

## Corrosion Inhibition Effect of Neem Leaf Oil Distillates on low Carbon Steel in Dilute HCl and NH<sub>4</sub>Cl Acid Media

Roland Tolulope Loto<sup>1\*</sup> and Kingsley Akpanyung<sup>1</sup>

<sup>1</sup>Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria

\*tolulope.loto@covenantuniversity.edu.ng

**Keywords:** neem oil; corrosion; carbon steel; NH<sub>4</sub>Cl; HCl

**Abstract.** Neem leaf oil distillates (NLD) was evaluated for its corrosion inhibition property on low carbon steel in 0.5 M HCl, 1 M HCl, 3.74 M NH<sub>4</sub>Cl and 5.61 M NH<sub>4</sub>Cl solutions. Weight loss analysis shows NLD performed effectively at all concentrations studied in HCl media with optimal inhibition efficiencies of 97.54% and 97.56% at 5% NLD concentrations. NLD performed poorly at 1-4% NLD concentration in 3.74 M and 5.61 M NH<sub>4</sub>Cl solutions with protection performance values below 50%. At 5% NLD concentration the protection performance values increased sharply to 73.53% and 79.0% at 312 h of exposure. Standard deviation values for NLD protection performance output in 0.5 M HCl solution were significantly high indicating highly unstable inhibition behavior and thermodynamic tendency to corrode with respect to exposure time. At 5% NLD concentration the standard deviation value decreased significantly. In 1 M HCl, 3.74 M NH<sub>4</sub>Cl and 5.61 M NH<sub>4</sub>Cl solutions the standard deviation values were relatively low due to improved stability of protected NLD molecules in interaction with the steel surface. Experimental data showed 92.44%, 100%, 30.77% and 20% of NLD protection performance data from 0.5 M HCl, 1 M HCl, 3.74 M NH<sub>4</sub>Cl and 5.61 M NH<sub>4</sub>Cl solutions are above 70% inhibition value with margin of error of  $\pm 7.99$ ,  $\pm 0$ ,  $\pm 11.22$  and  $\pm 9.72$ . Statistical data from analysis of variance showed exposure time dominates the performance output of NLD distillate on low carbon steel from 0.5 M HCl and 1 M HCl at values of 81.76% and 82.03% compared to the effect of NLD concentration which were negligible. In NH<sub>4</sub>Cl solution, NLD concentration dominates the protection performance output of NLD on the carbon steel compared to exposure time with values of 96.42% and 96.95%.

### Introduction

Carbon steel are broadly applied in petroleum refineries, fertilizer production, mineral/ore extraction, building construction, manufacture of vehicular radiators, parts of machining tools, distillation columns, desalination plants and as structural components [1–6]. Application of these steels results from their relatively low cost compared to alloy steels, stainless steels and nickel based alloys, ease of fabrication and production, recyclability and possession of mechanical properties which can be modified with respect to industrial requirements. Corrosion is generally defined as the reaction or electrochemical interaction of metallic alloys with their environment by reduction-oxidation half-cell reaction mechanism [7]. The corrosion process is more prevalent in environments with above threshold anionic content which reacts with metallic alloys degrading them. The presence of these anions in industrial conditions laden with reactive anions results electrochemical degeneration of the surface properties and metallurgical structure of these steels. Hydrochloric acid proves to be one of the most arduous common reagent to manage due to its corrosive nature and the presence of Cl<sup>-</sup> anions in the acid. The acid is produced in enormous quantities industrially due to its economic and industrial importance such as in descaling of metallic surfaces, acidizing, manufacture of carbon based and inorganic chemical derivatives, renewal of ion exchange resins, crude distillation overhead systems, pharmaceuticals production etc. Application of carbon steels in these environments is deleterious to their viability and operational lifespan. Ammonium chloride is majorly utilized industrially as origin of nitrogen in the application of fertilizers. Other applications include the production of laboratory buffers, batteries etc. Corrosion due to the presence of ammonium chlorides are prevalent in petrochemical, refineries overhead equipment and piping installations. Utilization of

