Materials Today: Proceedings 49 (2022) 1926–1931

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Comparative assessment and statistical data of admixed rosemary and castor oil on the corrosion inhibition of high carbon and P4 low carbon mold steels

Roland Tolulope Loto *, Cleophas Akintoye Loto, Muyiwa Fajobi, Gabriel Olanrewaju

Department of Mechanical Engineering, Covenant University, Ogun State, Nigeria

A R T I C L E I N F O

Article history:
Received 1 July 2021
Received in revised form 10 August 2021
Accepted 12 August 2021
Available online 26 August 2021

Keywords:
Carbon steel
Corrosion
Essential oil
Inhibitor

A B S T R A C T

Admixed rosemary and castor oil extracts (RSCO) were studied for their corrosion inhibition properties on high carbon steel (HCS) and P4 low carbon mold steel (P4S) in 1 M H_2SO_4 and HCl solution by coupon measurement. Results obtained showed that the admixed oil extract performed effectively on HCS and P4S with mean inhibition efficiency values above 90% for P4S and 80% for HCS in both acid solutions. The inhibition efficiency values of RSCO on P4S and HCS varied only with exposure time in H_2SO_4 with progressive increase in value compared to the effect of RSCO concentration which was negligible. The corresponding effect of RSCO in HCl solution showed no effect of exposure time and RSCO concentration on its performance on P4S while on HCS the effect of exposure time was observed. The standard deviation values obtained for RSCO inhibition efficiency at all concentrations on P4S and HCS in H_2SO_4, and HCS in HCl shows the degree of variation from mean values to be significant compared to the values obtained for P4S in HCl solution which were relatively small. The proportion of inhibition efficiency values above 70% inhibition performance are 39%, 44%, 100% and 39% at margin of error of 13%, 13.5%, 0% and 13% for P4S and HCS in H_2SO_4 and HCl solution. Analysis of variance shows exposure time is the dominant statistically relevant source of variation influencing RSCO inhibition performance in H_2SO_4 and HCl solutions.

1. Introduction

Corrosion of carbon steels in industrial operating environments containing certain levels chloride/sulphates anions is a major concern [1]. The resistance of carbon steels to corrosion under these conditions is of huge economic impact and industrial significance due to its versatility, excellent mechanical properties, low cost and recyclability. Carbon steels are extensively used as structural parts and components in machineries, building construction, oil production and refinery plants, radiator tank in automobile, chemical processing plants, high-temperature boilers, energy generation, fertilizer production and mining etc. The corrosion of carbon steels can be alleviated with the use of chemical compounds known as corrosion inhibitors to stifle the oxidation-reduction reactions on the steel surface. These compounds form a protective barrier over the steel surface often associated with chemical and/or physical adsorption. Some inhibitors modify the corrosive environment forming harmless precipitates or compounds. Inorganic chemical inhibitors containing phosphates, chromates, and other heavy metals are facing strong restriction by various environmental regulation bodies worldwide due to their toxicity [2,3]. Despite the relative advancement in corrosion inhibitor research, production and applications, inhibitor application is still limited due to their toxicity and high production cost [4–6]. Research is still on-going on the use of environmentally sustainable compounds for corrosion inhibition [7–10]. Use of plant extracts for corrosion inhibition has seen increasing use of recent due to their non-toxic nature [11–16]. Previous research on rosemary and castor oil has shown that they are promising with respect to further development and can be improved further [17–22]. This manuscript focusses on the optimal inhibition performance of the combined admixture of rosemary and castor oil on carbon steel in dilute H_2SO_4 and HCl solution.

