The Efficacy of Plant Inhibitors as Used against Structural Mild Steel Corrosion: A Review

U. S. Nwigwe[1*] and C. I. Nwoye[2]

[1] *Department of Mechanical Engineering, Faculty of Engineering and Technology, Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, 840001, Nigeria*
[2] *Department of Metallurgical and Materials Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka, Abambra State, 420007, Nigeria*
*Corresponding author: nwigweuzoma@gmail.com

Received 24/01/2022; accepted 15/05/2022
https://doi.org/10.4152/pea.2023410505

Abstract
MS acceptability for nowadays structural construction is premised on its availability and low cost. However, due to MS poor corrosion resistance, most especially in acidic and alkaline environments, there have been increasing concerns about its use. The use of inhibitors, as proposed by different researchers, mitigates MS CR, thus reducing the economic losses experienced by all chief users of this alloy. In recent years, scientists have focused on green inhibitors obtained from plant, fruit and vegetable extracts, and essential oils. Besides being environmentally friendly, in terms of corrosion resistance, plant extracts are becoming increasingly important, due to their low cost and toxicity, and high availability. Additionally, they are rich in organic compounds with polar atoms, such as O, P, S and N, containing multiple bonds in their molecules, through which they can adsorb onto the metal surface, forming a protective film, by various adsorption isotherms. This paper provides a review on research works done so far on MS corrosion control by naturally occurring plant extracts as corrosion inhibitors, in both acidic and alkaline environments, where this alloy is mainly applied.

Keywords: plant extracts; CR; inhibition; MS; adsorption isotherms; environments.

Introduction•

Steel is an indispensable alloy of Fe and C, but does not exclude other elements [1]. CS is classified as MS (0.10 to 0.3% C), medium CS (0.3 to 0.6% C) and high CS (0.6% to 1.7% C) [2]. Although MS is the cheapest among the steel grades, and it is mostly used for construction purposes, due to its availability and good mechanical properties, it is very susceptible to corrosion, especially when exposed to atmospheric

• The abbreviations list is in pages 387-388.

O in humid environments [3]. Other known options, which are readily available for metals protection against corrosion attack, include painting, anodic/cathodic protection and electroplating [4-13]. However, the use of inhibitors has gained general acceptance as one of the most efficient means of corrosion protection [5,14, 15]. Due to MS high susceptibility to dissolution, many researches have been done using different plant extracts to investigate the corrosion behaviour of this material in various media, such as HCl, H_2SO_4, NaCl and NaOH [16-21], among others. A corrosion inhibitor is an organic or inorganic chemical substance, which can have an anodic, cathodic or mixed behaviour, by adsorbing itself onto a dissolving metal surface, when added to an aggressive medium, thereby controlling and reducing CR [19, 22-30]. Most inorganic inhibitors are harmful to the environment, due to the presence of heavy metals. This has increased the search for green corrosion inhibitors that can be biodegradable, eco-friendly, cheap, easy to find and renewable, without containing heavy metals [6, 7, 16, 17, 31-44].

All metals are widely used in human activities, but MS is the most used among them [45, 46]. It is applied to a high degree in food, oil, chemical, energy and fabrication industries, due to its excellent mechanical properties. Therefore, MS is accorded the highest preference in all solutions to metals corrosion problems. Since the high costs associated with replacing rusted metals due to their dissolution can be reduced through the use of corrosion inhibitors [47, 48], a periodic review of related research done in this field, mostly targeting MS, is always required. This justifies and emphasizes the need for this review, on which premise it is based.

Metallic corrosion

Corrosion is a reversible process that converts pure metal into its oxides, hydroxides and so on [49]. At the present time, corrosion is viewed as a costly science and engineering materials problem. Metallic corrosion has been a great concern, since the first use of common metals [50]. As stated by Bardal E. [51], the cost caused by corrosion damage in industrialized countries is about 34% of the total GDP. Third world countries spend 10 times more than the above estimate in their fight against corrosion. In order to give credibility to this claim, a survey was conducted in 2003, in the United States, which is the most technologically advanced country in the world, for investigating corrosion costs. As a result, it was found that the United States spent about 13 times (about $41.9 billion) the total productivity of Nigeria in fighting this menace. Corrosion costs are mostly related to equipment, structures and attempts to embellish structures. Partly due to direct replacement and maintenance costs, there are associated losses due to plant interruptions, and additional expenditures related to the use of expensive products and other protection precautions [52]. Besides causing economic losses, corrosion also shortens structural steel life span, thus posing a safety problem to humans, who continuously use these products [49, 52].

Fig. 1 shows that metallic corrosion can be divided into three broad groups, as stated by [51]. Its morphological categorization [50] is general corrosion. Under this class are uniform, quasi-, non-uniform and galvanic corrosion. Localized corrosion involves crevice, pitting and filiform corrosion types. Then, there is microbiological corrosion. Metallurgically influenced corrosion includes sensitization, exfoliation, intergranular corrosion and dealloying. Environmentally induced cracking examples are high-temperature H attack, damage and induced cracking, hot-cracking, stress-corrosion, hydride formation, embrittlement, and solid and liquid metal-induced embrittlement. Mechanically assisted wear comprehends erosion, wear and fatigue corrosion.

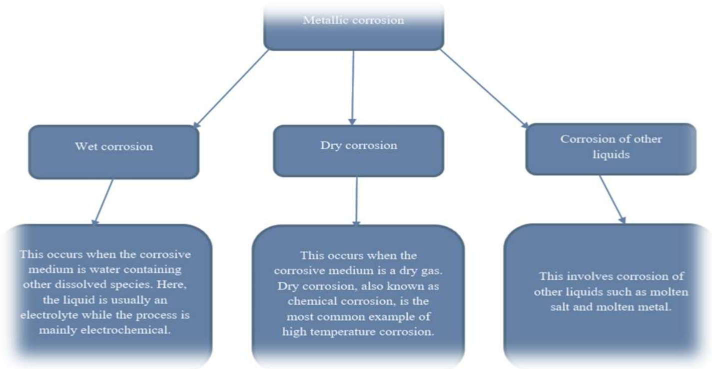

Figure 1. Forms of metallic corrosion.

Anticorrosion measures

Corrosion prevention aims to eliminate or reduce the effects of one or more of the conditions that may cause corrosion, through the following means (Fig. 2) [51]:

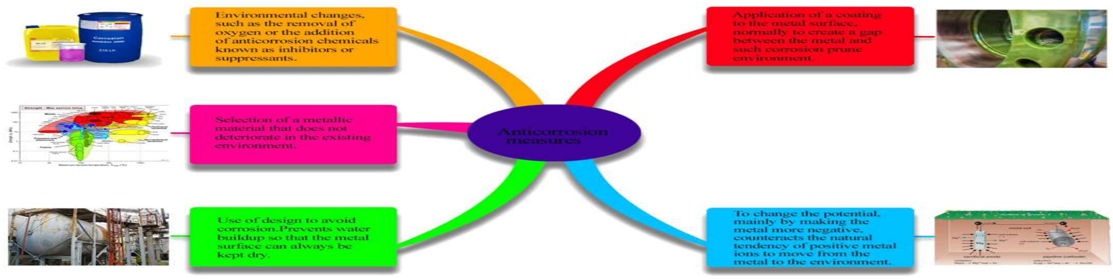

Figure 2. Anticorrosion measures.

Corrosion inhibition

Generally, any process that can cause corrosion delay is seen as inhibition. Corrosion prevention with inhibitors is achieved by adding a compound that suppresses metal oxidation. The chemical inhibitors added to the system can be in the form of liquids and/or vapors [50].

Plant extracts as MS corrosion inhibitors

Table 1 a and b show recent studies, by various authors, on the structural MS corrosion inhibition by plant extracts.

Table 1a. Plant extracts as MS corrosion inhibitors in various electrochemical media.

Plant	Corrosive medium	Technique(s) used	IE_{max}(%)	Adsorption isotherm	Ref.
Citrus aurantium	H_2SO_4	WL and SEM	89	L	[18]
Azadirachta indica	HCl, H_2SO_4 and HNO_3	WL, GC-MS and SEM	70.2, 65.6, 52.6	L	[55]
Cryptocarya nigra	HCl	PDP, EIS, SEM, EDX,	91.05	Fr, L and T	[56]
Pimenta dioica	HCl	PDP, EIS, DFT, SEM and AFM	95.25	L	[57]
Molasses	HCl	PDP, DEIS and GM	90	-	[58]
Thyme	HCl	WL, PDP and EIS	84	L	[59]
Eucalyptus	HCl	PDP, WL, EIS, FT-IR,	88	L	[60]
Castor seed	HCl	WL	71	-	[61]
Pterolobium hexapetalum	Industrial	WL, EIS and SEM	61.22	L	[62]
Ficus hispida	HCl	WL, EIS, PDP, GC-MS,	90	L	[63]
Pentaclethra macrophylla	HCl	WL, EIS, EDX and SEM	95.6	L and T	[64]
Gliricidia sepium	HCl	WL, FT-IR, EDX, SEM and AAS	90.79	L	[65]
Rosemarinus officinalis l.	HCl	WL, PDP	98.33	-	[66]
Euphorbia heterophylla l.	HCl	PDP	62	L, Fr, F-H, El-A, F and	[67]
Murraya koenigii	HCl	WL, GM, ACI and SEM	84.6	L	[68]
Glycyrrhiza glabra	HCl	EIS, PDP, FTIR, AFM and MDS	98.8	-	[69]
Pterocarpus soyauxi	HCl	WL	96.48	T and F	[70]
Phyllanthus fraternus	H_2SO_4	WL, ACI, PDP and GM	98	-	[71]
Juglans regia	NaCl	PDP, EIS, FRIR, SEM and EDX	94.2	-	[72]
Bryophyllum pinnatum	HCl	WL and SEM	94.27	L	[73]
Nypa fruticans wurmb	H_2SO_4	WL	74.48	-	[74]
Poinciana puleherrim and Cassia occidentalis	HCl	WL and PDP	96.94	-	[75]
Datura stramonium and Auforpio turkiale	HCl	WL and PDP	93.71	-	[75]
Imperrata cylindrica	H_2SO_4	WL	76	-	[23]
Eriobotrya japonica lindl	H_2SO_4	WL, PDP, SEM, FTIR	94.3	-	[76]
Spilanthes uliginosa	HCl	WL, PDP, FTIR and UV-Vis	90	-	[77]
Allium ampeloprasum	HCl	WL	98.3	L	[78]
Elaeis guineensis	NaOH	WL	45	-	[79]
Gmelina arborea	HCl	WL	96	L, T and F	[80]
Artocarpusaltilis	HCl	WL and PDP	87.19	-	[81]
Euphorbia heterphylla	HCl	WL and SEM	-	-	[82]
Alchornea laxiflora	HCl	WL	96	L	[83]
Ocimum gratissimum	HCl and H_2SO_4	WL, PDP, FTIR and SEM	92.4, 77.2	-	[84]
Jatropha curcas	H_2SO_4	WL and PDP	92.0	-	[85]
Bambusa glauscescens	H_2SO_4	GM and OPM	-	F	[86]
Cotton seed	HCl	WL, PDP, EIS and SEM	97.3	-	[87]
Pongamia pinnata	H_2SO_4	WL, PDP, EIS, GC-MS,	94.6	L	[88]
Cucurbita maxima	H_2SO_4	PDP and EIS	96	L, El-A, F and T	[89]
Biden pilosa	HCl	GM and PDP	100	L, T, Fr and F	[90]
Synsepalum dulcificum	HCl	WL and EIS	96.0	L	[91]
Fenugreek	H_2SO_4 and HCl	WL	88.33, 92.27	L and T	[92]
Hibiscus sabdariffa calynx	NaCl	PDP, EIS, FT-IR, ATR and EDX	90.26	-	[93]
Acalypha chamaedrifolia	HCl	WL, GC-MS and FTIR	85.11	L	[94]
Chromolaena odorata	H_2SO_4	GM and OPM	-	T	[95]
Costus afer	HCl	WL	95	T and L	[96]
Achyranthes aspera l.	H_2SO_4	WL	92.3	L, Fr and F-H	[97]
Ficus exasperata	Seawater	WL and SEM	87.52	-	[98]
Vernonia amygdalina	H_2SO_4	WL and FTIR	85	L	[99]
Pawpaw	H_2SO_4	WL, FTIR and SEM	85	-	[100]
Manihot esculenta	Na_2SO_4	WL and SEM	97.42	-	[101]
Boscia senegalensis	HCl	WL, PDP, FTIR and SEM	88.45	F	[102]
Combretum bracteosum	H_2SO_4	WL and HE	74.76	Fr	[103]
Milicia excelsa	H_2SO_4	WL and GM	62.07	L	[104]
Daucus carota l.	HCl	WL, PDP, FT-IR and OPM	88.08	L, T and F	[105]
Petersianthus	HCl and H_2SO_4	WL, PDP and EIS	93.5, 82.9	L	[106]
Siam weed	HCl	WL, SEM and EDX	83	L and Fr	[107]
Raphia hookeri gum	H_2SO_4	WL and HE	71.9	L	[16]
Gnetum africana	HCl	WL and FTIR	92.42	L and T	[13]

Table 1b. Plant extracts as MS corrosion inhibitors in various electrochemical media.

Spirulina platensis	HCl and H_2SO_4	WL, PDP, EIS and SEM	74.15, 82.65	T	[32]
Myristica fragrans	H_2SO_4	WL, EIS, SEM, UV-Vis,	87.81	L	[8]
Olea europaea l.	H_2SO_4	PDP, EIS, SEM and FTIR	99	T	[40]
Thapsia villosa	H_2SO_4	WL, PDP and EIS	74.09	L, T and F	[108]
Zenthoxylum alatum	HCl	WL, EIS, SEM, XPS, FT-IR and GC-MS	91	L	[109]
Mollugo cerviana	HCl	PDP, EIS, WL and SEM	96.95	L	[110]
Thymus vulgar l.	NaCl	WL and PDP	80.49	T	[111]
Lawsonia inermis	HCl	PDP, SEM and EDX	92.06	L	[112]
Nauclea latifolia	H_2SO_4	WL and GM	94.26	El-A	[113]
Stylosanthes gracilis	H_2SO_4	WL and PDP	94.23	-	[114]
Wormin mebendazole	H_2SO_4	PDP and SEM	99.53	L	[115]

Adsorption isotherms- El-A: El-Awary; F: Freundlich; F-H: Flory-Huggins; Fr: Frumkin; L: Langmuir; T: Temkin

Green corrosion inhibitors adsorption onto a metal surface is controlled by many factors, such as metal type, test medium, inhibitor chemical structure, type of substituents and additives that it contains, solution temperature and concentration [53, 54]. Some leaf extracts have been used as effective inhibitors against MS corrosion, in various electrochemical media.

Leaf extracts as corrosion inhibitors in selected weak acids

Researchers have added some plant extracts to weak acids, such as H_3O_4P, HCO_2H, CH_3COOH and HCOOH, as corrosion media. Some of the applied techniques are herein presented as pertaining to MS. Ameer and Fekry [116] studied *Thymo* inhibition property against MS corrosion in a H_3PO_4 solution, using different electrochemical techniques, such as PDP and EIS measurements. It was confirmed that higher *Thymo* concentrations increased its IE(%) against MS corrosion. The obtained PDP and EIS results were in good agreement with each other, while the surface inspection was done by SEM. Chaudhari and Vashi [117] studied *Lawsonia inermis* leaf extract, as a green inhibitor against structural MS corrosion in a CH_3COOH solution, by WL, ACI and PDP methods. The investigation indicated that, with higher acid concentrations, CR increased. However, corrosion IE(%) was also found to increase with higher extract concentrations, and the results obeyed Langmuir's adsorption isotherm. *Psidium guajava* leaf extract was investigated, by Noyel et al., as a green inhibitor against MS corrosion in a H_3PO_4 solution [118], using WL, ACI and PDP techniques. In that study, it was observed that IE(%) increased with higher inhibitor concentrations. The results obeyed Langmuir's and Temkin's adsorption isotherms. PDP results indicated that the extract reacted as a mixed-type corrosion inhibitor. The obtained IE_{max}(%) was 89%, while SEM and FTIR analysis were also conducted for the surface examination. The study of *Dendrocalamus brandisii* leaf extract IE(%), against MS corrosion in a Cl_3CCOOH solution, was carried out by Xianghong et al. [119], using WL, EIS and AFM. The compounds adsorption mode followed Langmuir's isotherm. The results proved that the plant extract was a good corrosion inhibitor, since IE_{max} (%) was 97.2%. Singh and Gupta [120] have studied structural MS corrosion with various HCOOH concentrations, using WL and electrochemical techniques. It was found that MS CR was a function of the acid concentrations and of temperature. Maximum CR was observed in a 20% HCOOH solution, with both techniques. The anodic polarization curve showed MS active corrosion over the entire potential range, at any concentrations and temperatures. Cathodic polarization curves were almost the same and did not depend on the HCOOH solution concentration.

Active compounds present in green inhibitors for structural MS corrosion
Plant extracts have the prospects of filling the role of inorganic and synthetic organic inhibitors, due to their proven track record in the literature. Since the plant extracts mechanism of action relies on their active ingredients structure, many researchers have devised several theories to illustrate this phenomenon [54, 121]. The plant extracts IE(%) is due to their phytochemical constituents [49], which contain some heteroatoms, such as N, O, and S compounds [122]. For instance, *Glycyrrhiza glabra* phytochemical analysis showed that its main constituents are glycyrrhizin, flavonoids, liquiritigenin, isoflavonoids, glabridin and licochalcone [123]. *Nypa fruticans wurmb* leaf extract contains phenols and flavonoids [74]. The chemical ingredients found, via GC–MS, in *Ficus hispida* leaf extract, in varying percentages, are stigmasterol, 2-(benzyloxyme thyl)-5-methylfuran, 5-(hydroxylmethyl)-2-furan car-boxaldehyde, 2,3–dihydro-3,5-dihydroxy-6-methyl-pyran-4-one, neophytadiene, phytol, palmitic acid, sitosterols and ethyl linoleate [63]. The methanolic phytochemical examination of *Pterolobium hexapetalum* and *Celosia argentea* plants extracts showed the presence of flavonoids, tannins and phenolic compounds. Steroids, antraquinones and triterpenes were found only in *Pterolobium hexapetalum* extract, and saponins and amino acids were detected in *Celosia argentea* extract [62]. These plants inhibitors are all capable of reducing or even blocking structural MS corrosion [49].

Conclusion and future outlook

Following the examined previous literature, it was concluded that plants extracts are right choice candidates to replace the already known conventional, expensive and highly toxic inorganic and synthetic organic corrosion inhibitors. Therefore, this article has proved that the use of such green inhibitors is the only way to find a safer and more environmentally friendly protection against metallic corrosion, which has a huge impact on the worldwide economy. In fact, plant extracts have numerous phytochemical constituents that are capable to easily be adsorbed onto metals, and thus inhibit their corrosion. This paper has pinpointed and summarized the types of corrosion, different plant extracts and techniques used for combating corrosion in practical terms, in the industries where structural MS is applied in acidic (H_2SO_4, HCl, HNO_3, CH_3COOH, HCOOH, HCO_2H and H_3PO_4), basic (NaOH) and neutral (NaCl, and Na_2SO_4) media. It also was concluded that most of the reviewed studies focused more on strong acidic media, such HCl and H_2SO_4, than on other weak acidic environments, like CH_3COOH, HCOOH, HCO_2H and H_3PO_4, while there were less studies on basic (NaOH) and neutral (NaCl and Na_2SO_4) media. Hence, it is encouraged that more studies soon be done, using basic, neutral and week acidic media.

Acknowledgement

The authors of this research paper are grateful to the colleagues in the department of Materials and Metallurgical Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria, for their encouragement and support.

Funding

This research did not receive any external funding.

Conflict of interest

The authors declare that there are no conflicts of interest.

Authors' contributions

Uzoma Samuel Nwigwe: gave minor contributions to the conception and design of the analysis; collected the data; contributed with data or analysis tools; performed the analysis of the outcomes; wrote the paper as the lead author; proofread the work. **Chukwuka Ikechukwu Nwoye**: gave substantial contributions to the conception/technical guidance of the analysis; contributed with data or analysis tools, providing intellectual support; helped with the data analysis and interpretation; proofread the manuscript, made editions where necessary, and gave the final approval of the version to be published.

Abbreviations

AAS: atomic absorption spectroscopy
ACI: AC impedance
AFM: atomic force microscope
ATR: attenuated total reflection spectroscopy
CH_3COOH: acetic acid
Cl_3CCOOH: trichloroacetic acid
CR: corrosion rate
CS: carbon steel
DEIS: dynamic electrochemical impedance spectroscopy
DFT: density functional theory
EDX: energy-dispersive X-ray spectroscopy
EIS: electrochemical impedance spectroscope
FTIR: Fourier-transform infrared spectroscope
GC-MS: gas chromatography mass spectrometry
GDP: gross domestic product
GM: gasometry
H_2SO_4: sulfuric acid
H_3PO_4: phosphoric acid
HCl: hydrochloric acid
HCO_2H: methanoic acid
HCOOH: formic acid
HE: hydrogen evolution
HNO_3: nitric acid
$IE_{max}(\%)$: maximum inhibition efficiency
LC-MS: liquid chromatography-mass spectrometry
MDS: molecular dynamics simulation
MS: mild steel
Na_2SO_4: sodium sulfate
NaCl: sodium chloride
NaOH: sodium hydroxide
OPM: optical microscopy
PDP: potentiodynamic polarization

SEM: scanning electron microscopy
UV-vis: ultraviolet-visible spectroscope or ultraviolet-visible spectrophotometry
WL: weight loss
XPS: X-ray photoelectron spectroscopy

References

1. Oyejide J, Orhorhoro E, Ogie A et al. Investigation of the Effect of Annealing on the Corrosion Resistance of Medium Carbon Steel in Sea Water. J Emerg Trends Eng Appl Sci. 2017;8(5):219-24.
2. Atanda P, Olorunniwo O, Alabi O et al. Effect of Iso-Thermal Treatment on the Corrosion Behaviour of Low Carbon Steel (Nigerian C2R grade) in a Buffered Solution Containing Chloride and Carbonate Ions. Int J Mater Chem. 2012;2(2):65-71. https://doi.org/10.5923/j.ijmc.20120202.04
3. Adebayo A, Ekiti A, Stephen J et al. Corrosion Behaviour of Heat Treated and Nickel Plated Mild Steel in Citrus Fruit: Lime and Lemon. Int J Sci Eng Technol Res. 2019;08:229-35.
4. Shukla S, Ebenso E. Corrosion Inhibition, Adsorption Behavior and Thermodynamic Properties of Streptomycin on Mild Steel in Hydrochloric Acid Medium. Int J Electrochem Sci. 2011;6:3277-91.
5. Ameh P, Eddy N. Theoretical and experimental studies on the corrosion inhibition potentials of 3-nitrobenzoic acid for mild steel in 0.1 M H_2SO_4. Cogent Chem. 2016;15(1):0-18. http://dx.doi.org/10.1080/23312009.2016.1253904
6. Idouhli R, Oukhrib A, Koumya Y et al. Inhibitory effect of Atlas cedar essential oil on the corrosion of steel in 1 M HCl. Corros Rev. 2018. https://doi.org/10.1515/corrrev-2017-0076
7. Gadow H, Motawea M. Investigation of the corrosion inhibition of carbon steel in hydrochloric acid solution by using ginger roots extract. RSC Adv. 2017;7:24576-88. http://dx.doi.org/10.1039/C6RA28636D
8. Haldhar R, Prasad D, Saxena A. *Myristica fragrans* Extract as an Eco-friendly Corrosion Inhibitor for Mild Steel in 0.5 M H_2SO_4 Solution. Biochem Pharmacol. 2018;1-40. DOI: https://doi.org/10.1016/j.jece.2018.03.023
9. Bala C, Balamurugan S, Balamurugan P, et al. Corrosion inhibition of mild steel by using banana peel extract. Int J Innov Technol Explor Eng. 2019;8(6):1372-5.
10. Mark U, Aharanwa I, Igwe C. The Inhibitive Effect of *Carica Papaya* Leaf Extract on the Corrosion of Mild Steel in Acidic (1 M HCl) Medium. Int J Eng Sci. 2019;8(3):10-20. https://doi.org/10.9790/1813-0803011020
11. Ajayi O, Omotosho O, Ifepe V. Acid Failure of Mild Steel in 2 M Sulphuric Acid in the Presence of *Vernonia Amygdalina*. J Mater Environ Sci. 2011;2(2):186-95.
12. Okewale A, Olaitan A. The Use of Rubber Leaf Extract as a Corrosion Inhibitor for Mild Steel in Acidic Solution. Int J Mater Chem. 2017;7(1):5-13. http://journal.sapub.org/ijmc
13. Nnanna L, Owate I, Nwadiuko O et al. Adsorption and Corrosion Inhibtion of *Gnetum Africana* Leaves Extract on Carbon Steel. Int J Mater Chem. 2013;3(1):10-6. https://doi.org/10.5923/j.ijmc.20130301.03

14. Malaibari Z, Kahraman R, Rauf A. Corrosion of inhibitor treated mild steel immersed in distilled water and a simulated salt solution. Anti-Corros Methods Mater. 2013;60(5):227-33. https://doi.org/10.1108/ACMM-06-2012-1186
15. Mo S, Luo H, Li N. Plant extracts as "green" corrosion inhibitors for steel in sulphuric acid. Chem Pap. 2016;70(9):1131-43. https://doi.org/10.1515/chempap-2016-0055
16. Umoren S, Obot I, Obi-Egbedi N. *Raphia hookeri* gum as a potential eco-friendly inhibitor for mild steel in sulfuric acid. J Mater Sci. 2009;44(1):274-9. https://doi.org/10.1007/s10853-008-3045-8
17. Mobin M, Rizvi M. Inhibitory effect of xanthan gum and synergistic surfactant additives for mild steel corrosion in 1 M HCl. Carbohydr Polym. 2016;136:384-93. https://doi.org/10.1016/j.carbpol.2015.09.027
18. Hassan K, Khadom A, Kurshed N. *Citrus aurantium* leaves extracts as a sustainable corrosion inhibitor of mild steel in sulfuric acid. South African J Chem Eng. 2016;22:1-5. https://doi.org/10.1016/j.sajce.2016.07.002
19. Loto R. Corrosion inhibition of mild steel in acidic medium by butyl alcohol. Res Chem Intermed. 2013;39(2):1899-910. https://doi.org/10.1007/s11164-013-1088-1
20. Möller H, Boshoff E, Froneman H. The corrosion behaviour of a low carbon steel in natural and synthetic seawaters. J South African Inst Min Metall. 2006;106(8):585-92.
21. Nwigwe S, Reginald Umunakwe, Moses Y et al. The inhibition of *Carica papaya* leaves extract on the corrosion of cold worked and annealed mild steel in HCl and NaOH solutions using a weight loss technique. EASR. 2019;46:114-9. DOI: https://doi.org/10.14456/easr.2019.14
22. Makanjuola O, Paul A, Fasakin J. Performance of Mild Steel in Nitric Acid/ *Carica Papaya* Leaf Extracts Corrosion System. Asian J Appl Sci. 2015;3:110-116.
23. Ofuyekpone O, Akaluzia R, Edibo S. Investigating the influence of immersion time and inhibitor concentration on the inhibiting potential of *Imperrata cylindrica* as corrosion inhibitor of mild steel. Int J Res Eng Innov. 2017;1(6):147-52. http://www.ijrei.com
24. Ndukwe A, Anyakwo C. Modelling of Corrosion Inhibition of Mild Steel in Hydrochloric Acid by Crushed Leaves of *Sida Acuta* (*Malvaceae*). Int J Eng Sci. 2017;06(01):22-33. https://doi.org/10.9790/1813-0601032233
25. Aramide F. Corrosion Inhibition of AISI/SAE Steel in a Marine Environment. Leonardo J Sci. 2009;(15):47-52.
26. Debi G, Esah H, Mohammad I et al. Effect of *Vernonia Amygdalina* Extract on Corrosion Inhibition of Mild Steel in Simulated Seawater. Aust J Basic Appl Sci. 2013;7(14):257-63.
27. Durowaye S, Sekunowo O, Durowaye V. Inhibitive Behaviour of Methyl Red Corrosion of Mild Steel in Alkaline Medium. Am J Mater Sci. 2014;4(2):111-7. https://doi.org/10.5923/j.materials.20140402.08
28. Ugwu B, Ekwuribe S, Onukwuli O. Corrosion inhibition of *papaya* (pawpaw) leaf extract on mild steel in HNO_3 and NaOH media. Umudike J Eng Technol. 2017;3(1):2-4.
29. Abeng F, Ikpi M, Anadebe V et al. Metolazone compound as corrosion inhibitor for API 5L X-52 steel in hydrochloric acid solution. Bull Chem Soc Ethiop. 2020;34(2):407-18. https://doi.org/10.4314/bcse.v34i2.16

30. Buchweishaija J. Plants as a Source of Green Corrosion Inhibitors: The Case of Gum Exudates from Acacia Species (*A. drepanolobium* and *A. senegal*). Tanzania J Sci. 2009;(35):93-106.
31. Rani B, Basu B. Green inhibitors for corrosion protection of metals and alloys: An overview. Int J Corros. 2012.
32. Kamal C, Sethuraman M. *Spirulina platensis* – A novel green inhibitor for acid corrosion of mild steel. Arab J Chem. 2012;5(2):155-61. http://doi.org/10.1016/j.arabjc.2010.08.006
33. Yaro A, Khadom A, Wael R. Apricot juice as green corrosion inhibitor of mild steel in phosphoric acid. Alexandria Eng J. 2013;52(1):129-35. http://doi.org/10.1016/j.aej.2012.11.001
34. Osuwa C, Okere C. *Aspilia Africana* extracts as organic corrosion inhibitor of mild steel in corrosive acidic media. IOSR J Environ Sci Toxicol Food Technol. 2013;4(5):61-5. https://doi.org/10.9790/2402-0456165
35. Abiola O, James A. The effects of *Aloe vera* extract on corrosion and kinetics of corrosion process of zinc in HCl solution. Corros Sci. 2010;52(2):661-4. http://doi.org/10.1016/j.corsci.2009.10.026
36. Li X, Deng S, Fu H. Inhibition of the corrosion of steel in HCl and H_2SO_4 solutions by bamboo leaf extract. Corros Sci. 2012;62:163-75. http://doi.org/10.1016/j.corsci.2012.05.008
37. Odejobi J, Akinbulumo A. Modeling and optimization of the inhibition efficiency of *euphorbia heterophylla* extracts based corrosion inhibitor of mild steel corrosion in HCl media using a response surface methodology. J Chem Technol Metall. 2018;54(1):217-32.
38. Olawale O, Oyawale F, Adediran A et al. Corrosion Inhibition of Mild Steel in Seawater using Jatropha Stem. Analele Univ Eftimie Murgu Reşiţa Fasc Ing. 2016;23(1):228-38.
39. Ofuyekpone O, Emordi N, Utu O. Effect of sulphuric acid concentration on the inhibiting action of 0.001 M adenine solution during the corrosion of AISI 304L. Adv Appl Sci Res. 2015;6(9):17-26.
40. Düdükcü M, Kaplan S, Avcı G. Green Approach to Corrosion Inhibition of Mild Steel in Sulphuric Acid Solution by the Extract of *Olea Europaea* Leaves. J Mater Environ Sci. 2020;11(1):45-56.
41. Raja P, Qureshi A, Abdul A et al. *Neolamarckia cadamba* alkaloids as eco-friendly corrosion inhibitors for mild steel in 1 M HCl media. Corros Sci. 2013;69:292-301. http://dx.doi.org/10.1016/j.corsci.2012.11.042
42. Mathina A, Rajalakshmi R. Corrosion inhibition of mild steel in acid medium using *Canna Indica* as green corrosion inhibitor. Rasayan J Chem. 2016;9(1):56-66.
43. Subhashini S, Rajalakshmi R, Prithiba A et al. Corrosion mitigating effect of *Cyamopsis Tetragonaloba* seed extract on mild steel in acid medium. E-J Chem. 2010;7(4):1133-7. https://doi.org/10.1155/2010/457825
44. Hart K, Orubite-Okorosaye K, Abodsede O. Corrosion Inhibition of Mild Steel in Simulated Seawater by *Nymphae Pubscens* Leaf Extracts (NLE). Int J Adv Res Chem Sci. 2017;4(12):32-40. https://doi.org/10.20431/2349-0403.0412004
45. Parthipan P, Elumalai P, Narenkumar J et al. *Allium sativum* (garlic extract) as a green corrosion inhibitor with biocidal properties for the control of MIC in carbon steel and stainless steel in oilfield environments. Int Biodeterior Biodegrad. 2018;132:66-73. https://doi.org/10.1016/j.ibiod.2018.05.005

46. Loto R, Olowoyo O. Synergistic effect of sage and jojoba oil extracts on the corrosion inhibition of mild steel in diluted acid solution. Procedia Manufacturing. 2019;310-4. https://doi.org/10.1016/j.promfg.2019.05.045
47. Ladan M, Basirun W, Kazi S et al. Corrosion protection of AISI 1018 steel using Co-doped TiO2/polypyrrole nanocomposites in 3.5% NaCl solution. Mater Chem Phys. 2017;192:361-73. http://doi.org/10.1016/j.matchemphys.2017.01.085
48. Miralrio A, Vazquez A. Plant Extracts as Green Corrosion Inhibitors for Different Metal Surfaces and Corrosive Media: a Review. Processes. 2020;8(8):942. https://doi.org/10.3390/pr8080942
49. Kaur J, Daksh N, Saxena A. Corrosion Inhibition Applications of Natural and Eco-Friendly Corrosion Inhibitors on Steel in the Acidic Environment: an Overview. Arab J Sci Eng. 2021. https://doi.org/10.1007/s13369-021-05699-0
50. Sastri V. Green corrosion inhibitors. New Jersey: John Wiley & Sons, Inc. 2011:1-310.
51. Bardal E. Corrosion and Protection. London: Springer-Verlag London Limited. 2003:1-315.
52. Fayomi O, Akande I, Odigie S. Economic Impact of Corrosion in Oil Sectors and Prevention: an Overview. J Phys Conf Ser. 2019;1378(2):1-8.
53. Verma C, Quraishi MA. Adsorption behavior of 8,9-bis(4 (dimethyl amino)phenyl)benzo[4,5]imidazo[1,2-a]pyridine-6,7-dicarbonitrile on mild steel surface in 1 M HCl. J Assoc Arab Univ Basic Appl Sci. 2017;22:55-61. http://doi.org/10.1016/j.jaubas.2016.01.003
54. Chigondo M, Chigondo F. Recent Natural Corrosion Inhibitors for Mild Steel: an Overview. J Chem. 2016;2016:1-7.
55. