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Data Article

Optimization and inhibitive effects of Sweet Potato Leaf Extract (SPLE) on mild steel

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ABSTRACT

Weight loss and electrochemical techniques were used to evaluate the inhibition efficiency of sweet potato leaf extracts (SPLE) as inhibitor on mild steel in phosphoric acid. Box Behnken design was used to examine the interactions of these variables: acid concentration (0.5–1.5 M); time (5–10 days); inhibitor concentrations (0.3–0.9 g/L) and temperature (30–60 °C) respectively. Polarization and Electrochemical impedance and were used to measure the inhibition efficiency. The surface morphology of coupons was analysed using Scanning Electron Microscope (SEM). The experimental data was statistically analysed and regression equation was generated for inhibition efficiency. The weight loss measurement revealed that extract acts as an inhibitor for mild steel in phosphoric acid and decreases rate of corrosion. The results of inhibition efficiency derived from polarization studies and impedance analyses agree. The validated experiment's coupon created a better protected inhibitive layer than coupon of the best process level as observed from experimental design, according to SEM analysis. It can be concluded that the extract operated as an inhibitor by producing outer film on the surface of mild steel.

1. Introduction

Inhibitors have been commonly used in acidic environments to mitigate mild steel against corrosion. Several preventive methods have been used by researchers [1]. Generally, when selecting an effective anti-corrosion material, the overall cost of operation, availability and biodegradability, must be taken into account. Furthermore, this has prompted researchers to investigate the usage of green corrosion inhibitors. Several of the extracts used as inhibitors are: *Dryopteris Cochleate* leaf extract [2]; xanthium strumarium leaves extract [3]; *azadiracha indica* [4]; bitter kola leaf extract [5]; heum Ribes Root Extract [6]; hunteria umbellate seed husk extracts [7]; Psidium Guajava Linn leaves extract. [8]; punica granatum; sun flower [7]; Rosmarinus officinalis extract [9]; Acanthopanax senticosus leaf extract [10]; rice straw [11]; Loquat Leaf Extract [12]; jatropha Stem [13]; vernonia amygdalina extract [14]; Soybean extract [15]; maple leaves extract [15]; Rosemary extract [16]; Beta vulgaris peel extract; Kapok leaves extract [17]; musa paradisiaca

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peels [18]; epiphyllum oxypetalum extract [19]; katemfe seed extract [20], Corchorus olitorius stem [21]. This research is innovative since it offered a workable replacement that is not only ecologically benign but also easily accessible for use as a green inhibitor to fight corrosion. According to [22]; investigated inhibiting action of the banana peel extract as a corrosion inhibitor in controlling corrosion of mild steel in 0.1 M HCl solution was studied and highest percentage inhibition observed was 87%. [23] Investigated the effect of a purple sweet potato extract mixed with turmeric (*Curcuma longa*) as a green inhibitor on the corrosion rate of API 5 L steel in a 3.5% NaCl environment. Curcumin and kaempferol antioxidants are found in turmeric extract, while antocyanin antioxidants are found in purple sweet potato extract. Weight loss and polarization methods were used to assess corrosion rates. The results showed that 16 ml of turmeric mixed with 2 ml of purple sweet potato had the highest inhibitor efficiency of 82.54%, while 8 ml of turmeric mixed with 6 ml of purple sweet potato had the lowest inhibitor efficiency of 74.2%.

Furthermore: [24] studied the inhibition of mild steel corrosion in 1 M sulphuric acid media by ethanolic extracts of Ipomoea batatas using the gravimetric and gasometric methods. The extracts recorded an inhibition efficiency of 61.1% and 52.6% at room temperature for the gravimetry and the gasometry respectively. No research had been reported on the Optimization and Inhibitive Effects of Sweet Potato Leaf Extract (SPLE) on Mild steel in Phosphoric Acidic environment, The novelty of this research is that Box Benkhen Design with four variables (temperature, time, inhibition concentration and acid concentration) were considered. The objective of this study is to optimize the inhibitive effect of sweet potato leaf extract on mild steel using four variables highlighted above.

