Electrochemical Behavior of C6.9 Mild Steel Corrosion Inhibition in Phosphoric Acid Using Extracted Aqueous of Red Pomegranate Peels

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Abstract:-

Corrosion inhibition of C6.9 mild steel alloy in 2M H_3PO_4 solution by extracted aqueous of red pomegranate peels (EARPP) as an green inhibitor have been investigated using Half – cell potentials measurments, electrochemical polarization technique measurments has been utilized to assess the corrosion parameters: I_{corr}., E_{corr}., β_c , β_a and R_P have been calculated using Extrapolation of cathodic and anodic Tafel plot and resistance of linear polarization technique. Experimental design of Taguchi procedure (EDTP) was applied for distribution of the polarization experiments conditions. The data obtained from the utilized two techniques are in great concurrence with each other. These investigations have demonstrated that EARPP is a very good "green", blended sort inhibitor. The inhibition procedure was ascribed to the formation of an adsorbed layer on the surface of metal that protects the metal against corrosive agents. The most important feature achieved was the polarization curves showed for a given temperature and exposure time, the corrosion potential E_{corr} of inhibited curves were shifted towards the potential axis, leading to lower corrosion rates I_{corr}, as the inhibitor concentration increased. The protective film formation on metal surface is investigated by means of FTIR.

Keywords: Corrosion inhibition, Mild steel, EARPP, FTIR, Electrochemical measurement

1. Introduction

Corrosion is the destructive attack of a metal by electrochemical or chemical reaction with its environment **[17]**. Metal are presented to the reaction of acids from multiple points of view and for a wide range of reasons. The exposures can be most severing but in many cases the corrosion can be controlled by methods of inhibitors **[2]**. Forms in which acids have an imperative influence **[3]**: (i) corrosive pickling in these procedure, undesirable oxide scales are expelled from metals (typically ferrous metal) and the surface is set up for further operations, for example, enameling, painting, … and so forth (ii) Industrial corrosive cleaning. This is critical technique which is connected mainly to the evacuation of scale and undesirable stores from steam generating equipment and from chemical and petrochemical reaction vessels **[15]**. Hydrochloric acid is generally utilized. Sulfuric and phosphoric acids are likewise utilized for chemical cleaning. (iii) Oil well acidizing. For oil well simulation, substantial amounts of corrosive are pumped at high rates of flow through the oil well tubing in the protection formation **[20]**. The essential object is to act of the formation is such a route as to simulate the oil stream. One of the used acids in these procedures is phosphoric acid. Likewise phosphoric acid solutions are an efficient catalyst for organic reaction such as the alkylation of aromatic hydrocarbons with olefins, the isomerization of olefins and polymerization of normally gaseous olefins **[10]**. Corrosion inhibitors are broadly utilized in industry to lessen the corrosion rate of the metals and alloys in contact with forceful condition. The vast majority of the corrosion inhibitors are synthetic chemicals, costly and exceptionally risky to condition. Thusly, it is desirable to source for ecologically save corrosion inhibitors **[8]**. There are a few reports on inhibition influences of non- dangerous mixes on the metals. The inhibition influences of some non- poisonous natural mixes have been additionally revealed for corrosion of steel **[1]**.

In the present study, the effect of extracted aqueous of red pomegranate peels (EARPP) was evaluated as green corrosion inhibitor for mild steel in phosphoric acid solution by using polarization measurement technique. The aim of this study was to research the influence of inhibition of EARPP as an inexpensive row and ecological corrosion inhibitor for mild steel in 2M H_3PO_4 solution at different temperatures (30, 40 and 50) °C. The electrochemical measurement was used to evaluate the inhibition behavior. In addition the effect of temperature, inhibitor concentration and exposure time on inhibition behavior of the inhibitor was also studied.

Experimental Work

Phosphoric acid solution was utilized throughout the present investigation as corrosive media, under static conditions in absence and presence of aqueous extracted for red pomegranate peels as a corrosion inhibitor of concentrations of 20 and 40 ml/L in corrosive solution at 2 M H_3PO_4 which was utilized as corrosive media at 30, 40 and 50 °C. The corrosion rate of mild steel was found by Polarization technique.

2.1 Materials

A C6.9 mild steel coupon (provided by building Lab. & Department of Inspection, Ministry of Science & Technology) was utilized as working electrode with the following chemical composition as appeared in **Table 1**. Test samples of rectangular shape with 2 cm (width), 4.0 cm (length) and 0.15 cm (thickness) dimensions were utilized in Polarization technique.

Table 1. Chemical Composition of C6.9 Mild Steel.

Comp. Wt%	C	Si	Mn	S	Ni	Fe
Measured	0.069	0.009	0.441	0.005	0.026	Balance

2.2 Sample Preparation

Polarization technique include samples preparation of coupons were strengthened in a vacuum at 570 °C for 1.5 h & were allowed to cool to 25 °C in the furnace in order to remove mechanical stresses. An annealed sample was abraded in sequence under running tap water using emery paper of grade 120, 220, 320, 400 and 600 respectively, washed with running faucet water took after by distilled water, dried on clean tissue, submerged in benzene for 15 seconds and dried with clean tissue, submerged in acetone for 15 seconds and dried with clean tissue and then kept in desiccators above silica gel bed until time of use **[19]**.