chemical derivatives identified as corrosion inhibitors is the most versatile and cost effective technique of corrosion control [8]. Corrosion inhibitors suppress the electrochemical mechanisms causing corrosion and protects carbon steels by modifying the corrosive medium, formation of non-corrosive precipitates and evolution of a protective barrier on the steel surface [9–17]. Most corrosion inhibitors are inherently toxic, unsustainable and costly; hence the need for appropriate alternatives. Utilization of plant extracts for corrosion inhibition of carbon steels has seen increasing use in recent years with promising results [18-25]. This manuscript focusses on data analysis of the corrosion inhibition of neem leaf oil distillates on low carbon steel in dilute hydrochloric acid and ammonium chloride solution.

## Experimental Methods

### Materials preparation

Low carbon steel (LCS) rod with 12 mm diameter were sliced into six representative exhibits with average length of 7 mm for weight loss evaluation. Analar grade HCl and  $\text{NH}_4\text{Cl}$  reagents were added to deionized  $\text{H}_2\text{O}$  to formulate acid electrolyte solutions of 0.5 M HCl, 1 M HCl, 3.74 M  $\text{NH}_4\text{Cl}$  and 5.61 M  $\text{NH}_4\text{Cl}$ . Neem leaf oil distillates (NLD) obtained from NOW foods USA were formulated in the prepared electrolytes at concentrations of 1%, 2%, 3%, 4%, 5% and 6% per 200 ml of the electrolytes. Weighed LCS exhibits were located in translucent containers with 0.5 M HCl, 1 M HCl, 3.74 M  $\text{NH}_4\text{Cl}$  and 5.61 M  $\text{NH}_4\text{Cl}$  electrolyte at specific concentrations of NLD.

### Gravimetric analysis

Weight measurements was performed at 24 h hiatus with Ohaus weighing device. Weight loss was computed by subtracting the first weight reading of the alloys (maintained for 312 h of exposure) from every subsequent weight value obtained. Corrosion rate of LCS was approximated from the mathematical description below;

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

W illustrates weight loss (g), D illustrates density ( $\text{g}/\text{cm}^3$ ), A illustrates area ( $\text{cm}^2$ ), and T time of observation (h). Inhibition efficiency ( $\eta$ ) was approximated from the mathematical description;

$$\eta = \left[ \frac{\omega_1 - \omega_2}{\omega_1} \right] \times 100 \quad (2)$$

$\omega_1$  illustrates weight loss of LCS without the extracts in the electrolyte while  $\omega_2$  illustrates weight loss of LCS at definite extracts concentrations.

### Statistical analysis

Binary-factor mono-component statistical ANOVA analysis (F - test) was utilized to ascertain the statistical applicability of NLD concentrates and observation time on extract inhibition output. The test was performed at confidence level of 95% (significance level of  $\alpha = 0.05$ ) with respect to the mathematical descriptions below. The aggregate of squares of columns (exposure time) was approximated as follows;

$$SS_c = \frac{\sum T_c^2}{nr} - \frac{T^2}{N} \quad (3)$$

The aggregate of squares between rows (NLD concentration) was approximated from the mathematical descriptions below;

