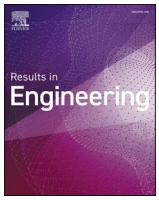
Results in Engineering 16 (2022) 100684

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering



Anti-corrosion using rice straw extract for mild steel in 1.5 M H2SO4 solution

Olamide Oyewole [a,b,*], T. Siji Abayomi [b], Toyin A. Oreofe [b], Temitope A. Oshin [b]

[a] SGD9: Industry, Innovation and Infrastructure, Nigeria
[b] Department of Chemical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria

ARTICLE INFO

Keywords:
Corrosion
Green inhibitors
Weight loss
Optimization

ABSTRACT

Recent research has focused on use of green inhibitors to combat corrosion in industries. This study investigates the effectiveness of rice straw extract (RSE) on mild steel corrosion mitigation in 1.5 M H_2SO_4 using an optimization technique. Temperature (30–60 °C), inhibitor concentration of 0.2–0.8 g/l and time (3–7 h), were the variables. Phytochemical analysis was used to investigate the chemical constituents of RSE. Scanning electron microscopy was used for the characterization. The thermometry test's maximum inhibitory efficiency was 85.11%. The experimental design revealed a maximum inhibition effectiveness of 84.71%, but the verified experiment revealed a maximum inhibition efficiency of 86.42%. The result of the SEM Showed that more adsorption was observed on mild steel of the validated experiment due to the bioactive constituents of the extract.

1. Introduction

Corrosion inhibitors are the cheapest approach to increase the useful life of mild steel equipment [1]. The greatest method for defending against damage on metals is to use plant extracts as corrosion inhibitors (green technology) [2]. Phytochemical factors like tannins, alkaloids, amino acids, flavonoids, phenols, saponins, are characteristics responsible for a good corrosion inhibitor. Some of the plant extracts reported as good inhibitors in the literature are: *Cyperus rotundus* [3]; Chamomile flower extract [4]; *Nepta Pogonesperma* plant stems extract [5]; Chrysanthemum indicum extract [6]; *dactylifera* extract [7]; friendly roselle (Hibiscus Sabdariffa) leaf extract [8]; Terebinth extracts [9]; Extract of *Cocos nucifera - Coconut Palm* [10]; Oxalis stricta leaf extract [11]; *Corchorus olitorium* stem [12]; *Hunteria umbellate* seed husk extracts [13]; *Tagetes erecta* [14]; Pawpaw leaves [15]; Centipeda minima leaves extract [16]; *Luffa cylindrica* [17]; Xanthium Strumarium leaves extract [18]; *Rollinia occidentalis* [19]; cashew extract [20]; tribulus terrestris plant [21]; licorice plant extract [22]; Phyllanthus niruri [23]; Cashew Nutshell [24]; *Lavandula* and *Ricinus communis* oil [25]; Parsley (*Petroselium sativum*) extract [26]; Aizoon canariense Extract [27]; *Senecio anteuphorbium* [28]; Aesculus hippocastanum seeds extract [29]; *Rosa canina* fruit extract [30]; Bark Extract of Tamarix aphylla [31]; *Primula vulgaris* flower aqueous extract [32]. The gap in this study is the use of rice straw which is an agricultural waste as corrosion inhibitor on mild steel using optimization approach. No work had been done on the use of Box Behnken Design for optimization as at when this research was done. This work is to examine in novelty, rice straw's corrosion-inhibiting efficiency.

2. Materials and method

2.1. Preparation of rice straw extract (RSE)

Rice Straw (RS) obtained from Landmark University Commercial Farm was dried for five (5) days and pulverized. 40 g of the RS powder was immersed in 1000 ml of ethanol for 48 h. After that, it was filtered at a lower pressure. A tiny amount of distilled water was used twice to remove the solid residue. A desiccator was used to store the product after the filtrate had been evaporated and concentrated at 80 °C.

2.2. Metal preparation

The mild steel used has the following element compositions (in weight percent): 0.15 (C), 0.15 (Si), 0.49 (Mn), 0.05 (P), 0.062 (S), and 0.05 (Cr).