* Corresponding author.
E-mail address: tolu.loto@gmail.com (R.T. Loto).

https://doi.org/10.1016/j.matpr.2021.08.086
2214-7853/

2. Experimental methods

Corrosion Rosemary oil and castor oil (abbreviated as RSCO) were combined together in ratio 1:1 prepared in volumetric concentrations of 1.5%, 2.5%, 3.5%, 4.5%, 5.5% and 6.5% respectively per 200 ml of 1 M H_2SO_4 and HCl solution respectively. High carbon steel (HCS) and P4 low carbon mold steel rods were cut and sectioned into 7 test specimens for each experimental study. HCS have an average dimension of 1.6 cm radius and 0.6 cm thickness while P4S has an average dimension of 0.65 cm thickness and 1.4 cm diameter. The cylindrical surface ends of the steels grades were grinded with silicon carbide abrasive papers of 80, 120 and 220 grits. Weighed steel specimens were individually submerged in 200 ml of H_2SO_4 and HCl solution at specific concentrations RSCO compounds for 216 h. The prepared steel specimens were weighed at 24 h interval with Ohaus analytical weighing balance. The weight loss was calculated from the difference between the initial weight of the steel specimen (kept constant for 216 h) and

Table 1
Data on corrosion rate of P4S from 1 M H_2SO_4/RSCO (0% − 6.5%) solution.

RSCO Conc. (%) Exp. Time (h)	0% RSCO	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	0.0026	0.0008	0.0012	0.0010	0.0008	0.0014	0.0011
48	0.0014	0.0004	0.0007	0.0005	0.0004	0.0008	0.0006
72	0.0009	0.0003	0.0004	0.0003	0.0003	0.0005	0.0004
96	0.0010	0.0003	0.0004	0.0003	0.0002	0.0005	0.0004
120	0.0019	0.0002	0.0004	0.0004	0.0002	0.0004	0.0003
144	0.0023	0.0002	0.0003	0.0003	0.0002	0.0005	0.0004
168	0.0038	0.0002	0.0003	0.0003	0.0001	0.0004	0.0003
192	0.0050	0.0002	0.0002	0.0002	0.0001	0.0004	0.0003
216	0.0066	0.0002	0.0002	0.0002	0.0001	0.0003	0.0002

Table 2
Data on corrosion rate of HCS from 1 M H_2SO_4/RSCO (0% − 6.5%) solution.

RSCO Conc. (%) Exp. Time (h)	0% RSCO	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	0.0122	0.0085	0.0090	0.0079	0.0066	0.0062	0.0098
48	0.0105	0.0057	0.0058	0.0050	0.0044	0.0041	0.0059
72	0.0091	0.0044	0.0046	0.0039	0.0034	0.0030	0.0044
96	0.0080	0.0037	0.0037	0.0031	0.0028	0.0025	0.0036
120	0.0116	0.0032	0.0033	0.0028	0.0025	0.0022	0.0032
144	0.0115	0.0029	0.0029	0.0025	0.0022	0.0020	0.0028
168	0.0119	0.0026	0.0026	0.0023	0.0020	0.0018	0.0026
192	0.0119	0.0024	0.0024	0.0021	0.0018	0.0017	0.0024
216	0.0129	0.0022	0.0022	0.0020	0.0018	0.0016	0.0023

Table 3
Data on corrosion rate of P4S from 1 M HCl/RSCO (0% − 6.5%) solution.

RSCO Conc. (%) Exp. Time (h)	0% RSCO	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	0.00116	0.00004	0.00007	0.00005	0.00003	0.00004	0.00001
48	0.00177	0.00006	0.00008	0.00011	0.00011	0.00011	0.00012
72	0.00219	0.00006	0.00008	0.00008	0.00009	0.00010	0.00011
96	0.00273	0.00024	0.00026	0.00021	0.00023	0.00026	0.00018
120	0.00432	0.00027	0.00023	0.00021	0.00032	0.00025	0.00016
144	0.00627	0.00030	0.00026	0.00021	0.00037	0.00027	0.00020
168	0.00747	0.00031	0.00028	0.00019	0.00042	0.00027	0.00018
192	0.00686	0.00031	0.00031	0.00017	0.00042	0.00026	0.00016
216	0.00648	0.00030	0.00030	0.00020	0.00049	0.00029	0.00016

Table 4
Data on corrosion rate of HCS from 1 M HCl/RSCO (0% − 6.5%) solution.