$$SS_r = \frac{\sum T_r^2}{nc} - \frac{T^2}{N} \quad (4)$$

Total aggregation of squares

$$SS_{\text{Total}} = \sum x^2 - \frac{T^2}{N} \quad (5)$$

## Results and Discussion

### Gravimetric analysis

The protection performance of MR, SA and GT distillates on MS in  $H_2SO_4$  and  $HCl$  solution at 30%, 60% and 90% concentration with respect to inspection time are shown in Tables 1 and 2. Inspection of Table 1 shows SA distillates exhibited generally the highest protection performance data compared to MR and GT, indicating SA effectively inhibited the corrosion of MS in  $H_2SO_4$  solution. SA protection performance data initiated at 85.5%, 93.86% and 50.54% (30%, 60% and 90% concentration at 72 h of exposure) and progressed to 92.95%, 89.53% and 83.45% at 576 h. The slight increase in protection performance data with respect to inspection time shows SA inhibition effect is less dependent on inspection time and is thermodynamically stable compared to MR and GT. SA instantaneously stifles the redox reaction processes causing corrosion attaining effective protection of MS exterior. GT inhibitor performed poorly at 72 h of exposure, and at 30% and 90% concentration. The values initiated at 3.82% and -4.92%, and progressively increased to 56.17% and 64.36% at 576 h. These values are significantly lower than the threshold values for effective corrosion inhibition. However, at 60% GT concentration, the protection performance values GT were generally stable and marginally effective throughout the exposure hours with values mostly around 70% though optimal protection performed was attained at 576 h (76.5%). Inspection of the protection performance data of MR distillate showed progressive decrease in protection performance data at 30%, 60% and 90% concentration. Though decrease at 60% and 90% MR concentration did not hinder the corrosion protection effect of MR with final values of 76.3% and 81.3%. But the decrease in protection performance data with respect to inspection time showed thermodynamic instability of MR inhibition effect. The inhibition performance of MR at 30% concentration at 576 h of exposure is below the threshold value for effective inhibition.

Table 2 shows SA and GT distillates generally performed more effectively in  $HCl$  solution compared to  $H_2SO_4$ . Their optimal values are generally above 70% at all concentrations. Inspection of their values with respect to inspection shows minimal variation in protection performance data due to the stability of the distillate molecules and their performance under thermodynamic equilibrium. It also shows the distillate performance is independent of inspection time. The performance of MR in  $HCl$  is marginally effective at 60% and 90% concentration with final values of 72.8% and 78.19%. At 30% MR concentration, the final protection performance value (at 576 h) is 69.45% which is below effective corrosion inhibition value. Generally, the protection performance values of MR at all concentrations is significantly time dependent with values increasing with respect to exposure time. Secondly, the protection performance data for MR, SA and GT distillates increase with increase in their concentration signifying concentration dependent performance.

Table 1. Protection performance data for MR, SA and GT distillates in 0.5 M  $H_2SO_4$  solution with respect to inspection time.

Distillate Conc. (%)	Moringa			Star Apple			Green Tea		
	30%	60%	90%	30%	60%	90%	30%	60%	90%
72	87.73	95.65	97.15	85.5	93.86	50.54	3.82	75.92	-4.92
144	81.17	87.18	90.83	91.52	92.35	71.48	37.93	72.04	35.75
216	76	80.51	85.87	93.47	91.85	78.3	50.2	75.86	49.43
288	72.09	77.37	83.11	91.72	90.46	78.89	50.28	75.04	53.17
360	67.31	76.02	82.04	92.32	89.81	81.13	55.31	76.31	59.99
432	63.71	75	81.24	92.7	89.34	82.64	54.96	78.49	63.32
504	61.67	76.3	81.3	92.95	89.53	83.45	56.17	76.5	64.36

Table 2. Protection performance data for MR, SA and GT distillates in 0.5 M HCl solution with respect to inspection time

Distillate Conc. (%) Inspection Time (h)	Moringa			Star Apple			Green Tea		
	30%	60%	90%	30%	60%	90%	30%	60%	90%
72	45.17	63.17	38.61	89.19	96.85	98.85	87.75	93.82	97.52
144	71.89	72.7	84.9	76.63	86.03	89.8	76.79	90.18	92.19
216	66.08	71.15	77.82	73.52	80.59	84.23	73.72	85.81	90.34
288	70.68	78	78	89.14	91.76	94.07	87.32	91.86	94.32
360	74.2	74.2	78.97	90.12	92.35	94.91	89.28	92.03	93.28
432	67.29	73.19	76.09	90.19	91.04	92.84	93.51	91.41	93.51
504	69.35	72.8	78.19	90.23	91.2	92.66	89.92	91.6	92.98

