a suitable inhibitory action [4].

Hydrochloric acid (HCl) solutions are widely used for acid cleaning, industrial acid pickling, oil well acidizing and acid descaling [5–8], but a hydrochloric acid medium has aggressive effect on substances. Plant extracts are considered cheap, safe, on-hand and renewable sources of inhibitors. Such plant extracts include different organic compounds containing heteroatoms, and some [9–12] have been used to act as metal dissolution inhibitors in various corrosive mediums. "So, we need the using of substances that have inhibiting effect to protect the metals which used in different fields of applications. The formation of thin layer resulting from interaction of organic compounds on the metal (mixed inhibitors) while in case of inorganic inhibitors may block anodic or/and cathodic sites [13–15]. Due to the currently imposed environmental requirements for eco-friendly corrosion inhibitors, there is a growing interest in the use of natural products such as leaves or seed extracts. The terms *eco-friendly corrosion inhibitor* or *green inhibitor* refer to the substances that are biocompatible such as plant extracts since they are of biological origin. Thus, such natural products are being studied by several researchers for their corrosion-inhibition potential as they are more environmentally friendly, showing good inhibition efficiency with the low risk of environmental pollution [16]. The use of extracts of plant as inhibitors in acidic solutions, as Nigella sativa L.[17], Apium graveolens L. [18], Glycyrrhiza glabra [19], pomelo peel extract [20], Dryopteris cochleata leaf extracts [21], Myrmecodia pendans extract [22], Morinda citrifolia [23], Thymus vulgaris plant extract [24], Mentha spicata L. extract [25], phytoconstituent of Ervatamia coronaria [26], myrrh extract [27], Cucurbita maxima [28], Adhatoda vasica, Eclipta alba and Centella asiatica [29] have been investigated. Pomegranate peel have shown several *in vitro* pharmacological effects such as antibacterial, antifungal and anti-inflammatory properties. It is also known for its ethno-medicinal properties, mainly used for boils, rheumatic pain and digestive disturbances. The current research is an attempt to study the inhibitory performance of a pomegranate peel extract as an inhibitor of carbon steel corrosion in 1M HCl. To evaluate the performance of this inhibitor, simple immersion tests were performed; moreover, a corrosion-erosion test and an electrical conductivity test of solutions were performed, and, finally, a microstructure test.

1.1. Corrosion Rate

Corrosion rate may be determined by mil per year (mpy), with a value expressed in (mpy), either from weight loss or from corrosion current density according to Equations 1 and 2. The weight loss can be converted into a corrosion rate (C.R.) [30].

$$C.R = (K*W) / (A*t*\rho)\dots\dots\dots\dots\dots\dots1$$

Where :

K: constant indicate the corrosion rate units $=3.45*10^6$
t : time of exposure in hours
A: area in cm^2
W: mass loss in grams
ρ: density in g/ cm^3

The corrosion rate can also be determined via an electrochemical method by (corrosion current density) and translated into other expressions by Equation 2:

$$Corrosion\ rate = \frac{0.13\ icorr(Ew)}{A\ \rho}\dots\dots\dots\dots\dots2$$

Where:

0.13 = metric and time conversion factor
Icorr = corrosion current (μA)
E.W = equivalent weight (g/eq.)
ρ = density of alloy (g/cm³)

A = Sample Area (cm^2)
mpy = Corrosion rate (mils per year).

1.2. Inhibition Efficiency

Inhibition efficiency was calculated for different inhibitors at different concentrations using the following formula [31]:

IE = (C.R^0 - C.R) / (C.R^0)* 100% ………….3

Where : IE is the inhibitor efficiency

C.R^0 is corrosion rate without inhibitor.

C.R is corrosion rate with an inhibitor.

1.3. Polarisation Resistance

The polarisation resistance (Rp) was calculated using Stern-Geary equation [32, 33]:
$Rp = (ßa *ßc) /[2.303 (ßa+ßc) i_{corr}]$ …………4

Where ßa, ßc are the anodic and cathodic Tafel slopes respectively, and i_{corr} is the corrosion current density. Current density i_{corr} was determined by the extrapolation of the Tafel lines to E= E_{corr} or according to the Stern-Geay equation, resulting in, where Rp was the polarisation resistance, as defined as the tangent of a polarisation curve at E_{corr} [4]. Corrosion-current values may be obtained from polarisation measurement, and the first step is to convert the measured or estimated current value to current density. This is accomplished by dividing the total current by the exposed area of the anodic specimen used in this equation. This calculation may be expressed as follows [33]:

$I_{corr}= i_{corr} / A$

Where $I_{corr :}$ the corrosion current density ($\mu A/ cm^2$)
i_{corr} : corrosion current μA
A: exposed specimen area, cm^2

1.4. Adsorption Isotherms

Adsorption isotherms are usually used to describe the adsorption process. The establishment of adsorption isotherms that describe the adsorption of a corrosion inhibitor can provide important clues as to the nature of the metal-inhibitor interaction. In order to obtain the adsorption isotherm, the degree of surface coverage ($\boldsymbol{\theta}$) for various concentration of the inhibitor has been calculated according to the following equation [35]:

$\boldsymbol{\theta} = [1- i_{inh} / i_{un inh}]$ …………………….4

The Langmuir isotherm was carried out for its fit to the experimental data. The Langmuir adsorption isotherm is given by the following equation [36]:

$C_{inh} / \boldsymbol{\theta} = (1/ K_{ads}) + C_{inh}$ ……………..5

Where

K_{ads}: the equilibrium constant of the adsorption-desorption process.