RSCO Conc. (%) Exp. Time (h)	0% RSCO	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	0.0061	0.0022	0.0031	0.0021	0.0032	0.0042	0.0015
48	0.0051	0.0013	0.0024	0.0015	0.0026	0.0025	0.0014
72	0.0038	0.0011	0.0019	0.0013	0.0019	0.0019	0.0014
96	0.0031	0.0010	0.0016	0.0011	0.0015	0.0017	0.0012
120	0.0047	0.0011	0.0015	0.0010	0.0013	0.0016	0.0011
144	0.0057	0.0011	0.0013	0.0009	0.0012	0.0016	0.0010
168	0.0068	0.0011	0.0011	0.0009	0.0012	0.0015	0.0010
192	0.0075	0.0010	0.0011	0.0009	0.0011	0.0014	0.0009
216	0.0084	0.0007	0.0010	0.0008	0.0014	0.0013	0.0009

the final weight of the steel after measurement every 24 h. Tabulated results of HCS and P4S corrosion at specific RSCO concentrations in both acids are shown from Table 1–4. Corrosion rate was calculated from the equation below;

$$R = \left[\frac{87.6W}{\mathrm{DAT}}\right] \quad (1)$$

W is the weight loss in grams, D is the density in g/cm^2, A is the area in

cm^2, and T is the time of exposure in hours. Tables 5–8 shows the calculated result of inhibition efficiency (IE) as follows;

$$IE = \left[\frac{W_1 - W_2}{W_1}\right] * 100 \quad (2)$$

W_1 and W_2 are the weight-loss of the control (0% RSCO concentration) and inhibited steels in the acid solution with respect to exposure time.

Table 5
Data on inhibition efficiency of RSCO on P4S in 1 M H_2SO_4 solution.

RSCO Conc. (%) Exp. Time (h)	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	69.12	53.19	62.99	69.61	46.57	57.35
48	69.60	50.12	60.33	69.12	43.23	53.21
72	65.25	57.92	67.61	67.14	44.21	59.81
96	73.64	61.45	70.18	76.28	50.91	62.11
120	86.98	77.71	79.75	89.91	78.60	83.78
144	90.49	86.05	86.33	93.33	79.20	83.16
168	94.35	92.84	93.08	96.33	89.05	91.52
192	95.87	95.70	95.66	97.47	92.41	94.98
216	97.11	97.30	97.03	98.18	94.73	96.76

Table 6
Data on inhibition efficiency of RSCO on HCS in 1 M H_2SO_4 solution.

RSCO Conc. (%) Exp. Time (h)	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	30.84	26.30	35.12	46.19	49.71	19.96
48	46.16	44.41	52.46	58.27	61.40	43.82
72	51.47	49.42	56.60	62.82	66.82	50.98
96	54.09	53.35	60.67	64.65	68.76	54.82
120	72.11	71.85	75.67	78.53	80.72	72.71
144	75.09	74.98	78.64	81.00	82.65	75.36
168	78.05	78.21	81.01	83.23	84.60	78.47
192	80.09	79.75	82.39	84.55	86.14	80.15
216	82.93	82.56	84.55	86.17	87.39	82.19

Table 7
Data on inhibition efficiency of RSCO on P4S in 1 M HCl solution.

RSCO Conc. (%) Exp. Time (h)	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	96.65	93.85	95.53	97.77	96.65	98.88
48	96.69	95.40	93.75	93.75	93.57	93.20
72	97.24	96.35	96.15	95.76	95.46	94.77
96	91.14	90.49	92.45	91.68	90.49	93.58
120	93.78	94.71	95.25	92.48	94.20	96.36
144	95.27	95.89	96.60	94.03	95.72	96.88
168	95.87	96.28	97.52	94.44	96.45	97.62
192	95.52	95.53	97.59	93.89	96.24	97.64
216	95.35	95.44	96.89	92.42	95.59	97.52

Table 8
Data on inhibition efficiency of RSCO on HCS in 1 M HCl solution.