### Statistical Analysis

The mean, standard deviation (SD) and margin of error for the protection performance data of MR, SA and GT distillates on MS in  $H_2SO_4$  and HCl solution are shown in Table 2. The mean output shows the average protection performance data with respect to inspection time and distillate concentration. The SD data shows the degree of variation of the protection performance data from mean values. Inspection of Table 3 shows the mean values from  $H_2SO_4$  solution are generally above 70% inhibition efficiency for MR and SA distillates while the corresponding values for GT distillates is generally below 70% inhibition efficiency with the exception of 60% GT concentration. This shows the average performance of MR and SA distillate compounds is above the threshold minimum for effective protection of MS while the performance of GT is poor and unreliable for corrosion inhibition of MS in  $H_2SO_4$  solution. The corresponding mean values of the distillates in HCl solution shows all the distillates performed effectively at all concentrations with values substantially higher than 70% inhibition. This assertion excludes the performance of MR at 30% concentration whose value is 66.38. This value is below the threshold minimum for effective corrosion inhibition. Generally, the distillates performed more effectively in HCl solution compared to  $H_2SO_4$  solution. The SD values for the distillates in  $H_2SO_4$  solution shows SA distillates at 30% and 60% concentration and GT distillates at 60% concentration depict the lower values signifying the least deviation from mean values. This shows at these distillate concentrations their protection performance is stable, effective and reliable with respect to inspection time. The higher variation from mean values are occurred at 30% and 90% GT concentration signifying a significant variation of protection performance data with respect to inspection time. The SD values of the distillates from HCl solution significantly differs from the values obtained in  $H_2SO_4$  solution. The lowest values from HCl solution occurred at 60% and 90% GT concentration though the values are slightly higher than the lowest values obtained in  $H_2SO_4$  solution while the highest value occurred only at 90% MR concentration with values lower than the corresponding values from  $H_2SO_4$  solution. Between the highest and lowest SD values from both acids, the other SD values are generally marginal and varies marginally from mean values. The proportion of protection performance data for MR, SA and GT distillates from  $H_2SO_4$  solution above 70% inhibition are 71.4%, 95.2% and 33.2% at  $\pm 15$ ,  $\pm 9.1$  and  $\pm 20.2$ . The corresponding values for the distillates from HCl solution are 71.4%, 100% and 100% at margin of error of  $\pm 19.3\%$ ,  $\pm 0\%$  and  $\pm 0\%$ .

Table 3. Mean, standard deviation and margin of error for protection performance data of MR, SA and GT distillates from H<sub>2</sub>SO<sub>4</sub> and HCl solution

H <sub>2</sub> SO <sub>4</sub>									
Distillates	MR			SA			GT		
Distillate Concentration (%)	30	60	90	30	60	90	30	60	90
SD	9.49	7.63	6.01	2.71	1.70	11.57	18.82	1.94	24.47
Mean	72.81	81.15	85.93	91.45	91.03	75.20	44.10	75.74	45.87
Margin of Error	±15			±9.1			±20.2		
Data above 70% Inhibition	71.4			95.2			33.4		
HCl									
Distillates	MR			SA			GT		
Distillate Concentration (%)	30	60	90	30	60	90	30	60	90
SD	9.74	4.51	15.51	7.24	5.20	4.55	7.31	2.51	9.9
Mean	66.38	72.17	73.23	85.57	89.97	92.48	85.47	90.06	93.9
Margin of Error	±19.3			0			0		
Data above 70% Inhibition	71.4			100			100		