2. Procedure

2.1. Metal preparation for the experiment

Mild steel was sourced from Mechanical Engineering workshop at Landmark University, Omu-Aran, Kwara, Nigeria. It was divided into 20 mm by 25 mm coupons with 10 mm thickness, and 10 mm hole was drilled into the center of mild steel. To achieve a smooth surface, emery paper was vigorously rubbed over each coupon and then cleaned with distilled water, and then degreased with acetone. This technique was adapted from Oyewole et al., (2021), Oyewole et al., (2022); respectively [11,12].

2.2. Preparation of the extract

The SPLE which was purchased from Omu-Aran, Kwara State, then air dried for 10 days, then grinded into fine powder. The cold extraction method was utilized. 100 g of SPLE were weighed and submerged in 1000 mL of ethanol for 24 h. The prepared extract was utilized with H_3PO_4 concentrations ranging from 0.5 M to 1.5 M

2.3. Phytochemical analysis

The quality and quantity of active constituents of the SPLE which are: Alkaloids, Tannins, Saponins, Flavonoids, and Glycosides that might be present were analysed for; phytochemical analysis

2.4. Experimental design

The Box Benkhen Design with four variables (temperature, time, inhibition concentration and acid concentration) generated twenty-nine experimental runs. Independent variables, with levels are shown in Table 1; while Table 2 showed the variable interactions.

2.5. Weight loss method

Weight loss measurement was conducted for 29 experimental runs generated by the Design Expert. The mild steel was then reweighed by obtaining difference in mild steel weight before and after immersion to determine weight loss for 29 experimental runs generated. Weight loss, corrosion rate, inhibition efficiency and surface coverage were calculated using Eqs. (1)-4 respectively.

$$\text{Wight loss} = W_b - W_a \tag{1}$$

Table 1
Experimental range of the independent variables, with factor levels for the inhibition of SPLE on mild steel in solution.

Independent variables	Codes	Levels	
		Low level	High level
Time(days)	X_1	5	10
Temperature(°C)	X_2	30	60
Inhibition Concentration(g/L)	X_3	0.3	0.9
Acid Concentration(M)	X_4	0.5	1.5

Table 2
Variables interaction for the inhibition of SPLE on mild steel in solution.

Std	Run	Factor 1 A: Temperature (°C)	Factor 2 B: Exposure Time (days)	Factor 3 C: Inhibitor Conc (gL^{-1})	Factor 4 D: Acid Conc (M)
24	1	45	10.0	0.6	1.5
5	2	45	7.5	0.3	0.5
10	3	60	7.5	0.6	0.5
4	4	60	10.0	0.6	1.0
12	5	60	7.5	0.6	1.5
6	6	45	7.5	0.9	0.5
3	7	30	10.0	0.6	1.0
28	8	45	7.5	0.6	1.0
27	9	45	7.5	0.6	1.0
21	10	45	5.0	0.6	0.5
8	11	45	7.5	0.9	1.5
22	12	45	10.0	0.6	0.5
7	13	45	7.5	0.3	1.5
29	14	45	7.5	0.6	1.0
17	15	30	7.5	0.3	1.0
19	16	30	7.5	0.9	1.0
26	17	45	7.5	0.6	1.0
9	18	30	7.5	0.6	0.5
14	19	45	10.0	0.3	1.0
25	20	45	7.5	0.6	1.0
2	21	60	5.0	0.6	1.0
15	22	45	5.0	0.9	1.0
23	23	45	5.0	0.6	1.5
1	24	30	5.0	0.6	1.0
11	25	30	7.5	0.6	1.5
13	26	45	5.0	0.3	1.0
16	27	45	10.0	0.9	1.0
18	28	60	7.5	0.3	1.0
20	29	60	7.5	0.9	1.0

$$CR = \frac{\Delta W}{At} \tag{2}$$

$$IE = \frac{CR_o - CR_{in}}{CR} X100 \tag{3}$$

$$\theta = \frac{IE\%}{100} \tag{4}$$

where: ΔW is weight loss (g); W_b is weight before immersion and W_a is weight after immersion., A is area of the specimen (cm^2), CR is corrosion rate (g/cm^2); *IE* is inhibition efficiency; t is time of exposure in days, CR_o and CR_{in} are corrosion rates of mild steel in the absence and presence of inhibitor, ϴ is surface coverage.