RSCO Conc. (%) Exp. Time (h)	1.5% RSCO	2.5% RSCO	3.5% RSCO	4.5% RSCO	5.5% RSCO	6.5% RSCO
24	63.75	49.49	65.81	48.07	31.23	74.68
48	75.02	52.67	70.07	48.57	51.35	72.39
72	70.15	49.04	66.44	51.10	50.41	64.17
96	68.37	47.60	64.86	52.59	46.01	60.83
120	76.78	68.82	78.62	71.60	66.14	76.55
144	80.58	77.38	83.83	78.65	72.41	81.78
168	83.43	83.23	86.56	82.87	78.60	85.86
192	86.25	85.90	88.57	84.83	81.76	88.00
216	91.77	88.23	90.10	83.00	84.63	89.27

3. Results and discussion

3.1. Coupon measurement

Observation of Tables 1 and 2 shows the corrosion rate of control P4S and HCS specimens at 0% RSCO concentration significantly vary from the inhibited specimens at specific RSCO concentrations due to the electrochemical action of SO_4^{2-} anions in H_2SO_4 solution. It is also observed that the value of corrosion rate for the control HCS specimens is significantly higher than the values obtained for P4S due to the higher corrosion resistance of P4S in H_2SO_4. Comparing the observations with the results in Tables 3 and 4 for corrosion in HCl solution. It can be seen that the rate of deterioration for P4S is much higher compared to values obtained in Table 1 while the rate of deterioration of HCS is relatively lower compared to Table 2 [23,24]. These differences, despite similar RSCO concentration are due to the Cl^- anion content in HCl responsible for corrosion of both steels and the competitive adsorption of the anions and inhibitor cations on the steel surface. The inhibition efficiency values of RSCO on P4S and HCS in both acid media is shown from Tables 5–8. Tables 5, 6 and 8 show similar trends in the rate of change of inhibition efficiency with exposure time. Observation shows the inhibition efficiencies on these tables progressively increased to values that signifies effective inhibitor protection at 216 h. This shows the inhibitor protection of RSCO on P4S and HCS in 1 M H_2SO_4, and HCS in 1 M HCl is time dependent [25]. The values presented in Table 7 shows the inhibition efficiency values of RSCO was generally stable at very effective values (above 90%) throughout the exposure hours signifying non-dependence on exposure to reach peak performance. However, RSCO showed total non-dependence on inhibition concentration. Comparative plot of the inhibition efficiency of RSCO on P4S and HCS at highest and lowest RSCO concentration in 1 M H_2SO_4 solution is shown in Fig. 1(a) while the corresponding plot for HCl is shown in Fig. 2(a and b). Fig. 1(a and b) shows the inhibition performance of RSCO on P4S and HCS varies significantly with exposure time and are closely aligned. However, the degree of alignment is much closer in Fig. 1(b) with respect to exposure time. The observation in Fig. 1(a and b) shows the protonated molecular species of RSCO in H_2SO_4 solution react with time gradually inhibiting the electrochemical action of SO_4^{2-} anions in the acid solution. Similar observation occurred in Fig. 2(b). However, Fig. 2(a) shows exposure time has limited influence on the performance of RSCO on P4S in HCl solution. Effective inhibition occurred from the onset of exposure with the inhibitor compounds strongly reacting with the steel to prevent the redox electrochemical processes responsible for corrosion.