To ensure complete immersion in the corrosive liquid, experiments

* Corresponding author. Department of Chemical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria.
E-mail address: olawale.olamide@lmu.edu.ng (O. Oyewole).

https://doi.org/10.1016/j.rineng.2022.100684
Received 18 August 2022; Received in revised form 2 October 2022; Accepted 3 October 2022
Available online 7 October 2022

were conducted using rectangular mild steel coupons with 0.1 mm diameter holes that were mechanically press cut into the 19 mm × 19 mm × 2 mm coupons. To get a smooth surface and remove any dirt from the metal surface, samples were abraded using emery paper.

After that, acetone and ethanol were used to clean and degrease. Then, in order to shield them from the effects of moisture, they were allowed to dry and kept in a desiccator.

2.3. Preparation of corrosive medium

The, solution in the concentration range of 0.2–0.8 g/l were utilized in the corrosive medium of 1.5 Molar H_2SO_4. The total amount of RSE used for this study was 200 g/l.

2.4. Thermometric test

Thermometric test was conducted using 50 ml beaker with inhibition solution and mild steel in the thermometric bath at 30 °C. Temperature changes were noted until steady temperature was observed. Equation (1) was used to calculate the reaction number (RN). Methodology adapted from Ref. [33].

$$RN = \frac{Tm - T_i}{t} \tag{1}$$

where Tm and Ti are the final and initial temperatures in degrees Celsius, respectively.

t is the time.

2.5. Phytochemical analysis

The RSE was subjected to phytochemical investigation to check if bioactive constituents were present.

2.6. wt loss measurement

Studies of weight loss were conducted on pre-weighted coupons submerged in 250 ml volume beakers containing 100 ml inhibitor solution held at 30–60 °C in a water bath with thermostat. The coupons were put in solution at the time variation of 3–7 h after which they were re-weighed. Difference in weight was considered as weight loss.

The corrosion rate (CR), inhibition efficiency (IE), and the surface coverage were calculated using Eqs. (2)-(5).

$$\Delta w = w_1 - w_2 \tag{2}$$

Weight before immersion is denoted by w1 and weight after immersion is denoted by w2.

$$CR = \frac{\Delta w}{At} \tag{3}$$

where CR is the corrosion rate (g/mm^{2}h).

Following an exposure time t (h), Δw is the weight loss (g), and A is the area.

Inhibition efficiency (IE) was calculated using Equation (4).

$$IE = \frac{\Delta w}{W_1} \times 100 \tag{4}$$

The surface coverage (Θ) was calculated using Equation (5).

$$\Theta = \left(1 - \frac{\Delta w}{W_1}\right) \tag{5}$$

The methodology used was adapted from Ref. [17].

2.7. Design of experiment

For the 17 developed experimental runs, the effect of variables was examined using the Box Behnken Design. Table 1 showed the variables, while Table 2 showed variable interaction matrix. The Design Expert software (6.0.8) was used for analysis.

2.8. Optimal predicted levels by the software

Time: Time: 5 h, Temperature: 60 °C; Concentration: 0.40 g/l was observed by the software as the optimal process level.

2.9. Surface analysis

The surface analysis was done for coupon with highest inhibition efficiency (from experimental design), coupon of the optimal process level (validated), and blank coupon.

3. Results and discussions

3.1. Result of thermometric test

The result of Thermometric Test is as shown in Table 3. It was found that as the Inhibitor Concentration increased, the reaction number decreased. The highest Inhibition efficiency observed was 85.11%. at 0.8 g/l. This result is higher than what was observed by [20].

3.2. Result of phytochemical analysis

Table 4 showed result of phytochemical analysis. It was observed that RSE contained bioactive constituents of a good inhibitive action of the extract.

3.3. Results of weight loss measurement

Table 5 showed results of weight loss measurement. The 10th Experimental Run's best process level; with: **5 h 60 °C 0.40 g/l** as shown in Table 6 with the highest IE of 84.71%.