2.3 Solutions Preparation

- The corrosive solution utilized in this work is phosphoric acid (H_3PO_4) provided by BDH lab supplies, England, was diluted by distilled water to get the required concentration.
- The extracted aqueous of red pomegranate peels: 250 g of totally dried red pomegranate peel powder was weighed and boiled with twofold distilled water. The particle size of peel powder was (50 μm). The extracted aqueous of pomegranate peel was filtered to remove suspending impurities and made up to 250 ml. The extracted aqueous pomegranate peels was utilized as corrosion inhibitor in the present study **[13]**.

2.4 Half-Cell Potential Measurements

The electric circuit described in **Fig. 2** represents the half-cell potential (HCP) measurments in which the range in potential of the working electrode was recorded as a function of time against saturated calomel electrode (SCE) bridged by a luggin Haber Probe. The testing technique is proficient by setting the luggin Haber capillary at a separation of 1 mm from the working electrode. The potential of half-cell can be perused straightforwardly on the show of the voltmeter. First for 45 min. the corrosion potential was measured every 2 min. and then after ten minutes every 5 min. by digital avometer until reaching steady state condition **[11]**.

2.5 Potentiostatic Polarization Measurements

Polarization measurement is the most used method for studying the corrosion behavior of metal in corrosive media. Metallic surfaces can be polarized by the application of an external voltage, which causes current flows between anode, and cathode caused a change in the electrode potential. This change is termed as polarization and it affect the rate of corrosion.

The polarization measurements were carried out in a corrosion cell shown in **Fig. 1**, the cell was equipped with four necks; one for the working electrode was mild steel alloy samples (exposed area of 8 cm^2 fitted in the electrode holder and opposite side and thickness of the samples were covered with the epoxy to prevent exposure to the solution), held by aluminum clamps in order to hold the samples, it was covered with rubber tube to hold it stable in the cell and prevent the short circuit contact. The 2nd for counter graphite electrode was utilized as the auxiliary electrode with circular shape (1 cm diameter x 10 cm long), wire was associated with the graphite and the graphite connected to plastic plate with epoxy resin. The electrode was mounted directly face to face to the working electrode. The 3rd neck used to immerse a thermometer to reach the goal of checking the temperature of solution, and the last one utilized for (reference electrode) saturated calomel electrode (SCE) sort (Tacussel sort C4) connected by a laggin-Haber test, to guarantee that (KCl) solution was saturated a little amount of (KCl solid) was kept in the solution of SCE as long as the test. The distance between the probe and the working electrode was set at about the optimal value of (1 mm) to limit the experimental error because of IR drop.

Prior to each test the working electrode (samples C6.9 mild steel alloy) was cleaned and rubbed in arrangement utilizing emery paper of grade number 220, 320, 400 and 600 at that point washed with running faucet water took after by distilled water. Immersing for 5 min. in (0.2N NaOH) wiping off the surface after that immersing for 1-2 min. in (3N HCl) then washed with water, degreased by acetone and dried with paper tissue and kept in a dissector above silica gel bed until utilize it **[19]**. The samples were then inundated in 2M H_3PO_4 solution with and without EARPP to temperatures at 30, 40 and 50 °C in different inhibitor concentrations 20 and 40 ml/L at different exposure times 1, 2 and 3 h. In this investigation, the corrosion behavior of resulting protection film because of inhibition and without inhibition corrosion process of mild steel alloy is tested by immersion in stagnate 3.5 % NaCl solution and using potential/current relationship recorded through curves of polarization and potential as HCP vs. exposure time during the corrosion test. Polarization was carried out in electrochemical cell with electrical circuit described in **Fig. 3**.

Table 2 shows the experimental conditions according to Experimental design of Taguchi procedure (EDTP) for the corrosion of inhibited & no inhibited C6.9 mild steel alloy in solution 2 M H_3PO_4 with and without of EARPP.