Analysis of variance was utilized to assess the statistical relevance of MR, SA and GT distillates with respect to their concentration and inspection time from H<sub>2</sub>SO<sub>4</sub> and HCl. The statistical data are shown in Table 4. The relevant parameters of study are the mean square ratio, theoretical significance factor and statistical relevance factor. The statistical relevant factor is the percentage value of statistical importance of the sources of variation in Table 4. The mean square ratio is the statistical value that must be greater than the theoretical significance factor for the statistical relevance factor to be established. The statistical relevance factor for MR, SA and GT distillates concentration in H<sub>2</sub>SO<sub>4</sub> solution are 35.83%, 58.12% and 43.52%. The corresponding mean square ratio values are greater than the theoretical significance factor; thus the data are established. The corresponding statistical relevance factor values for inspection time are 10.36%, 17.68% and 37.82%. However, the mean square ratio for MR is lower than the theoretical significance factor thus inspection time is statistically irrelevant to the inhibition output of MR distillate. This contrast the observation for SA and GT distillates where their mean square ratio is greater than the theoretical significance factor. The statistical relevance factor for MR, SA and GT distillates concentration from HCl solution are 8.18%, 22.15% and 37.57% while the corresponding mean square ratio values are 2.60, 16.42 and 37.57. The mean square ratio for MR is lower than the theoretical significance factor. Hence, only the statistical relevance factor for SA and GT distillate concentration are valid. The theoretical relevance factor for the statistical importance of inspection time on the inhibition output of MR, SA and GT distillates are 79.92%, 69.76% and 39.18%. The corresponding mean square ratio is greater than the theoretical significance factor thus the values are valid and significantly influences the inhibition output of MR, SA and GT distillates in HCl media. The highest statistical relevance factor values for inspection time are MR in H<sub>2</sub>SO<sub>4</sub>, MR in HCl and SA in HCl, while the highest statistical relevance factor values for distillate concentration occurred only for SA in H<sub>2</sub>SO<sub>4</sub>.



Table 4. Analysis of variance for the inhibition output of MR, SA and GT distillates with respect to distillate concentration and inspection time

<b>H<sub>2</sub>SO<sub>4</sub></b>									
<b>Distillate</b>	<b>MR</b>			<b>SA</b>			<b>GT</b>		
<b>Source of Variation</b>	<b>Mean Square Ratio (F)</b>	<b>Theoretical Significance Factor</b>	<b>Statistical Relevance Factor, F (%)</b>	<b>Mean Square Ratio (F)</b>	<b>Theoretical Significance Factor</b>	<b>Statistical Relevance Factor, F (%)</b>	<b>Mean Square Ratio (F)</b>	<b>Theoretical Significance Factor</b>	<b>Statistical Relevance Factor, F (%)</b>
Distillate Concentration	55.54	3.07	35.83	13.31	3.07	58.12	14.00	3.07	43.52
Inspection Time	31.15	2.57	60.30	1.20	2.57	15.68	4.06	2.57	37.82

  

<b>HCl</b>									
<b>Distillate</b>	<b>MR</b>			<b>SA</b>			<b>GT</b>		
<b>Source of Variation</b>	<b>Mean Square Ratio (F)</b>	<b>Theoretical Significance Factor</b>	<b>Statistical Relevance Factor, F (%)</b>	<b>Mean Square Ratio (F)</b>	<b>Theoretical Significance Factor</b>	<b>Statistical Relevance Factor, F (%)</b>	<b>Mean Square Ratio (F)</b>	<b>Theoretical Significance Factor</b>	<b>Statistical Relevance Factor, F (%)</b>
Distillate Concentration	2.60	3.07	8.18	16.42	3.07	22.15	9.70	3.07	17.57
Inspection Time	7.72	2.57	72.92	17.24	2.57	69.76	3.27	2.57	39.18

## Summary

Neem leaf oil distillates effectively inhibited low carbon steel corrosion in HCl media at all concentration studied compared to NH<sub>4</sub>Cl media were effective inhibition occurred at the highest distillate concentration. In HCl media the protection performance data of the distillate varied significantly with exposure time compared to significant variation with respect to distillate concentration in NH<sub>4</sub>Cl media. The standard deviation values from 0.5 M HCl media were significantly high while the values from 1 M HCl, 3.74 M HCl and 5.61 M NH<sub>4</sub>Cl were relatively low due to low variation of distillate inhibition from mean value. Data from statistical analysis showed depict the percentage influence of exposure time and distillate concentration on the protection performance output of the neem leaf distillate.