3.4. Result of the statistical analysis and optimization study

Table 6 showed the ANOVA. The coefficients were used to determine model's goodness (R^2 and adjusted R^2). The observed R^2 was 0.7838, while the adjusted R^2 was 0.5676. Analysis of ANOVA for the corrosion inhibition is as shown in Table 6. Fig. 1 showed the relationship of Predicted vs actual plot. The significant terms are B^2, C^2, AB. The regression equation is as stated in equation (6):

The temperature and the H_2SO_4 concentration is correlated with the IE.

Regression Equation:

$$IE = +71.68 - 0.57A - 1.74B + 0.81C - 1.47A^2 + 4.19B^2 - 25.80C^2 - 6.76AB + 2.60BC \tag{6}$$

The mechanistic interpretation revealed that the inhibitor concentration (C) had the greatest impact on the IE (response), with the effects of temperature (A) and H_2SO_4 concentration (B) having a substantially lower impact.

Table 1
Independent variables.

Independent variables	Codes	Range and levels		
		−1	0	+1
time (h)	A	3	5	7
temperature (°C)	B	30	45	60
inhibitor concentration (g/l)	C	0.2	0.4	0.8

Table 2
Matrix of process Variables.

S/N	variable 1	variable 2	variable 3
	time(h)	temp (°C)	inh. conc (g/l)
1	8.00	45.00	0.80
2	5.00	45.00	0.60
3	5.00	45.00	0.60
4	3.00	45.00	0.80
5	8.00	60.00	0.60
6	8.00	60.00	0.60
7	5.00	60.00	0.20
8	8.00	45.00	0.80
9	8.00	45.00	0.80
10	3.00	60.00	0.40
11	3.00	60.00	0.40
12	5.00	30.00	0.80
13	3.00	45.00	0.80
14	3.00	60.00	0.40
15	8.00	45.00	0.80
16	8.00	45.00	0.80
17	5.00	30.00	0.20

Table 3
Results of thermometric test.

Inhibitor Concentration (g/L)	RN (°C/min)	IE (%)
1.0	0.02730	
0.2	0.01180	56.77
0.4	0.00711	73.96
0.6	0.00425	84.43
0.8	0.00352	85.11

Table 4
Result of phytochemical analysis.

S/N	Substances	Presence
1	Saponins	++
2	Tannis	+
3	Flavonoids	+
4	Alkaloids	–
5	Phenolics	–
6	Glycosides	++

Where.
= not present.
+ = present.
++ = highly present.

3.5. Results of the 3D plots

Figs. 2–4 illustrates the 3-D plots for this study.

The inhibition increased with decreasing time as shown in Fig. 2. According to Fig. 3, inhibitor efficiency increased with temperature.

Table 6
ANOVA.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	2269.12	8	283.64	3.62	0.0435	significant
A	4.17	1	4.17	0.053	0.8232	
B	9.60	1	9.60	0.12	0.7352	
C	0.52	1	0.52	6.596	0.9373	
A2	105.92	1	105.92	1.35	0.2782	
B2	421.36	1	421.36	5.39	0.0489	
C2	559.94	1	559.94	7.16	0.0281	
AB	1338.81	1	1338.81	17.11	0.0033	
AC	0.000	0				
BC	35.34	1	35.34	0.45	0.5205	
Pure Error	625.97	8	78.25			
Cor Total	2895.09	16				
R-Squared	0.7838					
Adj R-Squared	0.5676					

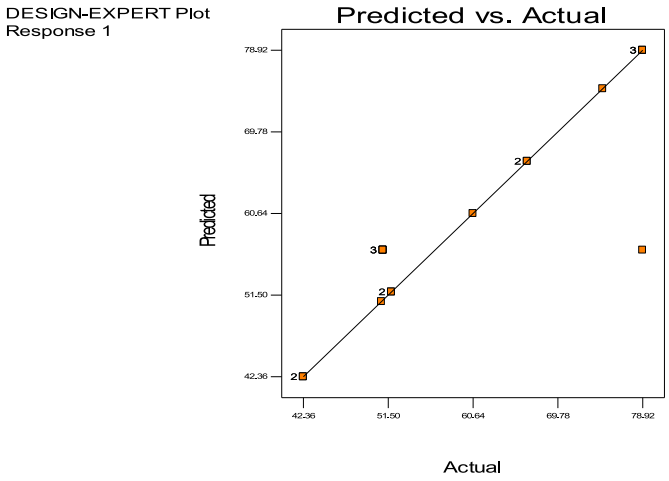


Fig. 1. Graph of predicted versus actual.