Fig 1. Corrosion process measurments units

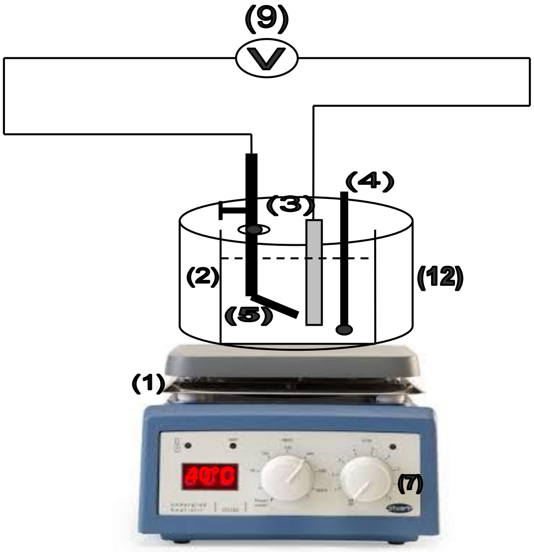


Fig 2. Schematic diagram of half cell circuit potential work

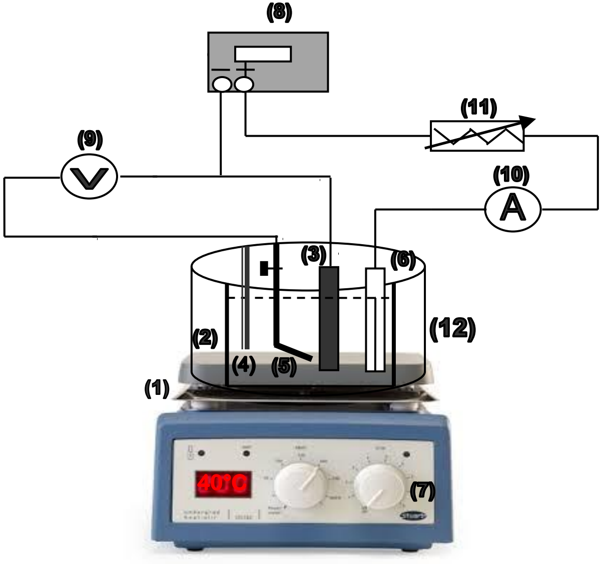


Fig 3. Schematic diagram of electric circuit for polarization work

1.	Heater and Controller	**7.**	Thermostat
2.	Corrosion Cell	**8.**	DC power supply
3.	Working Electrode	**9.**	Voltmeter
4.	Thermometer	**10.**	Ammeter
5.	Reference Electrode SCE	**11.**	Resistance box
6.	Auxiliary Electrode	**12.**	Water bath

The corrosion cell parts were joined to each other, and then connected to DC power supply (type 6236 B, triple output supply Hewlet Packard, USA with rang of 0-6V/0-2.5 A to 0-20V/0-0.5 A), two decade resistance box (type DR4/abcd with the range 0.1MΩ-100 and 100-0.1), multi-rang ammeter (type AV0840B) and multi-rang voltmeter (type AV0840B) as described in **Fig. 1**.

Polarization methods were carried out in corrosion cell with electrical circuit shown in **Fig. 3** and involve changing the potential of the working electrode and monitoring the current which is produced as a function of potential. The polarization started after the corrosion potential variety with time equivalent to around 1 mV/min. The cathodic polarization was done start from a low potential of −850 mV until reaching the corrosion potential, the potential changes 25 mV for each progression, sitting tight for 1.5 min and then the current was recorded. After the cathodic polarization the connection to the power supply were inverted and the polarization began in the anodic direction by change of the potential in the positive direction in 25 mV steps from the potential of about zero current density and at each step the current was observed when stable after about 1.5 min,

polarization proceeded to around 300 mV over the corrosion potential. The polarization figures were plotted under potentiostatic conditions at the actual corrosion potential. The corrosion cell was open to surrounding. The sensitivity of potentiostatic polarization makes it a successful technique for assessing the behavior of corrosion inhibition and corrosion parameters of the protective films **[12]**.

2.6 Characterization and Adsorption Studies

Characterization of the extracted aqueous, solid white zone and solid red zone of red pomegranate peels was carried out by FT-IR studies. Fourier transform infrared spectrophotometer (BRUKER FTIR, TENSOR 27, Germany) was employed to determine the type of functional and active groups composition analysis present in the pomegranate peels responsible for its inhibitive properties.

3. Results and Discussion

3.1 Half-Cell Potential Measurements:

The variation of the half-cell potentials (HCP) of C6.9 mild steel specimens with time of immersion in 2M H_3PO_4 solution with & without EARPP at different temperatures have been studied, **Fig. 4**, shows this variation. The potential changed from initial less negative potential to a highly more negative value within about the first 20 min and finally attains steady state for the rest of time. The reason of this variation with time depends and affected by many parameters (i.e., material purity, surface treatment, oxygen contact, etc.) **[14]**. The exposed

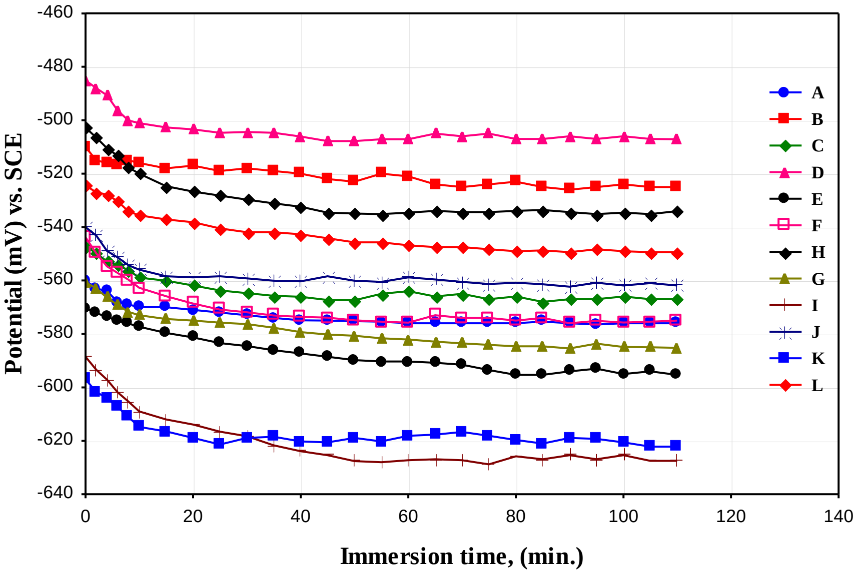


Fig 4. Half-cell potential for different specimens of C6.9 mild steel in 2M H_3PO_4 solution in presence and absence of different EARPP concentrations & exposure times at different temperatures

Table 2. Experimental half-cell potential conditions selected

Specimen symbol	Temp. (°C)	Inhibitor Conc. (ml/L)	Exposure Time (h)
A	30	0	2
B	30	20	2
C	30	0	3
D	30	40	3
E	40	0	1
F	40	20	1
G	40	0	2
H	40	40	2
I	50	0	3
J	50	20	3
K	50	0	1
L	50	40	1