3.2. Statistical evaluation

The mean, standard deviation and margin of error for RSCO inhibition efficiency data shown from Tables 5–8 are presented

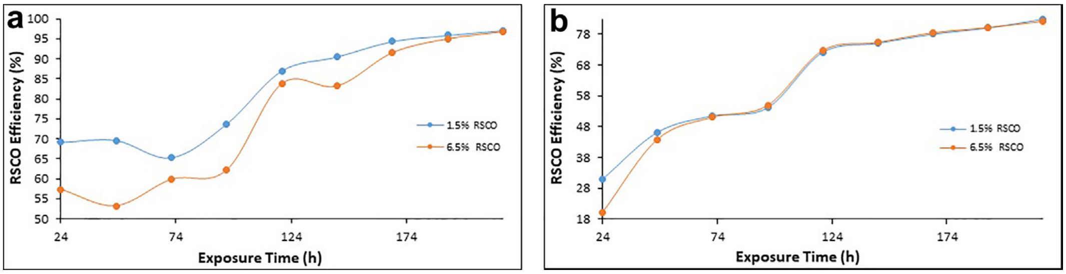

Fig. 1. Comparative plot of the inhibition efficiency of RSCO on (a) P4S and (b) HCS at highest and lowest RSCO concentration versus exposure time in 1 M H_2SO_4 solution.

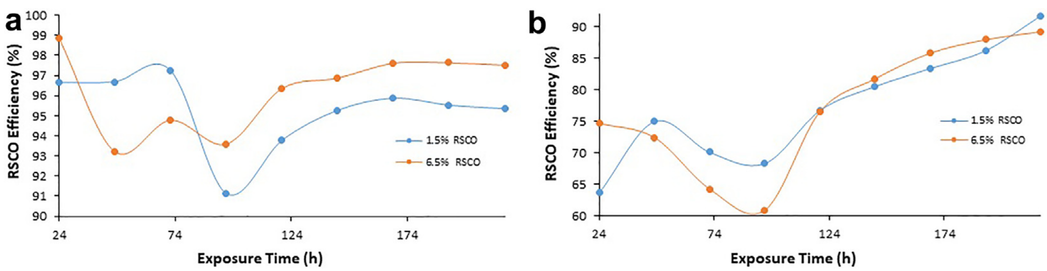

Fig. 2. Comparative plot of the inhibition efficiency of RSCO on (a) P4S and (b) HCS at highest and lowest RSCO concentration versus exposure time in 1 M HCl solution.

Table 9
Mean, standard deviation and margin of error for RSCO inhibition efficiency P4S and HCS in H_2SO_4 solution.

P4S						
ROSC Conc.	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%
Standard Deviation	12.93	19.18	14.44	13.36	22.13	17.56
Mean	82.49	74.70	79.22	84.15	68.77	75.85
Proportion of data above 70% Inhibition Efficiency	39%	Margin of Error	13%			
HCS						
Standard Deviation	18.28	19.63	17.05	14.14	13.16	21.13
Mean	63.43	62.31	67.46	71.71	74.24	62.05
Proportion of data above 70% Inhibition Efficiency	44%	Margin of Error	13.25%			

Table 10
Mean, standard deviation and margin of error for RSCO inhibition efficiency P4S and HCS in HCl solution.

P4S						
ROSC Conc.	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%
Standard Deviation	1.85	1.82	1.73	1.86	1.95	1.98
Mean	95.28	94.88	95.75	94.02	94.93	96.27
Proportion of data above 70% Inhibition Efficiency	100%	Margin of Error	0%			
HCS						
Standard Deviation	9.07	17.30	10.48	16.36	18.55	10.16
Mean	77.34	66.93	77.21	66.81	62.50	77.06
Proportion of data above 70% Inhibition Efficiency	39%	Margin of Error	13%			