## References

- [1] A.S. Fouda, B.A. Hanafy, Aqueous extract of propolis as corrosion inhibitor for carbon steel in aqueous solutions, *Appl. Pure Appl. Chem.* 7(10) (2013) 350–359
- [2] W. Burubai, C. Dagogo, Comparative study of inhibitors on the corrosion of mild steel reinforcement in concrete, *Agricultural Engineering International: CIGR E-J* 9 (2007) 1–10.
- [3] G.Q. Liu, Z. Zhu, W. Ke, C.I. Han, C.L. Zeng, Corrosion. *Natl Association of Chemical Engineers*, 57(6) (2001) 730.
- [4] C.O. Ilabor, G.M. Burstein, The inhibition of pitting corrosion of stainless steel by chromate and molybdate ions, *Corros. Sci.* 45 (2003) 1545–1569.
- [5] A.I. Lopez, J.G. Anton, S.L. Nuevalos, J.L. Guinon, V.P. Herranz, Corrosion studies of Austenitic and duplex stainless steels in aqueous lithium bromide solution at different temperatures, *Corros. Sci.* 46 (2004) 2955–2974.
- [6] Z.D. Cui, S.L. Wu, S.L. Zhu, X.J. Yang, Study on corrosion properties of pipelines in simulated produced water saturated with supercritical CO<sub>2</sub>, *Appl. Surf. Sci.* 252 (2006) 2368–2374.
- [7] S. Leelavathi, R. Rajalakshmi, *Dodonaea viscosa* (L.) leaves extract as acid corrosion inhibitor for mild steel—a green approach. *J. Mats Env. Sci.* 4(5) (2013) 625–638.
- [8] G. Trabianelli, Inhibitors—An old remedy for a new challenge, *Corrosion*. 47(6) (1991) 410–419.