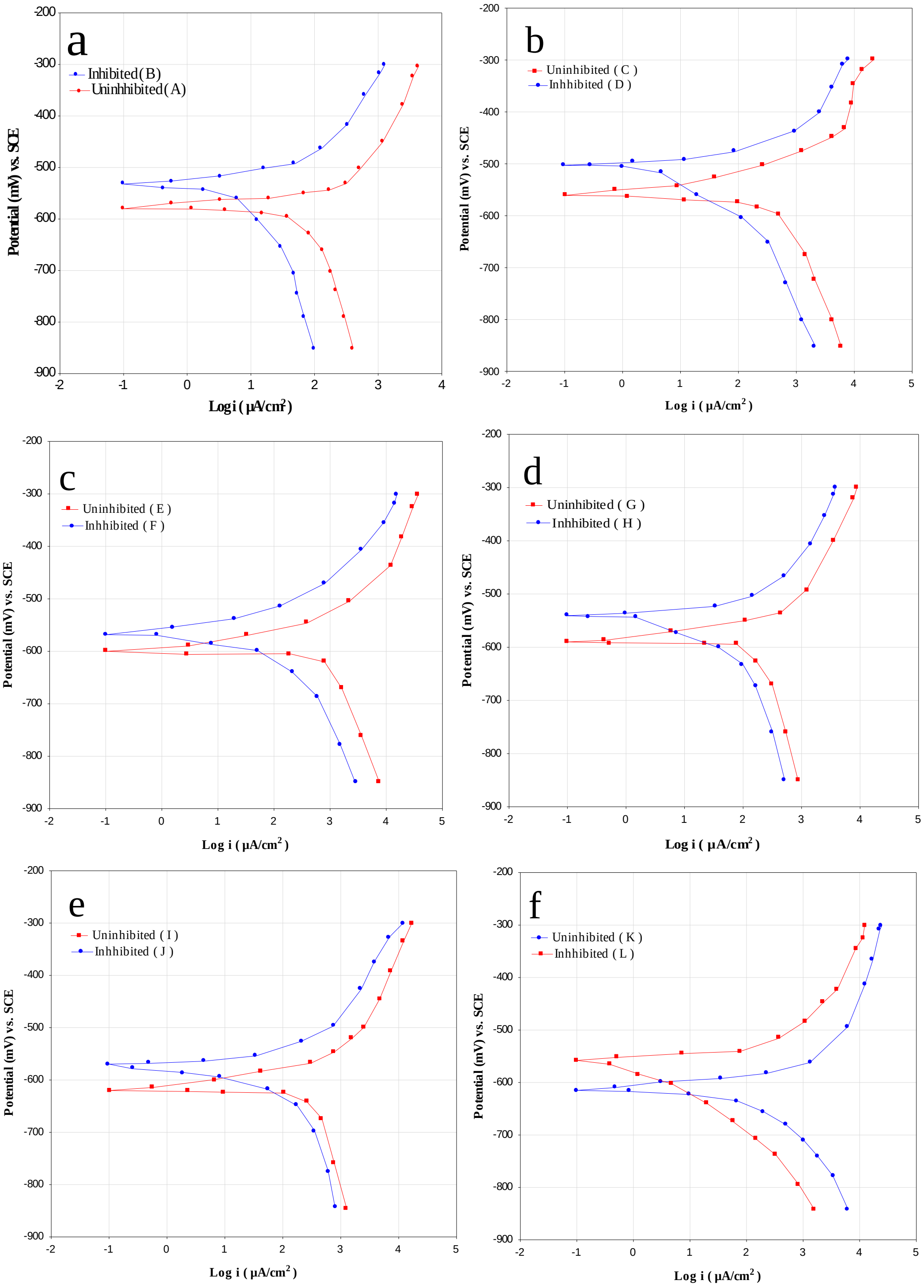


Fig 5. Polarization curves for different specimens of C6.9 mild steel alloy in 2M H_3PO_4 solution in presence and absence of different EARPP conc. & exposure times at different temperatures.

specimens in different conditions in absence & presence of inhibitor concentration developed the half cell circuit potential (HCP) for various specimens listed in **Table 3**. The potentials remain at these values for about 2 hours.

3.2 Potentiostatic Polarization Curves:

The corrosion resistance improvement of inhibited and uninhibited C6.9 mild steel alloy with and without of EARPP was evaluated by following its corrosion potential and current density. **Figs 5a** through **5f** show the anodic and cathodic polarization curves for inhibited and uninhibited mild steel alloy in presence and absence of EARPP in 2M H_3PO_4 solution at different temperatures according to following sequence of experimental polarization conditions for specimens of the three factors described in **Table 2**. The values for the potentials and current densities of corrosion were estimated from the intersection of the cathodic and anodic lines of Tafel. The values of corresponding potentials of corrosion (E_{corr}), current density of corrosion (I_{corr}), cathodic Tafel slope (β_c) and anodic Tafel slope (β_a) for various experimental conditions for specimens computed from curves of polarization have been given in **Table 3**.