in Tables 9 and 10. The standard deviation data in Table 9 for P4S and HCS are comparable with respect to RSCO concentration. Observation of the table shows the standard deviation data varies from 12.93 and 18.28 for P4S and HCS at 1.5% RSCO concentration to 17.56 and 21.13 at 6.5% RSCO concentration. These values show the mean values with respect to RSCO concentration significantly varies with the inhibition efficiency data obtained per exposure time. The results confirm the earlier observation that the effective inhibition performance of RSCO compound is proportional with time. The margin of error shows 39% of RSCO inhibition on P4S and 44% of RSCO inhibition on HCS are above 70% inhibition in H2SO4 solution at margin of error of 13% and 13.25%. The standard deviation value in Table 10 for RSCO inhibition on P4S and HCS are significantly lower than the values obtained in Table 9. The standard deviation value for RSCO inhibition on P4S in HCl solution ranges from 1.85 at 1.5% RSCO concentration to 1.98 at 6.5% RSCO concentration due to the minimal variation of inhibition efficiency values obtained with respect to exposure time. The mean values for inhibition efficiency are generally above 90% while the margin of error is 0% for 100% of the inhibition efficiency data above 70% inhibition efficiency. The corresponding data for HCS in HCl solution shows 39% of RSCO inhibition efficiency is above 70% inhibi-

Table 11
ANOVA data for statistical influence of RSCO concentration and exposure time on RSCO inhibition performance in H_2SO_4 solution.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	Mean Square Ratio (F)	Threshold Significance Factor	Statistical Relevance Factor (%)
P4S						
RSCO Conc.	1430.219	5	286.04	16.63	2.45	9.42
Exposure Time	13071.35	8	1633.92	95.01	2.12	86.06
Residual	687.9088	40	17.20			
Total	15189.47	53				
HCS						
RSCO Conc.	1205.966	5	241.19	23.37	2.45	7.61
Exposure Time	14227.5	8	1778.44	172.30	2.12	89.78
Residual	412.8814	40	10.32			
Total	15846.35	53				

Table 12
ANOVA data for statistical influence of RSCO concentration and exposure time on RSCO inhibition performance in H_2SO_4 solution.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	Mean Square Ratio (F)	Theoretical Significance Factor	Statistical Relevance (%)
P4S						
RSCO Conc.	27.10	5	5.42	3.96	2.45	13.93
Exposure Time	112.72	8	14.09	10.30	2.12	57.94
Residual	54.74	40	1.37			
Total	194.56	53				
HCS						
RSCO Conc.	1991.04	5	398.21	13.74	2.45	17.11
Exposure Time	8487.84	8	1060.98	36.61	2.12	72.93
Residual	1159.16	40	28.98			
Total	11638.04	53				

tion with margin of error of 13%. The standard deviation values are slightly higher than the corresponding values obtained for P4S in HCl but significantly lower than the corresponding values in H_2SO_4 solution.

Analysis of variance (ANOVA) was applied to study the statistical influence of RSCO concentration and exposure time (sources of variation) on the inhibition performance of RSCO on P4S and HCS in H_2SO_4 and HCl solution [26]. Tables 11 and 12 shows the ANOVA data for RSCO inhibition performance on both steels in the acid solutions. The statistical relevance factor shows the percentage statistical significance of the sources of variation on RSCO inhibition performance. The mean square ratio is the statistical significance value which must be greater than the threshold significance factor to be a statistically relevant factor on the inhibition performance of RSCO in both acids. The statistical relevance factor in Table 11 shows exposure time is the dominant source of variation (influencing factor) responsible for RSCO inhibition performance at 86.06% and 89.78% for P4S and HCS in H_2SO_4 solution. The corresponding value for RSCO concentration is 9.42% and 7.61%. Despite this relatively insignificant value. The mean square ration in Table 11 is significantly higher than the threshold significance factor making them statistically relevance with minimal influence on RSCO inhibition performance. The ANOVA data in Table 12 for P4S in HCl was observed to be quite similar to the ANOVA data for P4S and HCS in H_2SO_4 (earlier discussed). However, the corresponding data obtained for HCS in HCl shows the statistical relevance factor for RSCO concentration is generally higher than previous values earlier discussed signifying that RSCO concentration is more statistically relevant on HCS in HCl compared tp P4S in HCl and H_2SO_4 solution, and HCS in H_2SO_4 solution.