- [9] A.K. Satapathy, G. Gunasekaran, S.C. Sahoo, K. Amit, R.V. Rodrigues, Corrosion inhibition by *Justicia gendarussa* plant extract in hydrochloric acid solution, *Corros. Sci.* 51(12) (2009) 2848–2856.
- [10] A. Ghazoui, N. Bencat, S.S. Al-Deyab, A. Zarrouk, B. Hammouti, M. Ramdani, M. Guenbour, An Investigation of two novel pyridazine derivatives as corrosion inhibitor for C38 steel in 1.0 M HCl, *Int. J. Elect. Sci.* 8 (2013) 2272–2292.
- [11] A.H. Al Hamzi, H. Zarrok, A. Zarrouk, R. Salghi, B. Hammouti, S.S. Al-Deyab, M. Bouachrine, A. Amine, F. Guenoun, The role of acridin-9(10H)-one in the inhibition of carbon steel corrosion: Thermodynamic, electrochemical and DFT studies, *Int. J. Elect. Sci.* (8) (2013) 2586–2605.
- [12] H. Zarrok, A. Zarrouk, R. Salghi, H. Oudda, B. Hammouti, M. Assouag, M. Taleb, M. Ebn Touhami, M. Bouachrine, S. Boukhris, Gravimetric and quantum chemical studies of [4-acetyl-2-(4-chlorophenyl)quinoxalin-1(4H)-yl]acetone as corrosion inhibitor for carbon steel in hydrochloric acid solution, *J. Chem. Pharm. Res.* 4(12) (2012) 5056–5066.
- [13] H. Zarrok, A. Zarrouk, R. Salghi, Y. Ramli, B. Hammouti, M. Assouag, E.M. Essassi, H. Oudda, M. Taleb, 3,7- Dimethylquinoxalin-2-(1H)-one for inhibition of acid corrosion of carbon steel, *J. Chem. Pharm. Res.* 4(12) (2012) 5048–5055.
- [14] A. Zarrouk, H. Zarrok, R. Salghi, B. Hammouti, F. Bentiss, R. Tour, M. Bouachrine, Evaluation of N-containing organic compound as corrosion inhibitor for carbon steel in phosphoric acid, *J. Mats. Env. Sci.* 4(2) (2013) 177–192.
- [15] A. Zarrouk, A.H. Zarrok, R. Salghi, N. Bouroumane, B. Hammouti, S.S. Al-Deyab, R. Touzani, The Adsorption and Corrosion Inhibition of 2-[bis-(4-dimethyl-pyrazol-1-ylmethyl)-amino]-pentanedioic acid on carbon steel corrosion in 1.0 m HCl, *Int. J. Elect. Sci.* 7 (2012, 10215–10232.
- [16] D. Ben Hmamou, R. Salghi, A. Zarrouk, H. Zarrok, S.S. Al-Deyab, O. Benali, B. Hammouti, (2012). The inhibited effect of genolphtalein towards the corrosion of C38 steel in hydrochloric acid. *Int. J. Elect. Sci.* 7 (2012) 8988–9003.
- [17] A. Zarrouk, M. Messali, M.R. Ahmad, M. Assouag, H. Zarrok, R. Salghi, B. Hammouti, A. Chetouani, Some new azonic liquid derivatives: synthesis, characterization and comparative study towards corrosion of C-steel in acidic media, *J. Chem. Pharm. Res.* 4(7) (2012) 3427–3436.
- [18] A. Fidrus, S. Suryana, M. Mahmood, Ginger extract as green corrosion inhibitor of mild steel in hydrochloric acid solution, *IOP Conf. Ser.: Mater. Sci. Eng.* 290 (2018) 012087. <https://doi.org/10.1088/1757-899X/290/1/012087>
- [19] M. Gohra, B. Zaghloul, A. Baraka, M. Elsayed, M. Zorainy, M.M. Kotb, H. Elnabarawy, Green corrosion inhibition of mild steel to aqueous sulfuric acid by the extract of corchorus olitorius stems, *Mater. Res.* 4(4) (2017). <https://doi.org/10.1088/2053-1591/aa664a>
- [20] D.K. Verma, F. Khan, Green approach to corrosion inhibition of mild steel in hydrochloric acid medium using extract of spirogyra algae, *Green Chem. Lett. Rev.* 9(1) (2016). <https://doi.org/10.1080/17518253.2015.1137976>
- [21] R.T. Loto, Study of the synergistic effect of 2-methoxy-4-formylphenol and sodium molybdenum oxide on the corrosion inhibition of 3CR12 ferritic steel in dilute sulphuric acid, *Results Phys.* 7 (2017) 769–776. <https://doi.org/10.1016/j.rinp.2017.01.042>.
- [22] R.T. Loto, R. Leramo, B. Oyebade, Synergistic combination effect of *salvia officinalis* and *lavandula officinalis* on the corrosion inhibition of low-carbon steel in the presence of  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  containing aqueous environment, *J. Fail. Anal. Prev.* 18(6) (2018) 1429–1438. <https://doi.org/10.1007/s11668-018-0535-0>

- 
- [23] R.T Loto, E. Oghenerukewe, Inhibition studies of *rosmarinus officinalis* on the pitting corrosion resistance 439LL ferritic stainless steel in dilute sulphuric acid, *Orient. J. Chem.* 32(5) (2018) 2813-2832.
- [24] R.T. Loto, O. Tobilola, Corrosion inhibition properties of the synergistic effect of 4-hydroxy-3-methoxybenzaldehyde and hexadecyltrimethylammoniumbromide on mild steel in dilute acid solutions, *J. King Saud Univ. Eng. Sci.* 30(40) (2018) 384-390.
- [25] C.A. Loto, R.T. Loto, Effect of dextrin and thiourea additives on the zinc electroplated mild steel in acid chloride solution, *Int. J. Elect. Sci.* 8(12) (2013) 12434-12450.

RETRACTED