$\boldsymbol{\theta}$: the degree of surface coverage

C_{inh} : concentration of inhibitors in the bulk solution

The Langmuir isotherm is based on the presumption that every site of metal surface carries one adsorbed species H_2O. Therefore, one adsorbed H_2O molecule is replaced by one molecule of the inhibitor adsorbed on the metal surface. The apparent free energy of adsorption ($\Delta G°_{ads}$) can be calculated from the following equation [35]:

$\Delta G°_{ads}$ = - 2.303 RT log 55.5 K_{ads} …………6

Where

K_{ads} = θ / c (1- θ) ……………………………7

2.0. Experimental Work

2.1 Pomegranate Peel Plant Extracts

A pomegranate peel used as a green corrosion inhibitor. The pomegranate peel was collected, and then it was washed with distilled water, dried and ground into a powder. The process of extraction was achieved by two types of solvents in order to show the solvent effect on inhibition process: distilled water and diethyl ether.

An amount of 10g was dissolved in 200ml of solvent and put in the stirrer for four hours, left to soak for 24 hours and then filtered with a piece of gauze to separate the solids. After filtration, the liquid was further filtered by filter papers two times and then dried from both the distilled water and the diethyl ether extract to achieve a black powder and brown paste respectively several times to achieve a sufficient quantity. When needed as an inhibitor, the amount was dissolved from this extract to get a sample with a 10% concentration.

2.2. Preparation of Mild Steel Samples

The approximate chemical composition of the tested mild steel is explained in Table 1.

Table 1. The composition of mild steel sample (wt.%)

C	Si	Mn	P	S	Cr	Al	V	Cu	Mo	Ni	Fe
0.056	0.034	0.303	0.0008	0.007	0.018	0.049	0.0005	0.016	0.002	0.010	Bal

The mild steel samples were cut by a CNC machine into 1.5*1-cm pieces, and made into working electrodes for electrochemical measurements, as well as 2*2*0.4-cm pieces for weight loss studies, with a 2-mm bore to employ a cooling fluid during the cutting procedure to minimise mechanical damage. Prior to all corrosion experiments, the surface of mild steel was abraded with emery paper (80 to 2,000). Thereafter, the samples were polished with a cloth diamond paste with a size of 1 µm. Afterward, these samples were rinsed and degreased with ultrapure water and ethanol, and then dried and preserved in cans with a silica gel in order to keep them dry until use for corrosion investigation.

2.3. Microscopy Test

Mild steel samples were examined before exposure to HCl by using a light microscopy so as to explore the surface topography of the sample.

2.4. Inhibitor Evaluation
2.4.1. FTIR Spectra
Fourier transform infrared (FT-IR) spectra were recorded to detect the active groups. A 0.002 gm of pomegranate peel plant powder was mixed with 0.02 gm KBr; the mixture was triturated well, and then put in a spatial mould with a strong press to obtain a pellet to put in the device to achieve the FT-IR spectra.

2.5. Corrosion Tests
2.5.1. The Immersion Test
The weight loss examination by immersion test determined the rate of corrosion in addition to the percent of inhibition efficiency. This measurement will furnish a direct response to how corrosion environments affect the samples. The immersion test for polished mild steel engaged samples in HCl with and without different volume percentages of pomegranate peel plant extract (1, 2, 3 and 4% vol.) at laboratory temperature. The samples were submerged in 70 ml of 1MHCl in the presence of inhibitors for a duration of 20 h. Previous soak in HCl weights were achieved for the polishing, eviscerating as well as drying of the samples. Later, a settled interim of an exploratory examination of every test was brought out, washed completely in ultrapure water and ethanol and desiccated in warm air, whereupon the weight reduction was computed.

2.5.2. Tafel Extrapolation Measurements
A Tafel plot was extrapolated to determine corrosion current density and corrosion rate. A three-electrode cell was employed in electrochemical measurements, with mild steel as a working electrode, a calomel electrode as a reference electrode and a platinum electrode as an auxiliary. The exposed part to HCl is 1.33 cm^2 and the working electrode was immersed in 1M HCl to 70 ml for 30 minutes to open circuit potential. Before electrochemical tests, substantial variations of rest potential did not confirm the attainment of steady state. Then, the device was set to a scan rate of 0.1 mV/s. from an O.C.P over and below the potential with ±200 mV. All experiments were completed in laboratory temperature, fresh prepared solution and under-stirred conditions before tests.