4. Conclusion

The combined admixture of rosemary and castor oil extracts effectively inhibited the corrosion of P4 low carbon mold steel and high carbon steel in H_2SO_4 and HCl solution with optimal inhibition performance generally above 90% at the end of the exposure hours. The effect of inhibitor concentration was negligible as the inhibition efficiency did not vary with concentration compared to exposure time which significantly influenced the performance of the oil extract due to the time dependent action of the inhibitor. The standard deviation values show the degree of variation from mean values varies significantly due to variation with time. Statistical data through analysis of variance shows exposure time is the only statistical relevant variable influencing the performance of the extract with statistical value generally above 80%.

CRediT authorship contribution statement

Roland Tolulope Loto: Supervision, Conceptualization, Writing – original draft. **Cleophas Akintoye Loto:** Supervision, Conceptualization, Writing – original draft. **Muyiwa Fajobi:** Visualization, Investigation, Validation, Methodology, Data curation. **Gabriel Olanrewaju:** Visualization, Investigation, Validation, Methodology, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The author is grateful to Covenant University Ota, Ogun State, Nigeria for their support for this project.

References

[1] R.T. Loto, Comparative assessment of the synergistic combination of ricinus communis and rosmarinus officinalis on high-carbon and P4 low-carbon mold steel corrosions in dilute acid media, J. Bio & Tribo Corr. 4 (47) (2018), https://doi.org/10.1007/s40735-018-0163-y.