Table 5
Results of weight loss measurement.

S/N	Factor 1 A: time(h)	Factor 2 B: temp (°C)	Factor 3 C: Conc (g/l)	WT Loss	CR (mg/mm²h)	IE	Sur. coverage
1	7.00	45.00	0.80	0.286	0.970	50.940	0.509
2	5.00	45.00	0.60	0.372	0.178	66.490	0.665
3	5.00	45.00	0.60	0.372	0.178	66.490	0.665
4	3.00	45.00	0.80	0.288	2.290	42.360	0.424
5	7.00	60.00	0.60	0.346	1.200	51.860	0.519
6	7.00	60.00	0.60	0.346	1.200	51.860	0.519
7	5.00	60.00	0.20	0.355	1.600	50.780	0.508
8	7.00	45.00	0.80	0.286	0.970	50.940	0.509
9	7.00	45.00	0.80	0.286	0.970	50.940	0.509
10	**5.00**	**60.00**	**0.40**	**0.474**	**3.770**	**84.710**	**0.847**
11	3.00	60.00	0.40	0.474	3.770	78.920	0.789
12	5.00	30.00	0.80	0.344	1.640	60.640	0.606
13	3.00	45.00	0.80	0.288	2.290	42.360	0.424
14	3.00	60.00	0.40	0.474	3.770	78.920	0.789
15	7.00	45.00	0.80	0.286	0.970	50.940	0.5090
16	7.00	45.00	0.80	0.286	0.970	50.94	0.5094
17	5.00	30.00	0.20	0.4209	2.010	74.62	0.7462

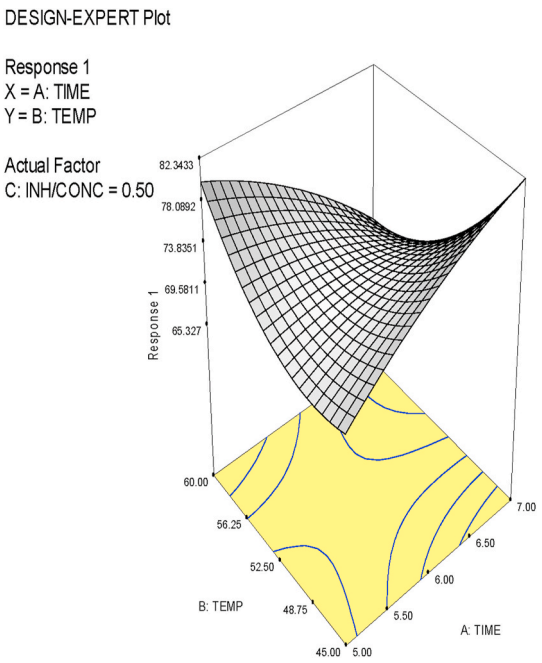


Fig. 2. 3D plot of temp and time.

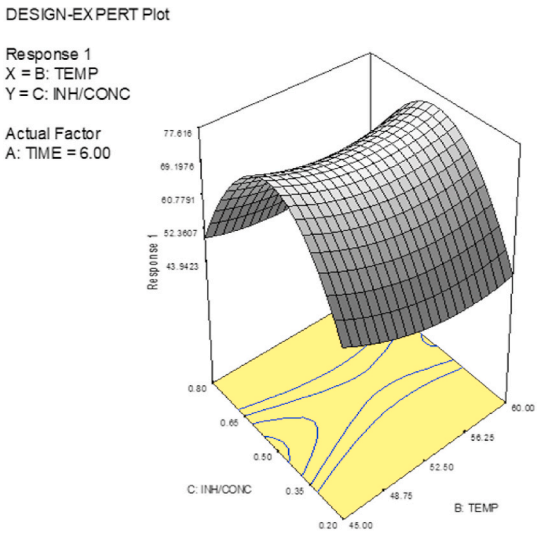


Fig. 3. 3D Plot of Inh conc and Temp.