2.6. The Absorption Spectroscopy
Atomic absorption spectroscopy (AAS) was used to determine the concentration of Fe^{+2} when the mild steel had been immersed for 3 hrs in HCl only and with pomegranate peel plant extract at laboratory temperature. The absorbance was concluded to the standard elaboration, and set up an adjustment curve from got esteems. Then, the researchers determined Fe^{+2} from the calibration curve for HCl with and without pomegranate peel plant extraction.

2.7. pH Measurement
The pH of HCl has been measured wit and without pomegranate peel plant extract before the immersion test at laboratory temperature, and after 3 h of immersion in order to identify its effect on inhibition.

2.8. Surface Roughness Test
A surface roughness test was used to measure the surface roughness of mild steel before and after the immersion test. The samples tested with and without pomegranate peel plant extract run over the surface of mild steel to register roughness.

3.0. Results and Discussion
3.1. The Microstructure Examination for Mild Steel Surface
A deliberate choice of a mild steel sample to experience microstructure examination. This progression is trailed by segmenting, pounding, cleaning and carving in Nital solution to uncover a precise microstructure and substrate. The specification survey of the mild steel is

finished through the light microscope. The microstructure of mild steel, shown in Fig. 1, consists of ferrite in addition to pearlite.
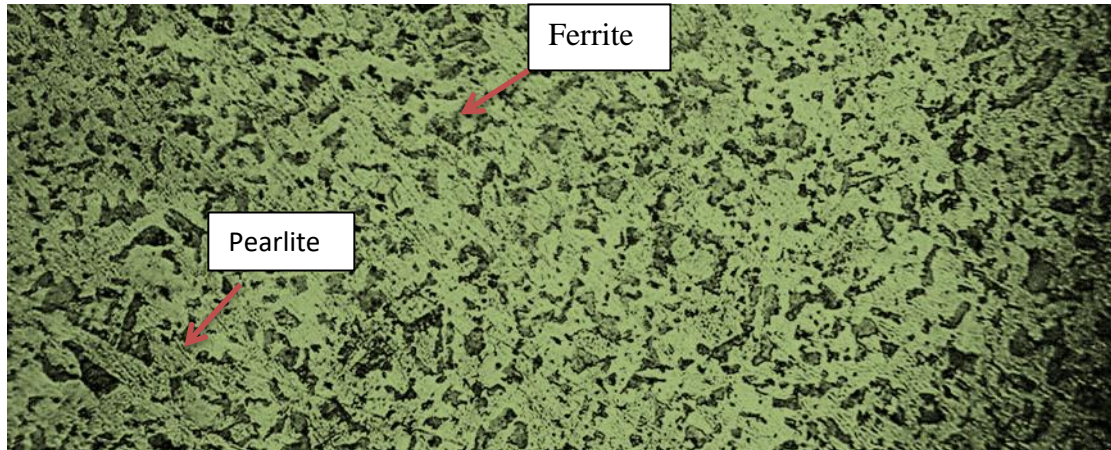

Fig. 1: The microstructure of mild carbon steel (100X)

3.2. Fourier Transform Infrared Spectroscopy Measurement (FTIR)

FTIR Spectra were utilised to assess the defensive film created on the mild steel surface to determine the sort of bonding for organic inhibitors adsorbed on the surface. FTIR to organic inhibitor, as illustrated in Figure 2, showed the results of this test for pomegranate peel powder, and Table 2 shows the effective groups and the corresponding wave numbers in the pomegranate peel plant powder. According to the table, the powder contains many active groups, which are mostly aldehyde compounds, ketones, amines, amides, alcohols, or aromatic or phenolic compounds; all of these compounds have inhibitory properties. Also, the presence of double and triple bonds and aromatic rings in this powder will enhance its inhibitory action, and this is consistent with [37].
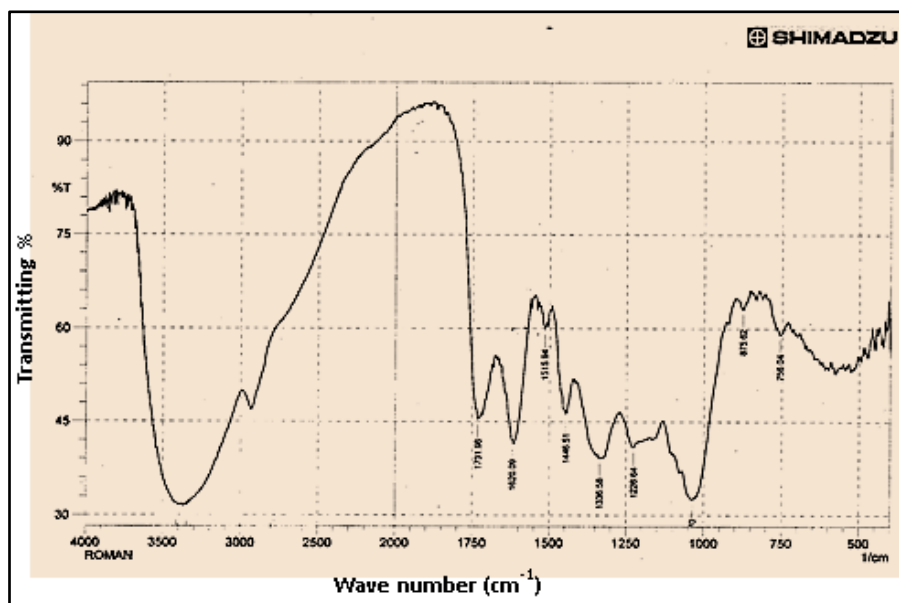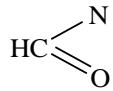