[2] R.L. Twite, G.P. Bierwagen, Review of alternatives to chromate for corrosion protection of aluminum aerospace alloys, Prog. Org. Coat. 33 (2) (1998) 91–100.
[3] A.C. Bastos, M.G. Ferreira, A.M. Simões, Corrosion inhibition by chromate and phosphate extracts for iron substrates studied by EIS and SVETCorros, Sci. 48 (6) (2006) 1500–1512.
[4] L.A. Hernandez-Alvarado L.S. Hernandez S.L. Rodriguez-Reyna Evaluation of corrosion behavior of galvanized steel treated with conventional conversion coatings and a chromate-free organic inhibitor Int. J. Corros. 2012 10.1155/2012/36813 0.
[5] D.K. Singh, S. Kumar, G. Udayabhanu, R.P. John, 4(N, Ndimethylamino) benzaldehyde nicotinic hydrazone as corrosion inhibitor for mild steel in 1M HCl solution: an experimental and theoretical study, J. Mol. 216 (2016) 738–746.
[6] M.M. Solomon, S.A. Umoren, Enhanced corrosion inhibition effect of polypropylene glycol in the presence of iodide ions at mild steel/sulphuric acid interface, J. Environ. Chem. Eng. 3 (3) (2015) 1812–1826.
[7] R.T. Loto, O. Tobilola, Corrosion inhibition properties of the synergistic effect of 4-hydroxy-3-methoxybenzaldehyde and hexadecyltrimethylammonium bromide on mild steel in dilute acid solutions, J. King Saud Univ. Eng. Sci. 30 (4) (2018) 384–390.
[8] A.O. Odiongenyi, S.A. Odoemelam, N.O. Eddy, Corrosion inhibition and adsorption properties of ethanol extract of Vernonia amygdalina for the corrosion of mild steel in H_2SO_4, Port. Electrochim. Acta 27 (1) (2009) 33–45.
[9] P.D. Rani, S. Selvaraj, Inhibitive and adsorption properties of punica granatum extract on brass in acid media, J. Phytochemistry. 2 (11) (2010) 58–64.
[10] P.B. Raja, M.G., Sethuraman Natural products as corrosion inhibitor for metals in corrosive media—A review, Mater. Lett. 62 (1) (2008) 113–116.
[11] D.K. Verma, F. Khan, Corrosion inhibition of mild steel by extract of bryophyllum pinnatum leaves in acidic solution, Chemistry and Material Research 7 (2015) 2225–10956.
[12] S. Subhashini, R. Rajalakshmi, A. Prithiba, A. Mathina, Corrosion mitigating effect of Cyamopsis Tetragonaloba seed extract on mild steel in acid medium. E-J, Chemistry 7 (4) (2010) 1133–1137.
[13] I.B. Obot, N.O. Obi-Egbedi, S.A. Umoren, E.E. Ebenso, Synergistic and antagonistic effects of anions and ipomoea invulcrata as green corrosion inhibitor for aluminium dissolution in acidic medium, Int. J. Elect. Sci. 5 (7) (2010) 994–1007.
[14] R.T. Loto, C.A. Loto, B. Ayozie, T. Sanni, Anti-corrosion properties of rosemary oil and vanillin on low carbon steel in dilute acid solutions, The Minerals, Metals & Materials Society, TMS 147th Annual Meeting & Exhibition Supplemental Proceedings, The Minerals, Metals & Materials Series (2018) 883–890, https://doi.org/10.1007/978-3-319-72526-0_84.
[15] R.T., Loto Corrosion inhibition effect of non-toxic α-amino acid compound on high carbon steel in low molar concentration of hydrochloric acid, J. Mater. Res. Techn. (2017), https://doi.org/10.1016/j.jmrt.2017.09.005.
[16] R.T. Loto, Electrochemical analysis of the corrosion inhibition properties of 4-hydroxy-3-methoxybenzaldehyde on low carbon steel in dilute acid media, Cogent Eng. 3 (1) (2016) 1242107.
[17] Roland Tolulope 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.
[18] R.T. Loto, Surface coverage and corrosion inhibition effect of Rosmarinus officinalis and zinc oxide on the electrochemical performance of low carbon steel in dilute acid solutions, Results in Phys. 8 (2018) 172–179.
[19] R.A.L. Sathiyanathan, M.M. Essa, S. Maruthamuthu, M. Selvanayagam, N. Palaniswamy, Inhibitory effect of Ricinus communis (Castor-oil plant) leaf extract on corrosion of mild steel in low chloride medium, J. Indian Chem. Soc. 82 (4) (2005) 357–359.
[20] S. Mohanan, N. Palaniswamy, Corrosion inhibition of mild steel by ethanolic extracts of Ricinus communis leaves, Indian J. Chem. Technol. 12 (2005) 356–360.
[21] R. Saratha, N. Kasthuri, P. Thilagavathy, Environment friendly acid corrosion inhibition of mild steel, Ricinus Communis Leaves Der Pharma Chem. 1 (2) (2009) 249–257.
[22] M. Bendahou, M. Benabdellah, B. Hammouti, A study ofrosemary oil as a green corrosion inhibitor for steel in 2 M H_3PO_4, Pigm. Resin. Technol. 35 (2) (2006) 95–100.
[23] B. Sun X. Zuo X. Cheng X. L. The role of chromium content in the long-term atmospheric corrosion process NPJ Mater. Degrad. 4 37 (2020) 1249.
[24] Bomi Kim, Soojin Kim, Heesan Kim, Effects of alloying elements (Cr, Mn) on corrosion properties of the high-strength steel in 3.5% NaCl solution, Adv. Mater. Sci. Eng. 2018 (2018) 1–13, https://doi.org/10.1155/2018/7638274.
[25] O.A. Akinbulumo, O.J. Odejobi, E.L. Odekanle, Thermodynamics and adsorption study of the corrosion inhibition of mild steel by Euphorbia heterophylla L. extract in 1.5 M HCl, Results in Materials 5 (2020) 100074.
[26] M. Parveen, M. Mobin, S. Zehra, R. Aslam, L-proline mixed with sodium benzoate as sustainable inhibitor for mild steel corrosion in 1M HCl: An experimental and theoretical approach, Sci. Rep. 8 (2018) 7489.