Table 3. The results of electrochemical corrosion in 2M H_3PO_4 solution

Specimen symbol	HCP (mV) SCE	I_{corr} ($\mu A/cm^2$)	E_{corr} (mV) SCE	β_c (mV/dec)	β_a (mV/dec)	R_P ($\Omega.cm^2$)	C.R (mpy)	θ (%)
A	-576	194.98	-580	− 83.9	57.7	412.02	89.49	70.5
B	-525.3	57.54	-531.9	− 119.2	83.9	2140.75	26.41	
C	-567.1	524.81	-560.8	− 86.9	83.9	2013.40	240.87	91.7
D	-507.1	43.65	-502.8	− 70.0	56.4	2891.52	20.03	
E	-595.3	194.98	-600	− 86.9	50.9	273.98	89.49	49.9
F	-575.5	97.72	-568.1	-86.9	62.6	996.04	44.85	
G	-585.6	295.12	-590.2	− 119.2	83.9	417.39	135.45	80.5
H	-534.9	57.54	-540.6	− 86.9	70.0	2719.78	26.41	
I	-627.5	301.99	-620	− 75.4	62.5	525.95	138.60	62.8
J	-561.9	112.20	-569.5	− 78.1	70.0	2615.43	51.49	
K	-622.2	501.19	-615	− 70.0	60.1	368.64	230.03	85.2
L	-549.4	74.13	-557.9	− 83.9	46.6	614.78	34.02	

The linear polarization resistance (R_P) is expressed in **Table 3** can be calculated from the following Stern and Geary equation **Eq. (1) [16]**:

$$R_P = \frac{\beta_a \beta_c}{2.303\ I_{corr}\ (\beta_a + \beta_c)} \qquad (1)$$

Where R_P linear polarization resistance in ($\Omega.cm^2$), I_{corr} current density of corrosion ($\mu A/cm^2$),

β_a & β_c are the Tafel slopes for anodic and cathodic behavior respectively.

The corrosion rate is expressed in **Table 3** can be calculated from the following equation **Eq. (2) [17]**:

$$C.R(mpy) = \frac{0.129 \times I_{corr} \times EW}{d} \quad (2)$$

Where: C.R (mpy) is corrosion rate in (mils/year), I_{corr} = corrosion current density(μA/cm^2); EW = equivalent weight of the corroding iron species = 28 g/eq; and d = density of the corroding iron species = 7.87 g/cm^3.

The percentage inhibition efficiency (% θ) is expressed in **Table 3** can be calculated by using polarization-technique measurement from the following equation **Eq. (3) [17]**:

$$\theta = \frac{I_{corr,un} - I_{corr,in}}{I_{corr,un}} \times 100 \quad (3)$$

Where: $I_{corr,un}$& $I_{corr,in}$ are corrosion current densities for uninhibited & inhibited acid respectively.

In these figures it can be seen that:

1. At potentials more positive than E_{corr} for uninhibited, mild steel alloy under the mentioned circumstances of implemented runs, the current density rises sharply indicating more chemical dissolution of metal surface.
2. At potentials more negative than E_{corr}, the 1st zone of all cathodic curves of uninhibited is practically flat, described by a current density expanding quickly with little variation in the applied potential. This is followed by an almost vertical zone where the current density is practically independent on the potential, as additionally announced by Bouklah et al. **[6]**.
3. The cathodic arm of the curves of polarization generally represents the cathodic reaction complicated with mass transfer due to oxygen reduction reaction and its effect on the rate of dissolution reaction of the mild steel alloy.
4. E_{corr} for inhibited mild steel appear to shift to more noble direction by about 50 mV compared to E_{corr} of uninhibited one (improvement of the corrosion resistance of inhibited steel surface) and lower corrosion current density than those obtained for uninhibited steel.
5. Repressing the kinetics of curves of anodic polarization at anodic locations on the surface are more evident in circumstances 30°C temperature, 40 ml/L EARPP concentration and 3 h exposure time, inhibited sample than other inhibited samples for polarization circumstances so at certain potentials more positive than E_{corr}, the anodic current density was 30-40 % less for inhibited compared with the uninhibited one, which means a significant protection could be obtained.
6. Curves of Tafel demonstrate higher values for slopes for cathodic behavior than anodic

because of the disintegration of anode into the acidic solution.

3.3 Effect of variables on the corrosion potential:

Nonlinear least squares regression investigation in view Levenberg-Marquardt estimation method employing the Statistica software , version 10 can be used for estimation of coefficients A_0, A_i and A_{ij}, the results showed in **Table 4.** And creating the accompanying condition for C6.9 mild steel alloy with 0.997 correlation coefficient for polynomial quadratic model **Eq. (4)** to produce the following equation **Eq. (5)** was obtained from the results of the corrosion potentials measurments from polarization curves under different conditions, temperature (30-50) °C, inhibitor concentration (0-40) ml/L EARPP and exposure time (1-3) h.

$$E_{corr} = A_0 + A_1\,T + A_2\,C + A_3\,t + A_4\,T^2 + A_5\,C^2 + A_6\,t^2 + A_7\,TC + A_8 Tt + A_9\,Ct \tag{4}$$

Table 4. The regression analysis coefficient values of the predicted correlation (polynomial model)

Coeff.	A_0	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Value	-667.521	1.901	1.986	65.866	- 0.019	- 0.040	- 3.208	0.015	- 1.133	0.204
Correlation Coefficient (R^2)			0.997			**Proportion of Variance**			0.994	
Final Value of Loss Function			81.115							