Fig. 4 shows that increasing the temperature reduced inhibitor efficiency. Metal corrodes more quickly the longer it is exposed to an acidic medium at a higher temperature which explains why [12,34] respondents agreed with the study's findings.

3.6. Validated experiment

The optimal process level was subjected to experimental validation. The Inhibition efficiency observed was 86.42%.

3.7. Results of scanning electron microscope (SEM)

SEM results for blank, coupon with the maximum inhibitory efficiency, and coupon seen at the optimal process level were shown in Figs. 5–7. Pitting corrosion was seen in Fig. 5, and an outer film with fewer cracks, which indicated less corrosion damage was seen in Fig. 6. Additionally, as illustrated in Fig. 7, additional film that served as a

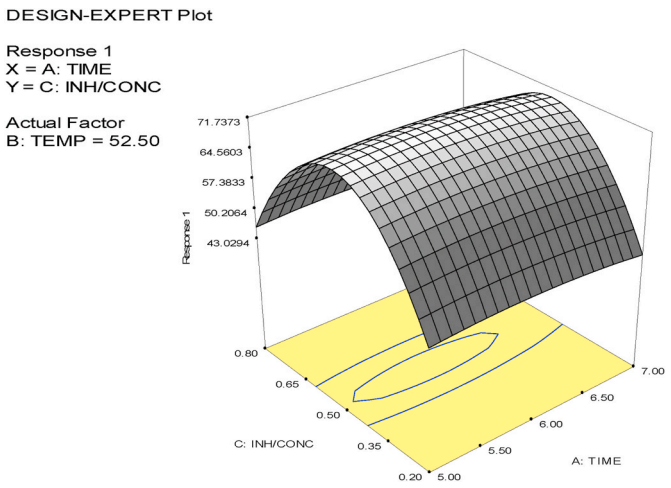


Fig. 4. 3D plot of inhibitor conc. And time.

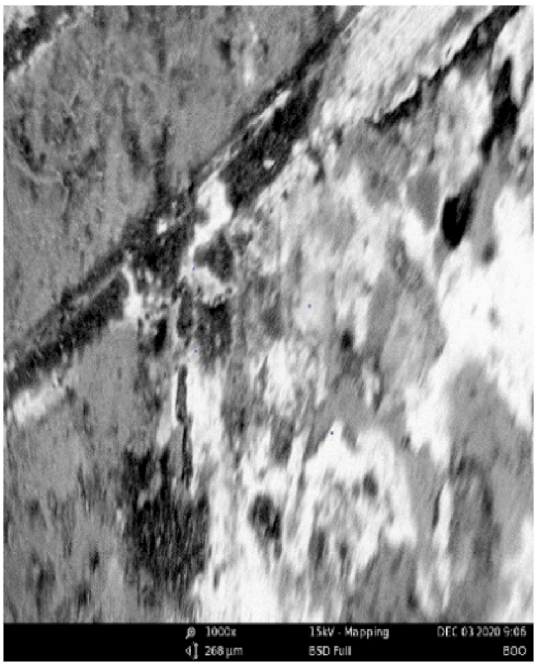


Fig. 5. Blank coupon.

corrosion barrier was generated on the confirmed optimal process level coupon.

3.7.1. Inhibition mechanism

The metal gains a positive charge due to metal dissolution at the anodic area of the RS molecule protonated in H_2SO_4 solution, while H^{2+} ions from the solution are reduced at the cathodic region. The negatively charged SO_4^{2-} ion from H_2SO_4 is drawn to this positively charged metal surface, creating an electrical double layer at the metal solution interface. In contrast to chemical adsorption, which is caused by interactions between donors and acceptors, this double layer promotes the electrostatic interaction-based adsorption of protonated RS molecules onto it.