Fig.2: Fourier Transform Infrared (FT-IR) spectroscopy of pomegranate peel plant powder

Table 2: FTIR detection of functional groups of pomegranate peel plant

	Functional Groups	Wave Numbers (cm^{-1})
1	C-H aromatic	756.04
2	C-C	875.62
3	C-H bending	1035.7
4	C-N (amide) HC=N, =O	1226.64
5	C-H stretching	1336.58
6	CH$_2$	1446.51
7	CH$_3$	1515.94
8	C=C	1620.09
9	C(=O)-OH	1731.96
10	$\equiv$ CH$_2$	3365.55
11	C$\equiv$C-O	3392.55

3.3. Corrosion Test

3.3.1. Immersion Test

Figure 3 shows the effect of the period of exposure to a solution of 1M HCl on weight loss in the presence and absence of the inhibitor, wherein the mild carbon steel submerged in the acid solution free of the inhibitor showed a continuous and significant loss in weight with an increase in the period of exposure to the acid solution. The reason is due to the presence of hydrogen ions that work on discharging electrons and speeding up the reaction [38]. As for the loss of weight of the samples submerged in the acidic solution that contains the inhibitor and its different concentrations, it decreased significantly compared to the absence of the inhibitor. This completely reduces the corrosion rate [39].

According to Figure 3, the mild steel sample is subjected to a higher weight loss in 1M HCl without organic inhibitors to 0.37 mg/ cm2 , while, in presence of 1, 2, 3 and 4% vol. organic inhibitors, the lower loss is 0.101 mg/cm2 for organic inhibitor in a concentration 4% vol.

The weight loss, corrosion rate and efficiency of pomegranate peel plant extract have been calculated from the immersion test samples in the absence and presence of 1, 2, 3 and 4% vol. in 1M HCl, as given in Table 3. The corrosion rate in 1M HCl is 186.78 mpy without the addition of an inhibitor. The rate of corrosion is significantly diminished respectively by the addition of an inhibitor to 1MHCl, which exhibited lower corrosion rates of 64.85, 57.54, 46.43 and 31.41 mpy according to organic inhibitors in 1, 2, 3, and 4% vol. concentrations. The corrosion rate without and with different vol.% of organic inhibitor is illustrated in Figure 4.
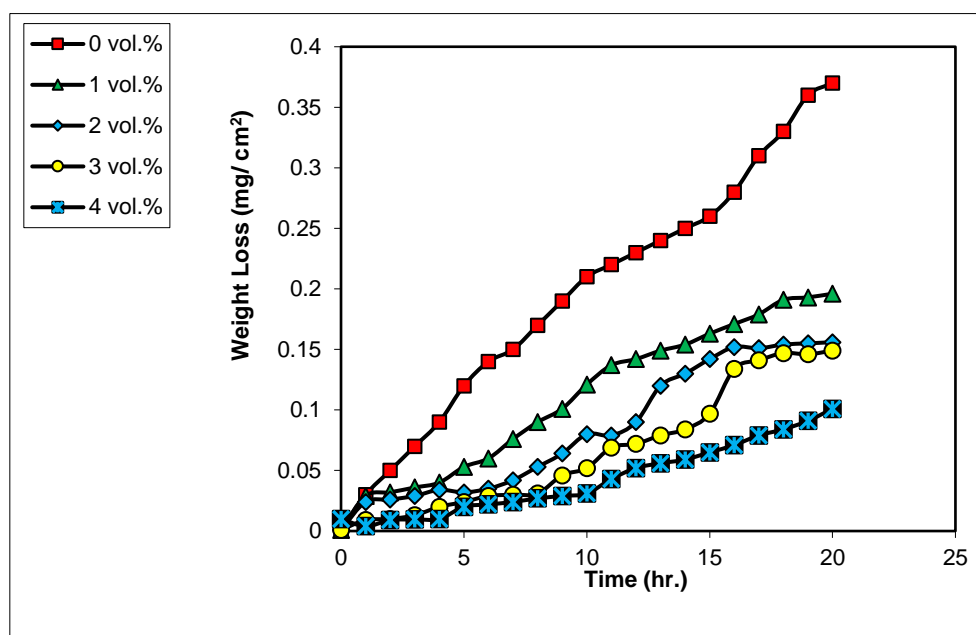
Fig. 3. Weight loss change over time of mild carbon steel samples in a 1M HCL solution
containing different concentrations of inhibitor: 0, 1, 2, 3 and 4% vol.