2.6. Electrochemical impedance spectroscopy (EIS)

The electrochemical analysis was carried out with the help of an Autolab brand potentiostat and the Nova 1.7 software. A cell with three thermostats and a double wall (Tacussel Standard CEC/TH) is attached. A saturated calomel electrode (SCE) and a platinum electrode were used as reference and auxiliary electrodes. The electrolyte's accessible surface area is $1cm^2$. Ecorr uses an electrochemical system (Tacussel) with a digital potentiostat model Autolab 1.7 computer to perform electrochemical impedance spectroscopy (EIS) measurements after immersion in solution. The extract concentrations used were: blank, 0.3 g/L, 0.6 g/L and 0.9 g//L respectively) for evaluation of its anticorrosion performance. This was calculated using Eq. (5)

$$IE = \frac{R_{ct} - R_{ct}^{i}}{R_{ct}} \tag{5}$$

where: R_{ct}^{i} and R_{ct} are charge transfer resistance in the absence and presence of the inhibitor respectively.

2.7. Polarization test

Tafel polarization measurements were taken with an electrochemical apparatus controlled by a computer (Autolab PGSTAT 302 N). In 1 M H_3PO_4, platinum electrode was used as the counter electrode (CE), Ag/AgCl as the reference electrode (RE), and steel as the working electrode (WE). Polarization measurements were performed at 45 °C using a typical three-electrode Pyrex glass cell. For each measurement, however, a test specimen with 1 cm^2 of exposed area was used as a working electrode, with a lugging probe placed near the working electrode. Furthermore, all of the tests were conducted in static aerated liquids. A stable open circuit potential was obtained by immersing the working electrode in test solution for one hour. The potentiodynamic polarization study was performed with a linear sweep technique at a scan rate of 1 m V/s and a potential range of −250 mV + 250 mV in relation to the corrosion potential. After achieving a consistent open circuit voltage, the working electrode was immersed in a test solution for 1 h. Extrapolating the linear Tafel segments of the anodic and cathodic curves to equilibrium potential provided the corrosion current densities (I_{corr}). The studies were carried out with concentrations of 0 g/L, 0.3 g/L, 0.6 g/L, and 0.9 g/L. This methodology was adapted from the work done by Onukwuli et al., 2020; Annes et al., 2018 respectively [3,25]. The Tafel inhibition efficiency (IE_T%) was obtained from Eq. (6).

$$\text{Tafel Inhibition efficiency } (IE_T\%) = \frac{Icorr_{cont} - Icorr_{inh}}{Icorr_{cont}}(100) \quad (6)$$

where:

$Icorr_{cont} =$ uninhibited solution corrosion current density and

$Icorr_{inh} =$ inhibited corrosion current densities

2.8. Scanning electron microscope (SEM)

The surface morphology of the coupon with the maximum inhibitory efficiency as established by the Experimental Design, the coupon from the optimal process level that had been validated, and the blank coupon were examined using SEM.

3. DATA, value and validation

3.1. Result of phytochemical analysis

SPLE has bioactive compounds such as saponnis, phenol, tannis, alkaloids, steroids, and glycosides, which were responsible for the inhibitory effects of a strong inhibitor, according to the phytochemical study. The phytochemical results also showed that the constituents acted as anti-oxidants, which protect metals and alloys from corrosion. The result of phytochemical analysis indicated SPLE contained bioactive compounds that were responsible for the inhibitory properties of a good inhibitor. The result observed confirmed the report of Deng and Xianghong (2012), Okewale et al., 2020 [26–27]. Furthermore; Table 3 showed the quantitative and qualitative properties of the SPLE.

3.2. Statistical analysis and modeling for the inhibition efficiency

Table 4 is the result from Design of experiment with reponses generated while Table 5 is for ANOVA. The model's coefficient of determination R^2 was 0.8684 while the Adjusted R^2 was 0.7368. This was found to be in close agreement because the difference was less than 0.2. The regression equation formed in coded terms is as given below (Eq. (7)). Fig. 1 showed the plots of predicted versus actual. Figs. 2(a-e), shows 3-D plots of the interaction between the variables and responses. The increase in the temperature and time had an impact on the response variables. Furthermore, increase in amount of inhibitor, promoted the inhibition process. This indicated that SPLE is a strong eco-friendly extract.