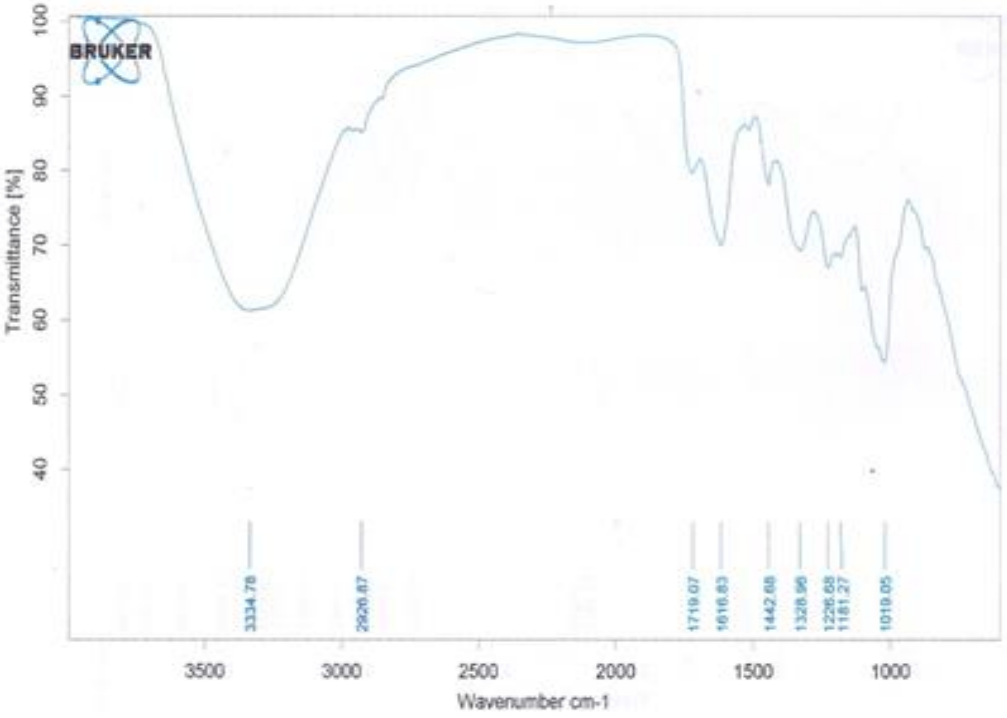
$$E_{corr} = -667.521 + 1.901\,T + 1.986\,C + 65.866\,t - 0.019\,T^2 - 0.040\,C^2 - 3.208\,t^2 + 0.015\,TC - 1.133\,Tt + 0.204\,Ct \tag{5}$$

Where E_{corr} is the corrosion potential (mV), T is the temperature (°C), C is the EARPP concentration (ml/L) and t is exposure time (h)

The preliminary information of the qualitative and quantitative influence on the corrosion potential E_{corr} of each individual variable in the regression equation can be obtained from its coefficients magnitude and sign **[9]**. The positive sign for the coefficients of the temperature of solution, EARPP concentration and the exposure time indicates that the corrosion potential increases with the increase in these three variables. Furthermore, the given polynomial regression equation suggest that the dominant process variable is the exposure time is more pronounced than that of temperature and EARPP concentration, while the effects of the temperature of solution and the EARPP concentration are considerably smaller. The variable square (quadratic) and interactions have generally is very small influence on the considered problem, except the variable quadratic of the exposure time. In order to take into account the contribution from the remainder variable quadratic and interactions, these terms were not neglected **[5]**.

3.4 Effect of RPP Compositions and FT-IR measurements:

The nature and kind of components present in the red pomegranate peel (RPP) might be responsible for its inhibition influence. FT-IR tests were performed and the infrared spectrum for the (RPP) is shown in **Figs. 6A** through **6D**. Three zones of peel were examined in order to assess the classification of compounds within the (RPP). **Figs. 6A** through **6C** exhibit FT-IR curves for aqueous extract, solid white and solid red of (RPP). While, **Fig. 6D** appear the total curves. It can be seen that the IR spectrum ranged from 1020.33 to 3334.78 cm^{-1}. It can be seen a peak present around 3334.78 cm^{-1} which likely agree to phenols **[18]**, fundamentally by the flavonoid, which has a chemical structure shown in **Fig. 7**. Peaks in the range of 2926.87 to 3334.78 cm^{-1} that coincide to absorption caused by O-H and C-H single bonds. Peaks existing about 2100 cm^{-1} agree to a combination of substituted aromatic combination. The peak present at 1600 cm^{-1} indicate the existence of either the carbonyl, C=O combination, or a C-O-C connection, or C=C bond. These results agree with previous works of many researchers **[7]**. They founds that red pomegranate peel keep a whole phenolic contents of 64.2 mg/g dry solids **[4]** and that flavonoid is a significant phenolic antioxidant in pomegranate peel **[21]**.