Table 3. Corrosion Parameters Obtained from Immersion Test for Mild Steel

Concentration vol.%	W (mg/ Δcm^2)	CR(mpy)	η(%)
0	0.37	186.78	……
1	0.196	64.85	65.28
2	0.156	57.54	69.19
3	0.149	46.43	75.14
4	0.101	31.41	83.18

The addition of an organic inhibitor to 1 M HCl plays a favourable role in reducing the rate of corrosion through forming a hydrophobic film barrier on the surface, which could prevent the dissolution of the mild steel grains in a HCl solution [40]. A higher efficiency of an organic inhibitor is 83.18% at a concentration of 4% vol., as illustrated in Figure 5, which reveals the efficiency with various concentrations of organic inhibitors in 1 M HCl for the mild steel. The efficiency of an organic inhibitor is a significant evaluation because of the existence of (-C=N-) and other active groups in the molecules [41]. Active groups are adsorbed on the surface, spontaneously consisting of a monolayer. The planer in organic inhibitor includes electronegative atoms as N as well as O as active centres; moreover, having solitary electron pairs plus conjugated two-fold bonds in the aromatic rings hinders corrosion via adsorption [42].
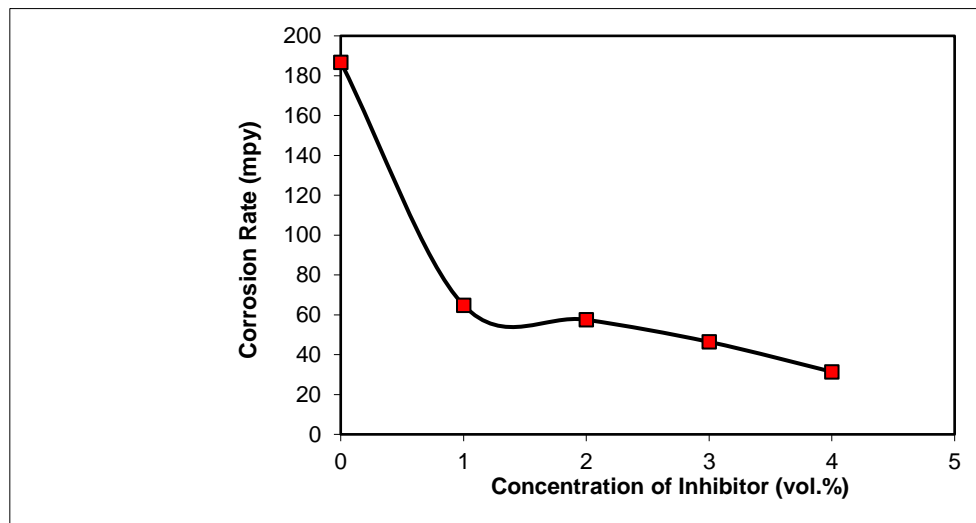
Fig.4. Corrosion rate (mpy) changes without and with 1, 2, 3 and 4% vol. inhibitor concentration immersed in a 1 M HCl solution at 30 °C.

3.3.2. Adsorption Isotherm

The surface coverage values ($\boldsymbol{\theta}$) according to Langmuir model for different inhibitor concentrations have been calculated by immersion test measurements. Plots of inhibitor concentrations (C) versus (C/ $\boldsymbol{\theta}$) are shown in Figure 6. The adsorption for standard free energy of (ΔG°_{ads}) values for the investigated inhibitor is reported in Table 4. Outcomes reveal a spontaneous estimation of the free energy of adsorption in addition to an extreme interface among inhibitor molecules and surface of mild steel. In the organic inhibitor (ΔG°_{ads}) smaller than (-20 KJ/ mol), this construes a physical adsorption happening by electrostatic cooperation. The surface comprises a settled number of adsorption destinations, and every site holds a unique adsorbed. A large adsorption equilibrium is constantly proportional with the interface to the inhibitor with the surface of mild steel. The (K_{ads}) equilibrium constant signifies a bigger adsorption as an organic inhibitor [43]
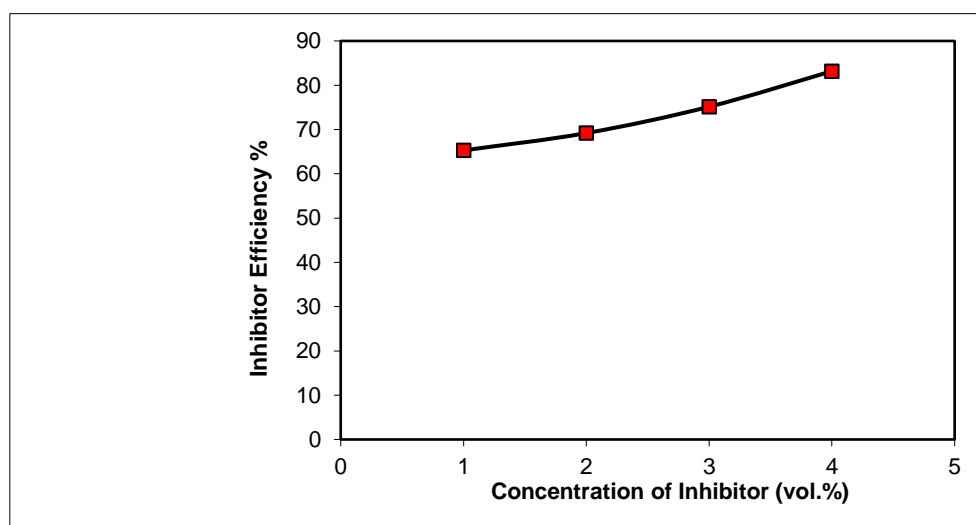

Fig. 5. Inhibition efficiency changes without and with 1, 2, 3 and 4% vol. inhibitor concentration immersed in 1 M HCl solution at 30 °C.
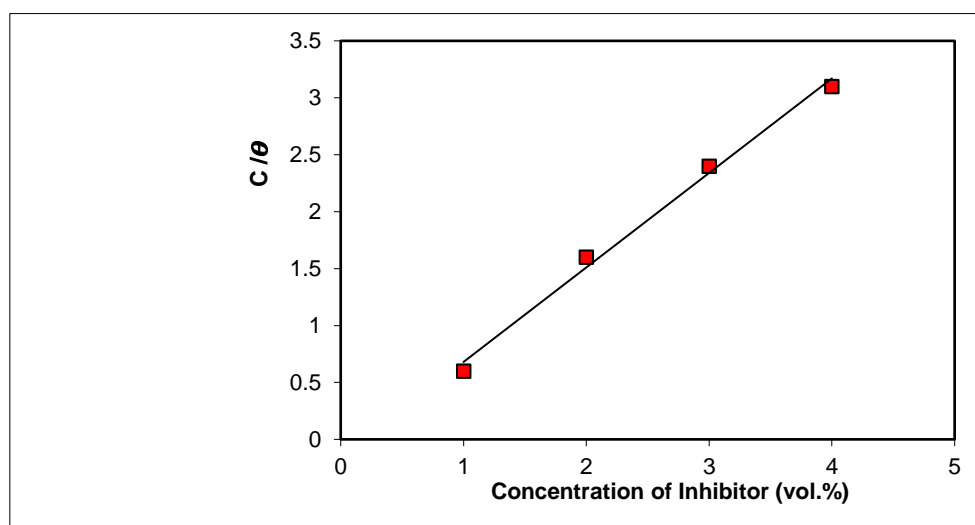
Fig. 6. Langmuir adsorption isotherm of organic inhibitor

Table 4: Standard free energy

Concentration of inhibiter (vol.%)	θ	C / θ	K_{ads} (mg/ l)$^{-1}$	ΔG°_{ads} (KJ/mol)
1	1.66	0.5	0.089	-4.856
2	1.26	1.6		
3	1.25	2,4		
4	1.29	3.1		