4. Conclusions

Rice straw extract contained bioactive constituents of a good corrosion inhibitor; Optimal process level observed was: Time: 5.49 h, Temperature: 55 °C; Concentration: 0.47 g/l with Inhibition efficiency of

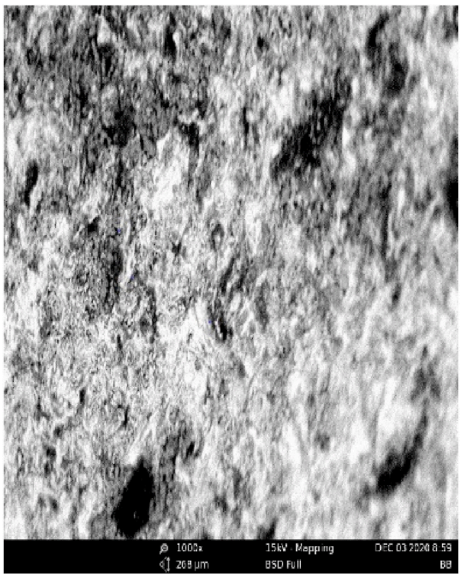


Fig. 6. Coupon with highest IE.

Fig. 7. Coupon from optimal process.

86.42 while 84.71% was the maximum inhibition efficiency observed from the experimental design.

The SEM analysis revealed that more passive film acted as corrosion barrier on surface of coupon from validated experiment. This confirmed that rice straw extract was a good corrosion inhibitor. This research can benefit manufacturing industries which used mild steel as the major material.

The roles of authors

Conceptualization: **Olamide OYEWOLE.** Data curation: **Olamide OYEWOLE' T. Siji ABAYOMI, Temitope A. OSHIN.** Formal analysis: **Olamide OYEWOLE' T. Siji ABAYOMI, Toyin A. OREOFE, Temitope A. OSHIN.** Investigation and Methodology: **Olamide OYEWOLE, T. Siji ABAYOMI.** Project administration: **Olamide OYEWOLE, T. Siji ABAYOMI, Toyin A. OREOFE, Temitope A. OSHIN.** Resources, Software: **Olamide OYEWOLE, T. Siji ABAYOMI, Toyin A. OREOFE, Temitope A. OSHIN.** Validation,: **Olamide OYEWOLE' T. Siji ABAYOMI, Toyin A. OREOFE, Temitope A. OSHIN.** Writing - original draft: **Olamide OYEWOLE.** Writing - review and editing: **Olamide OYEWOLE' Temitope A. OSHIN**.

Declaration of competing interest

The authors declare that they have no competing interest.

Data availability

Data will be made available on request.

References

[1] C.G. Dariva, A.F. Galio, Corrosion inhibitors – principles, mechanisms and applications, in: M. Aliofkhazraei (Ed.), Developments in Corrosion Protection, IntechOpen, 2014, pp. 365–379, https://doi.org/10.5772/57255. Available from: https://www.intechopen.com/books/developments-in-corrosion-protection/corrosion-inhibitors-principles-mechanisms-and-applications.

[2] R.T. Loto, Corrosion inhibition performance of the synergistic effect of *Rosmarinus officinalis* and 5-bromovanillin on 1018 carbon steel in dilute acid media, J. Fail. Anal. Prev. 17 (5) (2017) 1031–1043.

[3] I.M. Chung, S.H. Kim, M. Prabakaran, Anti-corrosive potential of *Cyperus rotundus* as a viable corrosion inhibitor for mild steel in sulphuric acid, Pigment Resin Technol. 49 (4) (2020) 295–304.

[4] M.H. Shahini, M. Keramatinia, M. Ramezanzadeh, B. Ramezanzadeh, G. Bahlakeh, Combined dvatomic-scale/DFT-therotical simulations & electrochemical assessments of the chamomile flower extract as a green corrosion inhibitor for mild steel in HCl solution, J. Mol. Liq. 342 (2021).

[5] M.H. Shahini, M. Ramezanzadeh, B. Ramezanzadeh, Effective steel alloy surface protection from HCl attacks using *Nepta Pogonesperma* plant stems extract, Colloidal Surf. A Physicochem. Eng. Aspects (2022) 634.