BRUKER
Transmittance [%]
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80
70
60
50
40
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1719.07
1616.83
1442.68
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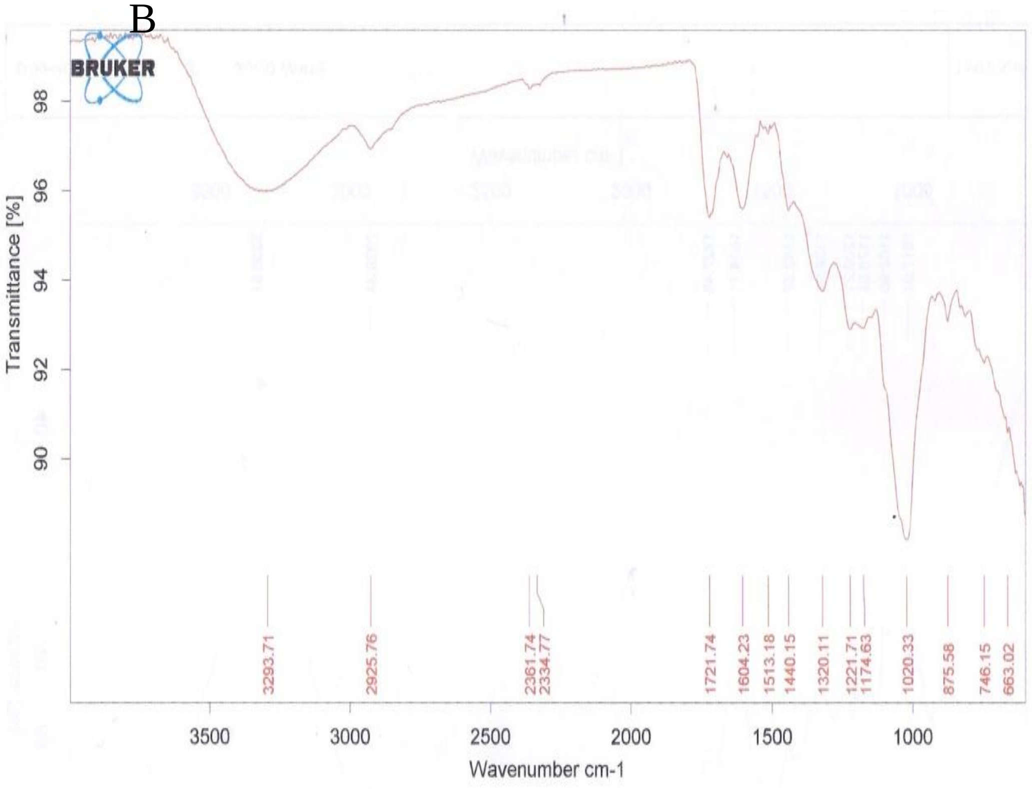
1226.68
1181.27
1019.05
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