$$\text{Inhibitor efficiency} = +91.26 - 3.03A + 1.85B + 9.95C + 1.35D + 3.75A^2 + 2.35B^2 - 7.31C^2 - 3.72D^2 + 0.56AB + 8.47AC - 2.32AD - 1.33BC - 1.51BD + 10.80CD \quad (7)$$

3.3. Validation of the optimal process levels

Table 6 is the result of validated experiment. With temperature (38 °C), time (5 days,), inhibitor concentration (0.9 g/L) and acid concentration (1.0 M) respectively, the Inhibition efficiency was 99.80%. This result is higher than the amount generated by Edoziuno

Table 3
Phytochemical Component result of SPLE.

Test	Confirmation	Quantity (mg/100 g)
Saponins	+++	0.832
Flavonoid	–	–
Steroid	++	0.321
Phenol	+++	1.341
Alkaloid	–	–
Tannin	++	0.439
Glycoside	++	0.241

- Not present; ++: moderately present, +++: highly present.

Table 4
Box Behnken Design layout showing calculated values of weight loss, corrosion rate, inhibition efficiency and surface coverage of mild steel, varying temperature, time, inhibitor concentration and acid concentration.

Std	Run	Factor 1 A: Temperature (°C)	Factor 2 B: Exposure Time (days)	Factor 3 C: Inhibitor Conc (gL^{-1})	Factor 4 D: Acid Conc (M)	Response 1 Weight loss (g)	Response 2 Corrosion rate (g/cm^2.hr)	Response 3 Inhibition Efficiency (%)	Surface Coverage (ϴ)
24	1	45	10.0	0.6	1.5	0.51	0.0004250	92.61	0.9261
5	2	45	7.5	0.3	0.5	0.46	0.0005100	76.28	0.7628
10	3	60	7.5	0.6	0.5	0.07	0.0000778	96.38	0.9683
4	4	60	10.0	0.6	1.0	0.31	0.0002580	93.86	0.9386
12	5	60	7.5	0.6	1.5	0.24	0.0002670	95.36	0.9536
6	6	45	7.5	0.9	0.5	0.02	0.0005670	73.63	0.7363
3	7	30	10.0	0.6	1.0	0.18	0.0001500	96.00	0.9600
28	8	45	7.5	0.6	1.0	0.51	0.0003670	91.26	0.9126
27	9	45	7.5	0.6	1.0	0.51	0.0003670	91.26	0.9126
21	10	45	5.0	0.6	0.5	0.22	0.0003670	85.20	0.8520
8	11	45	7.5	0.9	1.5	0.07	0.0000778	98.65	0.9865
22	12	45	10.0	0.6	0.5	0.14	0.0001170	94.57	0.9457
7	13	45	7.5	0.3	1.5	2.17	0.0024100	58.09	0.5809
29	14	45	7.5	0.6	1.0	0.51	0.0003670	91.26	0.9126
17	15	30	7.5	0.3	1.0	0.17	0.0001890	95.50	0.9550
19	**16**	**30**	**7.5**	**0.9**	**1.0**	**0.04**	**0.0000440**	**98.95**	**0.9895**
26	17	45	7.5	0.6	1.0	0.51	0.0003670	91.26	0.9126
9	18	30	7.5	0.6	0.5	0.22	0.0002440	88.65	0.8865
14	19	45	10.0	0.3	1.0	0.92	0.0007670	81.74	0.8174
25	20	45	7.5	0.6	1.0	0.51	0.0003670	91.26	0.9126
2	21	60	5.0	0.6	1.0	0.24	0.0004000	90.48	0.9048
15	22	45	5.0	0.9	1.0	0.01	0.0000167	99.60	0.9960
23	23	45	5.0	0.6	1.5	0.37	0.0006170	89.27	0.8927
1	24	30	5.0	0.6	1.0	0.13	0.0002170	94.84	0.9484
11	25	30	7.5	0.6	1.5	0.16	0.0001780	96.90	0.9690
13	26	45	5.0	0.3	1.0	0.59	0.0009830	76.60	0.7660
16	27	45	10.0	0.9	1.0	0.03	0.0000250	99.40	0.9940
18	28	60	7.5	0.3	1.0	1.49	0.0016560	60.56	0.6056
20	29	60	7.5	0.9	1.0	0.08	0.0000898	97.88	0.9788

Table 5
ANOVA result for response surface quadratic model (inhibition efficiency).

Source	Sum of squares	*Df*	Mean Square	F-value	*Prob > F*	
Model	2823.69	14	201.69	6.60	0.0006	Significant
A	109.93	1	109.93	3.60	0.0787	
B	41.03	1	41.03	1.34	0.2660	
C	1186.84	1	1186.84	38.83	< 0.0001	
D	21.79	1	21.79	0.71	0.4127	
A^2	91.14	1	91.14	2.98	0.1062	
B^2	35.81	1	35.81	1.17	0.2974	
C^2	346.77	1	346.77	11.34	0.0046	
D^2	89.90	1	89.90	2.94	0.1084	
AB	1.23	1	1.23	0.040	0.8438	
AC	286.79	1	286.79	9.38	0.0084	
AD	21.48	1	21.48	0.70	0.4159	
BC	7.13	1	7.13	0.23	0.6366	
BD	9.09	1	9.09	0.30	0.5941	
CD	466.78	1	466.78	15.27	0.0016	
Residual	427.93	14	30.57			
Lack of Fit	427.93	10	42.79			
Pure Error	0.000	4	0.000			
Cor Total	3251.62	28				

et al., (2020) in his study [28].

3.4. Electrochemical impedance spectroscopy (EIS)

Fig. 3 depicts the EIS plot. The charge transfer resistance (Rct), which is inversely proportional to the rate of corrosion, revealed the extent of electron transport across the surface [29]. Additionally, Table 7 demonstrated that Rct values increased as extract concentration increased, indicating a decrease in the rate of mild steel corrosion with an increase in inhibition efficiency. The electrochemical tests showed a mixed anodic/cathodic type inhibition behavior, with a maximum efficiency of 95.47% when the extract

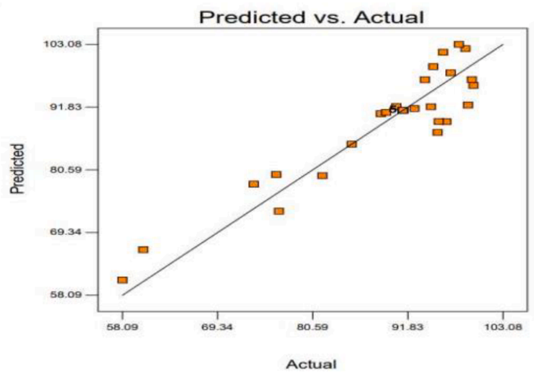


Fig. 1. Diagnostic plot of predicted vs. actual for inhibition efficiency.

concentration was 0.9 g/l. The obtained polarization curves clearly showed a shift of both cathodic and anodic branches to lower corrosion current densities, demonstrating the mixed inhibition mechanism of the SPLE.

Additionally, parallel cathodic branches in the polarization curves of the metal in the H_3PO_4 electrolyte with and without the various conceptions of the SPLE showed the negligible influence of the inhibitor on the cathodic sites, where the hydrogen evolution reaction occurred.

Furthermore; due to the desorption of adsorbed H_2O molecules from electrode surface and adsorption of protective inhibitor film, charge on mild steel surface decreased, resulting in a decrease in capacitance of double layer and a decrease in local dielectric constant [30,1]. The greatest inhibitor concentration under study, 0.9 g/L, was found to have an IE of 95.47%. This revealed more inhibitor adsorption, presumably due to a higher potential of $PO4^{-1}$ions to adsorbed firmly on mild steel surface. As a result, $PO4^{-1}$ ions played a significant part in the inhibition process on mild steel surface [1]. The concentrations of the inhibition used were: 0.3 g/l, 0.6 g/l, 0.9 g/l and blank. The findings strongly suggested that sweet potato leaf extract (SPLE) peel has excellent corrosion-preventing properties

3.5. Potentiodynamic polarization measurement/tafel extrapolation studies

Potentiodynamic Polarization Measurement was used for evaluating SPLE performance, corrosion rate, and corrosion prevention mechanisms, another electrochemical-based method is PDP. The plots are then used to calculate the corrosion potential (Ecorr) and current density of corrosion (Icorr). Furthermore, different SPLE concentrations and experimental temperature was used to investigate the effects of SPLEs on corrosion inhibition performance. The counter electrode measures and regulates the current, whereas the reference electrode measures and regulates the system's voltage (V) (I). As the electrochemical reactions happen, the metal's open circuit potential (Eocp) varies. The PDP scan was performed after a steady value has been measured and equilibrium has been reached.

Tafel polarization was used to assess the effects of SPLE concentrations at 0.3 g/L, 06 g/L, and 0.9 g/L as well as the blank solution. The potentiodynamic polarization result (in Table 8) showed the maximum inhibitory efficiency of 95.47%, which was significant compared to the 83.68% seen from the impedance result (in Table 8). The Tafel plot in Fig. 3 when extract was present and absent, indicated that inhibitor had an impact on both cathodic and anodic reactions. Furthermore, a shift that appeared as the extract concentration increased suggested that the extract was an effective inhibitor. This proved that the extract's inhibitory actions are mixed-type. Additionally, as seen in Table 9, value of current density rose with increase in extract content, which was caused by an increase of metal surface that was blocked by adsorption, as reported in studies by Anadebe et al. (2018); Muthukrishnan et al.,(2019); Tsoeunyane et al., (2019); Galai et al., (2021a); Dahmani et al., (2015); Ouakki et al., 2021; Galai et al., (2021b);Ouakki et al., (2022); Dkhireche et al., (2018); Galai et al., (2017); Alaoui et al., (2016) Ouass et al., (2021); El-Kacimi et al., (2016) [5,31,32,33,34,35,36,37,38,39,40,41,42].

SPLE appeared to act as a good corrosion inhibitor for mild steel in M_3PO_4 solution, as evidenced by the fact that the corrosion current density (icorr) decreased noticeably with an increase in SPLE concentration and that the mild steel corrosion potential (Ecorr) shifted toward the less negative direction. When the change in Ecorr value is greater than 85 mV, an inhibitor is categorized as either being of the anodic or cathodic type. Table 9 makes it clear that the value of Rp increased as the inhibitor concentration increased. The development of an insulating protective film at the metal/solution interface was blamed for the rise in Rp values

3.6. Surface characterization

The result of SEM for blank coupon showed that the surface was severely damaged as shown in Fig. 4a. The SEM in Figure 5b showed that some protective films were formed which blocked the surface from corrosion while more films were formed in Fig. 4c. This showed that the extract had more blockage than the result of Fig. 4b. This was in agreement with findings of Annes et al., 2018 [3].

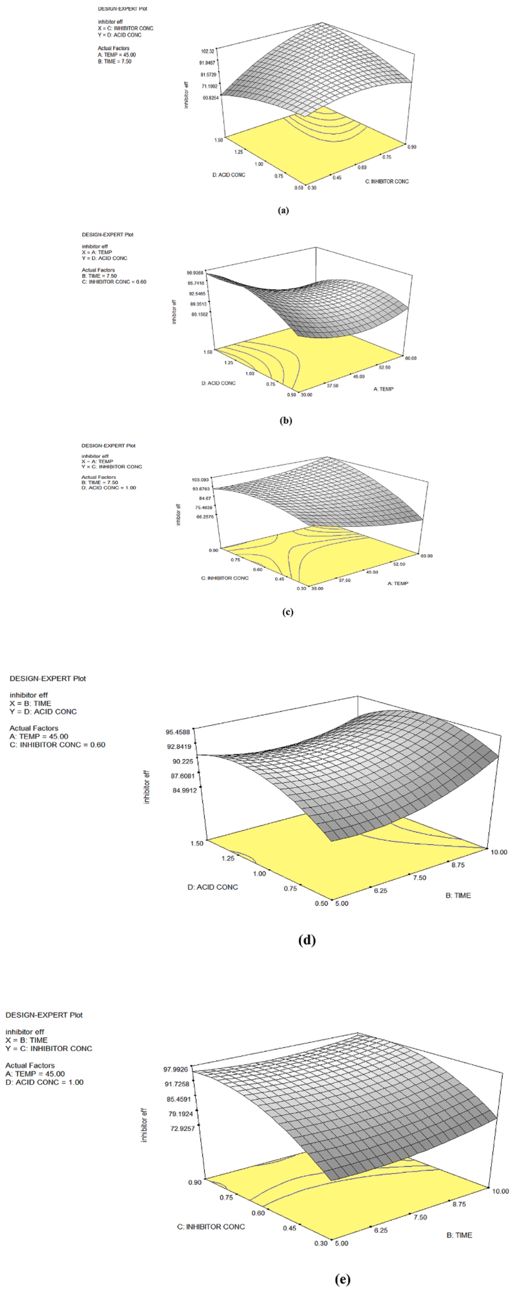


Fig. 2. (a-e) 3-D model plot for inhibition efficiency: (a) Inhibition concentration versus acid concentration; (b) temperature versus acid concentration; (c) temperature versus inhibition concentration; (d) Time versus Acid concentration; (e) inhibition concentration versus time.

Table 6
Fit statistics for the response parameter considered (inhibition efficiency).

Std. Dev.	5.53	**R^2**	0.8684
Mean	89.22	**Adjusted R^2**	0.7368
C.V.	6.20	**Predicted R^2**	0.2420
PRESS	2464.85	**Adeq Precision**	10.628

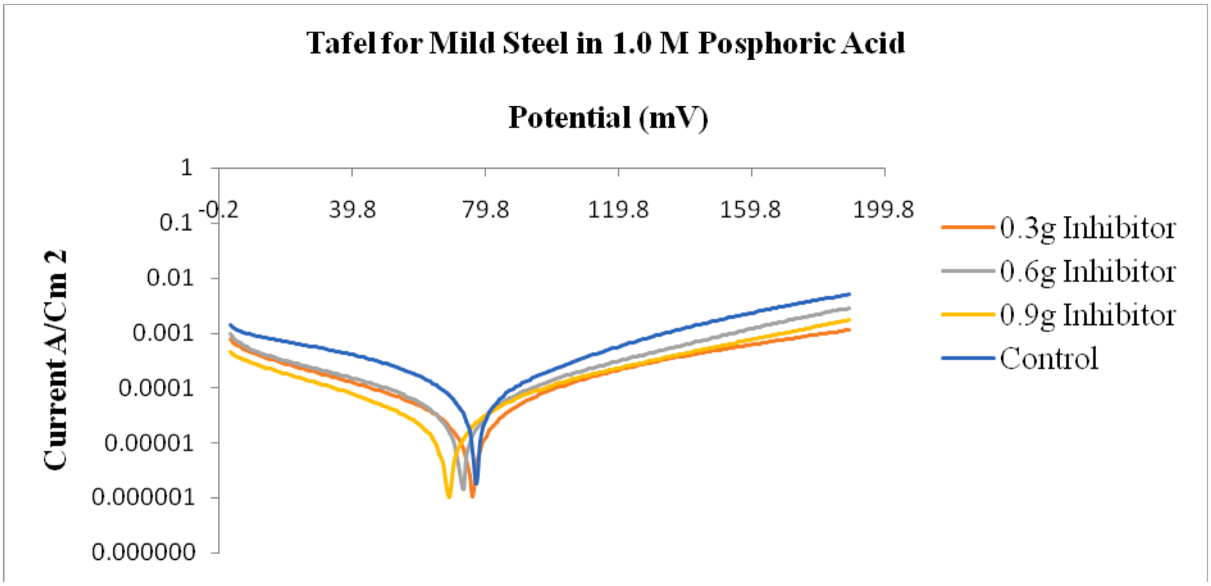


Fig. 3. Polarization curves for MS in the presence and absence of SPLE.

Table 7
Inhibition efficiency and surface coverage of the optimal process levels.

s/n	Factor 1 A: Temperature (°C)	Factor 2 B: Exposure Time (days)	Factor 3 C: Inhibitor Conc (gL^{-1})	Factor 4 D: Acid Conc (M)	Response Inhibition Efficiency (%)	Surface Coverage (ϴ)
1	38	5	0.9	1.0	99.80	0.9980

Table 8
Impedance parameters for the corrosion of MS, in the presence of SPLE, in 1 M H_3PO_4.

Conc (gL^{-1})	Rs (Ω cm^2)	Rct (Ω cm^2)	CPE (μFcm^{-2})	N	IE (%)
Blank H_3PO_4	1.7858	11.268	0.01614100	0.99827	–
0.3	2.6330	32.746	0.00003125	1.00040	65.59
0.6	2.7028	140.010	0.00013866	0.99572	91.95
0.9	3.4138	248.620	0.00011902	0.99507	95.47

Table 9
Tafel polarization / Corrosion parameters for 1 M H_3PO_4 in the presence and absence of SPLE.

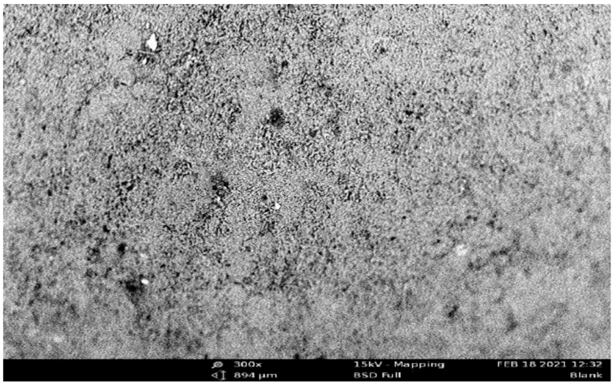
Cs Conc (gL^{-1})	$-E_{corr}$ (v)	I_{corr} (A/cm^2)	Ba (v/dec)	Bc (v/dec)	Rp (Ω)	CR (mm/yr)	IE (%)
Blank H_3PO_4	0.48754	0.0000269700	0.0036060	0.0046500	38.860	0.263740	–
0.3	0.47252	0.0000175810	0.0042657	0.0040495	51.317	0.204290	34.81
0.6	0.48211	0.0000105400	0.0037611	0.0044846	84.280	0.122470	60.92
0.9	0.47284	0.0000044007	0.0010822	0.0031251	179.384	0.051136	83.68

4. Conclusion

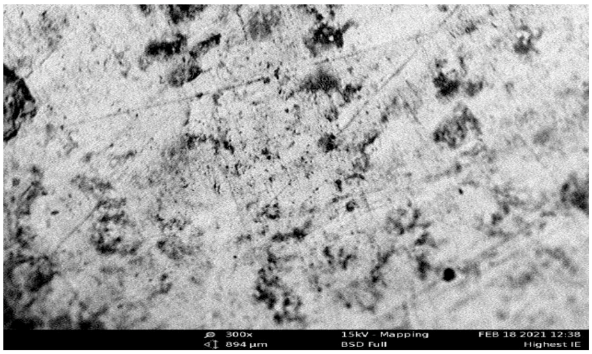
The validated optimal process levels obtained are; temperature: 38 °C, time: 5 days, 0.9 g/L inhibition concentration and 1 M acid concentration, with 99.80% as inhibition efficiency. The result of SEM showed that more films were formed on coupon of validated experiment than coupon with highest inhibition efficiency observed from experimental design. Electrochemical measurements showed that SPLE can be identified as an efficient mixed form of inhibitor. According to the findings, SPLE is an effective inhibitor that is also inexpensive and environmentally friendly.

Declaration of Competing Interest

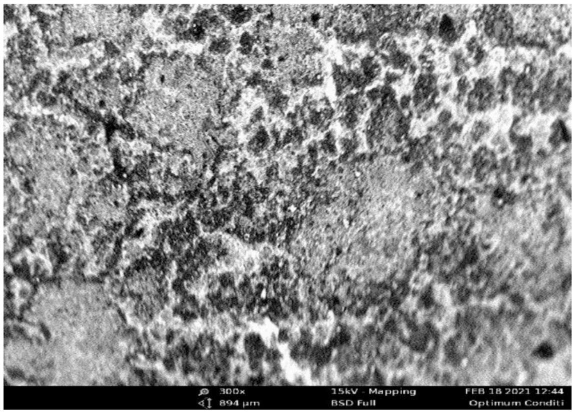
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to



(a)



(b)



(c)

Fig. 4. SEM images of mild steel; (a) Blank (b) Highest inhibition efficiency (c) optimal process level validated (894μm).

influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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