[6] H. Zhang, Z. Ni, H. Wu, P. Xu, Z. Li, W. Zhang, H. Huang, Q. Zhou, X. Yue, J. Bao, X. Li, Corrosion inhibition of carbon steel in hydrochloric acid by Chrysanthemum indicum extract, Int. J. Electrochem. Sci. 15 (2020) 5487–5499.

[7] E.A. Sahin, R. Solmaz, H.I. Gecibesler, G. Kardas, Adsorption ability and corrosion inhibition mechanism of phoenix *dactylifera* extract on mild steel, Mater. Res. Express (2020), 16585.

[8] S. Shahen, A.M. Abdel-karim, G.A. Gaber, Eco-friendly roselle (Hibiscus Sabdariffa) leaf extract as naturally corrosion inhibitor for Cu-Zn Alloy in 1M HNO3, Egypt. J. Chem. 65 (4) (2022 Apr 1) 1–2.

[9] M. Barbouchi, B. Benzidia, A. Aouidate, A. Ghaleb, M. El Idrissi, M. Choukrad, Theoretical modelling and experimental studies of Terebinth extracts as green corrosion inhibitor for iron in 3% NaCl medium, J. King Saud Univ. Sci. 32 (2020) 2995–3004.

[10] P.R. Vijayalakshmi, R. Rajalakshmi, S. Subhashini, Corrosion inhibition of aqueous extract *of Cocos nucifera - Coconut Palm - petiole* extract from destructive distillation for the corrosion of mild steel in acidic medium, Port. Electrochim. Acta 29 (1) (2011) 9–21.

[11] P.N. Sannaiah, V.D. Alva, S. Bangera, An experimental, theoretical, and spectral approach to evaluating the effect of eco-friendly Oxalis stricta leaf extract on the corrosion inhibition of mild steel in 1 N H2SO4 medium, J. Iran. Chem. Soc. 19 (5) (2022 May) 1817–1835.

[12] O. Oyewole, T.A. Oshin, B.O. Atotuoma, *Corchorus olitorium* stem as corrosion inhibitor on mildsteel in sulphuric acid, Heliyon.Ee (2021), 06840.

[13] K.K. Alaneme, S.J. Olusegun, O.T. Adelowo, Corrosion inhibition and adsorption mechanism studies of *Hunteria umbellate* seed husk extracts on mild steel immersed in acidic solutions, Alex. Eng. J. 55 (2016) 673–681.

[14] P. Mourya, S. Banerjee, M.M. Singh, Corrosion inhibitor of mild steel in acidic solution by *Tagetes erecta* (Marigold flower) extract as a green inhibitor, Corrosion Sci. 85 (2014) 352–363.

[15] M. Omotioma, O.D. Onukwuli, Evaluation of pawpaw leaves extract as anticorrosion agent for aluminium in hydrochloric acid medium, Niger. J. Technol. 36 (2) (2017) 496–504.

[16] Q. Wang, X. Wu, H. Zheng, X. Xiao, L. Liu, Q. Zhang, P. Gao, Z. Yan, Y. Sun, Z. Li, X. Li, Insight into anti–corrosion behavior of Centipeda minima leaves extract as high–efficiency and eco–friendly inhibitor, Colloids Surf. A Physicochem. Eng. Asp. 640 (2022 May 5), 128458.

[17] O. Ogunleye, A.O. Arinkoola, O.A. Eletta, O.O. Agbede, Y.A. Osho, A.F. Morakinyo, Green corrosion inhibition and adsorption characteristics of *Luffa cylindrica* leaf extract on mild steel in hydrochloric acid environment, Heliyon 6 (1) (2020), e03205.

[18] A.A. Khadom, A.N. Abd, N.A. Ahmed, M.M. Kadhim, A.A. Fadhil, Combined influence of iodide ions and Xanthium Strumarium leaves extract as eco-friendly corrosion inhibitor for low-carbon steel in hydrochloric acid, Curr. Res. Green Sustain. Chem. 5 (2022 Jan 1), 100278.