B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Wavenumber cm-1

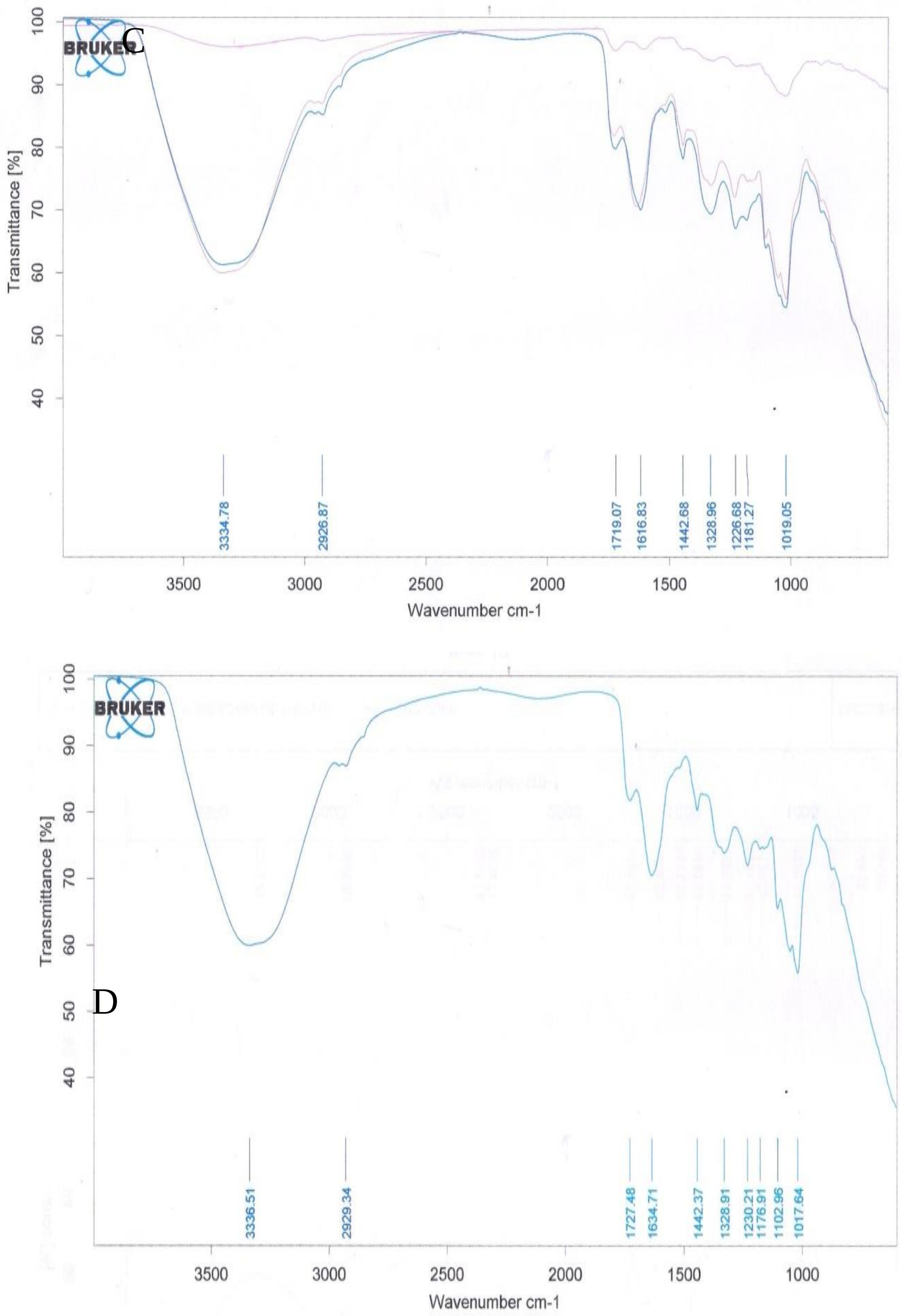

Fig 6. Infrared spectrum FT-IR curves for the red pomegranate peel.
(A) Extracted aqueous. (B) Solid white. (C) Solid red. (D) Total FTIR curves.

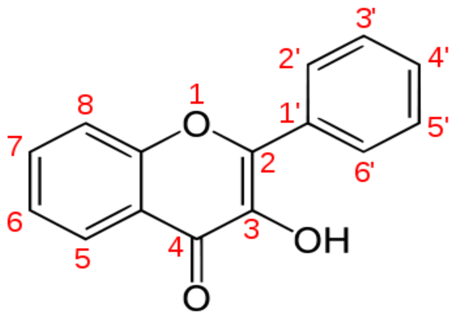

Fig 7. Structure of flavonol

4. Conclusions

Results of polarization measurement shows that EARPP acts as an effective corrosion inhibitor for C6.9 mild steel alloy in 2 M H_3PO_4 within the studied region of temperature , inhibitor concentration and exposure time, and it inhibts mild steel from corroding by H_3PO_4 by influencing both anodic and cathodic reactions, with the anodic reaction prevailing.

The polarization measurement of inhibited C6.9 mild steel alloy corrosion conditions by EARPP in phosphoric acid solution shows a supper suppression of current density in following order:

$$D > L > H > B > J > F$$

Many critical assessments have been made concerning the possibility of accurately predicting general corrosion behavior by the potential measurments in different temperatures, inhibitor concentration and exposure time. Accordingly, an attempt was made to find a simple relation between the potential and the variables (temperatures, inhibitor concentration and exposure time); a quadratic model is proposed to predict the effect of mentioned parameters on the corrosion potential (E_{corr}) in phosphoric acid environment.

The mechanism of inhibition is probably, the formation of an oxide layer as a result of combination action of the inhibitor blend and dissolved oxygen.

It was found that the corrosion current density increases with temperature in all exposure times in the presence and absence of the inhibitor.

The inhibiting effect of EARPP increases with increase of inhibitor concentration and decreases with increase temperature of the corrosion medium in all exposure times.

FT-IR displays that Flavonol represent the most efficient compound of EARPP.

5. References

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التصرف الكهروكيمياوي لتثبيط تآكل سبيكة حديد مطاوع كاربون 6,9 في حامض الفوسفوريك بإستخدام المُستخلص المائي لقشور الرُّمان الأحمر

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الخلاصة:-

تم دراسة تثبيط التآكل لسبيكة حديد مطاوع الحاوية على نسبة كاربون 6,9 في محلول حامض الفوسفوريك بتركيز 2 مولاري بإستخدام المُستخلص المائي لقشور الرُّمان الأحمر كمآنع أخضر وذلك بإجراء قياسات جهود نصف الخلية و قياسات تقنية الأستقطاب الكهروكيمياوي التي أستخدمت لتعيين عوامل التآكل: تيار التآكل وجهد التآكل و ميل تافل الكاثودي و ميل تافل الأنودي وتم حسابها بإستخدام طريقة إستقراء تافل لمخطط تافل الكاثودي والأنودي وتقنية مقاومة ألأستقطاب الخطية. تم أستخدام طريقة تصميم تاكوجي العمليّة لتوزيع ظروف تجارب الأستقطاب. البيانات التي تم الحصول عليها من جميع الطرق المُستخدمة متوافقة جيداً كلاهما مع بعض. وقد أظهرت هذه الدراسات أن المُستخلص المائي لقشور الرُّمان الأحمر كمآنع "أخضر" جيد جداً من النوع المختلط. تُعزى عملية التثبيط تكوين الطبقة المُمتزة على السطح المعدني التي تحميه ضد العوامل المسببة للتآكل. أهم ميزة تم تحقيقها أن مُنحنيات الأستقطاب أظهرت لدرجة حرارة معينة وزمن تعرض ، كلما أزداد تركيز المآنع حصل تحول لجهد التآكل لمنحنيات الأستقطاب بوجود المثبط بإتجاه محور الجهد الأكثر موجباً مُسبباً أقل معدّلات تآكل. تم دراسة تكوين الطبقة الحامية على سطح المعدن بواسطة تحليل مطياف تحويل فوريير بالأشعة تحت الحمراء لتأكيد المجاميع الفعّالة لجزيئات الفلافونول.

الكلمات الرئيسية: تثبيط تآكل ، حديد مطاوع ، مُستخلص مائي لقشور الرُّمان الأحمر ، تحويل فوريير بالأشعة تحت الحمراء ، المقياس الكهروكيمياوي