3.3.3. Tafel Extrapolation Curves

Polarisation offers important data regarding the dynamic of reactions. The limitations, for instance, the rate of corrosion, anodic in addition to the cathodic Tafel slopes, corrosion current density, potential and polarisation resistance are mentioned in Tables 5 and 6. The results show that, in incremental concentrations of an organic inhibitor, the corrosion current density declines as shown in Figure 7. Also, corrosion potential (E_{corr}) values do not change with incremental organic inhibitor concentrations. The change in the corrosion potential is slight, given that the addition of organic inhibitors can be interpreted as an inhibition of both the anodic and cathodic processes [44]. Organic inhibitors are mixed-type inhibitors, which inhibit the corrosion process by geometric obstructive of both cathodic and anodic sites [45]. The increase in polarisation resistance (R_P) magnitude is because of the creation of a protecting layer on the mild steel / HCl interface. The impediment influence emerges from the interface of ɳ –electrons of the inhibitor rings as well as the existence of C-N (amide) and **C=C** forming bonds per mild steel [46]. The efficiency attained in both immersion tests, besides Tafel investigations, shows analogous performance through slight variance in the efficiencies of organic inhibitor.
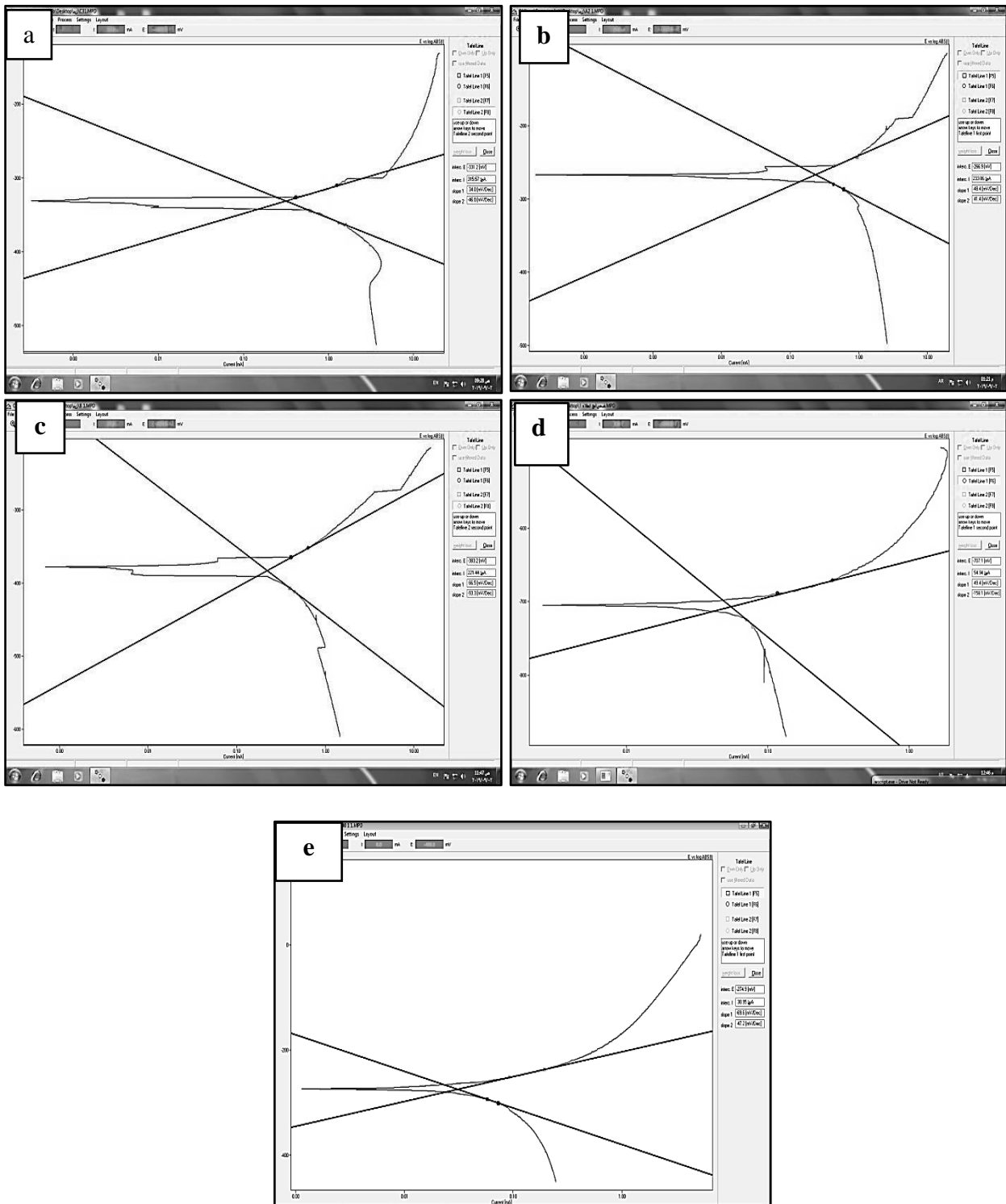
Fig. 7. Polarisation curves for mild carbon steel in 1M HCl without and with (a) 0% vol., (b) 1% vol., (c) 2% vol., (d) 3% vol. and (e) 4% vol. organic inhibitor.

Table 5. The Polarisation Constraints in 1 M HCl for mild steel

Concentration of inhibiter (vol.%)	i_c (µA)	I_C (µA/cm^2)	CR(mpy)	η(%)
0	315.58	238.173	111.425	…….
1	233.86	176.498	82.571	25.985
2	221.44	167.124	78.186	29.830
3	54.94	41.464	19.398	82.813
4	30.95	23.358	10.927	90.193

Table 6. The Polarisation Constraints in 1 M HCl for the mild steel

Concentration of inhibiter (vol.%)	E (mV)	Rp (Ohm.cm^2)	ßa(Mv/Dec)	ßc(Mv/Dec)
0	-331.2	0.08	34.0	- 46.0
1	- 266.9	0.83	41.4	- 48.4
2	-383.2	0.61	66.5	- 93.3
3	- 707.1	0.42	49.4	-158.1
4	-274.9	0.29	47.2	-69.6

3.4. Atomic Absorption Spectroscopy (AAS)

The analysis of AAS results obtained shown in Table 7 could explain the dissolution concentration of Fe^{+2} in 1 M HCl only, without and with organic inhibitor for three hours.

Table 7. Atomic Absorption Spectroscopy Results

Concentration of inhibiter (vol.%)	(Fe^{+2}) concentration dissolved in 1 M HCl (mg/ l)
0	79.6
1	56.7
2	44.2
3	34.9
4	29.9

Results obtained indicate that organic inhibitors reduced in Fe^{+2} amount compared to the HCl without inhibition in 1 M HCl only Fe^{+2} dissolved is 79.6 mg/ l. This value is reduced to 29.9 mg/ l for an organic inhibitor with a concentration of 5% vol. This could impute adsorption of organic inhibitor on the surface, producing an obstruction that separates the surface from the corrosion [47]. The result is consistent with the observed trend from weight loss and Tafel polarisation measurements.

3.5. The surface roughness test
From the results of surface roughness test, it appears that the surface roughness of the pure mild steel sample is 0.147 µm, but, when the sample is immersed in 1M HCl for just 3 hr, it is 0.510 µm. When adding an organic inhibitor to HCl , the surface roughness is 0.094 µm in a 5% vol. concentration. There is a convergence of value in surface roughness between the sample immersed with organic inhibitors. The same goes for the pure sample. This significant improvement in the surface roughness for the sample with an organic inhibitor reveals that organic molecules cover the protective surface, isolating the mild steel from HCl and saving it from corrosion [48] .

3.6. Measurement of PH
The pH of HCl has been measured with and without organic inhibitors before the immersion test, as well as after 3 h of immersion. The pH of 1 M HCl is 0.38 before immersion, while, after 3 hr, the pH is 0.47. The pH values with organic inhibitor before the immersion test are the same (0.35), unchanged after 3 hrs from the immersion test. The lack of sensitivity to pH refers only to corrosion control, and the organic inhibitor remains active in HCl [49].

3.7. Microscopic Examination Test
The optical microscopy was used to scan the surface with and without organic inhibitors in 1M HCl as shown in Figure 8. Fig. 8a shows the pure mild steel surface after being immersed without an organic inhibitor for 20 hrs, which is highly corroded with cracks and pits due to rapid corrosion attack. Thus, the mild steel surface is exceedingly susceptible to damage from HCl attack in the absence of an organic inhibitor. However, in the presence of an inhibitor, a relatively smoother and less-corroded morphology of the mild steel surface can be observed as shown in Figure 8b, which is indicative of the construction of a passive layer on the surface of the mild steel [50].

4.0 Conclusions
Pomegranate peel plant extract, as an organic inhibitor, exhibits excellent inhibition performance when exposed to a series of techniques. In an immersion test, the inhibiting efficiency increases to (83.18%) with organic inhibitor at a concentration of 4% vol. Whereas, from the Tafel polarisation outcomes, the least corrosion current density is 23.358 $\mu A/ cm^2$ with an organic inhibitor at a concentration of 4% vol. The adsorption according to Langmuir isotherm is a preferable deposition of an organic inhibitor, including physical adsorption. From the results of atomic absorption spectroscopy, the organic inhibitor produces a barrier which isolates from the HCl medium, and less Fe^{+2} is dissolved in the organic inhibitor: 29.9 mg/ l. Results of surface roughness test reveal that the roughness is reduced to 0.049 µm with an organic inhibitor at a concentration of 4% vol.
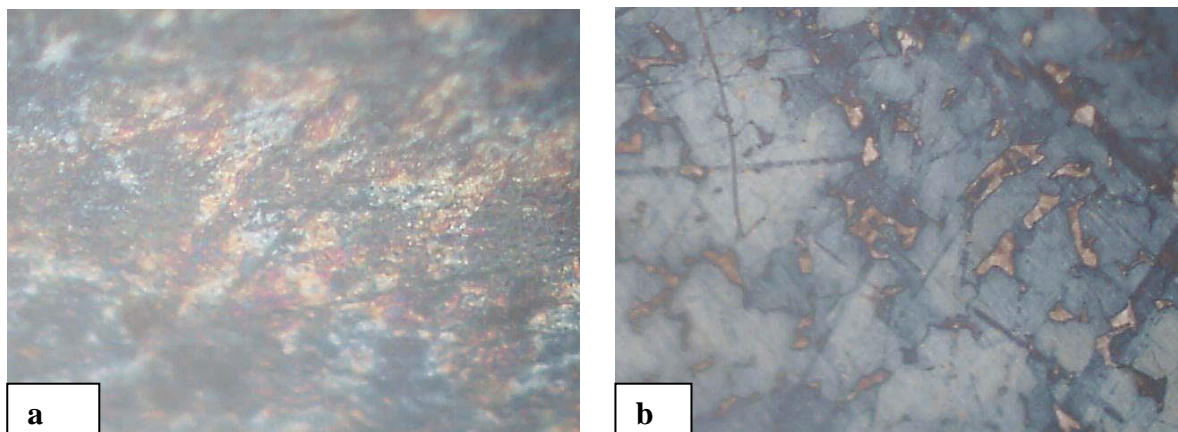
Fig. 8. Microscopy of submerged mild carbon steel samples in: (a) uninhibited 1 M HCl solution, and (b) inhibited 1 M HCl solution: 5% v. organic inhibitor.

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