[19] P.E. Alvarez, M.V. Fiori-Bimbi, N. Adriana, A.B. Silvia, A.G. Claudio, Rollinia occidentalis extract as green corrosion inhibitor for carbon steel in HCl solution, J. Ind. Eng. Chem. 58 (2018) 92–99.

[20] M. Omotioma, O.D. Onukwuli, I. Obiora-Okafo, Phytochemicals and inhibitive properties of cashew extract as corrosion inhibitor of Aluminium in H_2SO_4 medium, Lat. Am. Appl. Res. 1 (49) (2019) 99–103.
[21] S. Chaudhary, R.K. Tak, Natural corrosion inhibition and adsorption characteristics of tribulus terrestris plant extract on aluminium in hydrochloric acid environment, Biointerface Res. Appl. Chem. 12 (2) (2022) 2603–2617.
[22] R. Naderi, A. Bautista, F. Velasco, M. Soleimani, M. Pourfath, Use of licorice plant extract for controlling corrosion of steel rebar in chloride-polluted concrete pore solution, J. Mol. Liq. 346 (2022 Jan 15), 117856.
[23] O. Meena, A. Chaturvedi, Corrosion inhibition effect by extract of aerial parts of Phyllanthus niruri on tin metal in hydrochloric acid solutions and its SEM study, J. Interdiscip. Cycle Res. 12 (2020) 1046–1060.
[24] D.O. Enabulele, G.O. Bamigboye, M.M. Solomon, B. Durodola, Exploration of the corrosion inhibition potential of cashew Nutshell on thermo-mechanically treated steel in seawater, Arabian J. Sci. Eng. (2022 Jun 9) 1–5.
[25] C.A. Loto, R.T. Loto, Effects of lavandula and ricinus communis oil as inhibitors of mild steel corrosion in HCl and H_2SO_4 media, Procedia Manuf. 35 (2019) 407–412.
[26] B. Moktar, M. Abdelkader, B. Nora, N. Mahieddine, Mild steel corrosion inhibition parsley (petroselium sativum) extract acidic media, Egypt. J. Petroleum. 28 (2019) 155–159.
[27] A.E. Fouda, S.M. Motaal, A.S. Ahmed, H.B. Sallam, A. Ezzat, A. El-Hossiany, Corrosion protection of carbon steel in 2M HCl using Aizoon canariense extract, Biointerface Res. Appl. Chem. 12 (1) (2022) 230.
[28] R. Idouhli, Y. Koumya, M. Khadiri, A. Aiyoub, A. Abouelfida, A. Benyaich, Inhibitory effect of *Senecio anteuphorbium* as green corrosion inhibitor for S300 steel, Int. J. Integrated Care 10 (2) (2019) 133–143.
[29] M.A. Deyab, Q. Mohsen, L. Guo, Aesculus hippocastanum seeds extract as eco-friendly corrosion inhibitor for desalination plants: experimental and theoretical studies, J. Mol. Liq. 361 (2022 Sep 1), 119594.
[30] S. Zahra, R. Mohammad, B. Ghasem, R. Bahram, Use of *Rosa canina* fruit extract as a green corrosion inhibitor for mild steel in 1M HCl solution: a complementary experimental, molecular dynamics and quantum mechanics investigation, J. Ind. Eng. Chem. 69 (2019) 18–31.
[31] I.H. Ali, Experimental, DFT and MD assessments of Bark extract of Tamarix aphylla as corrosion inhibitor for carbon steel used in desalination plants, Molecules 26 (12) (2021) 3679.
[32] M.T. Majd, S. Asaldoust, G.M. Bahlakeh, Green method of carbon steel effective corrosion mitigation in 1M HCl medium protected by *Primula vulgaris* flower aqueous extract via experimental, J. Mol. Liq. 284 (2019) 658–674.
[33] A. Hameed, M. Alfakeer, M. Abdallah, Inhibiting properties of some heterocyclic amide derivatives as potential nontoxic corrosion inhibitors for carbon steel in 1.0 M sulfuric acid, Surf. Eng. Appl. Electrochem. 54 (6) (2018 Nov) 599–606.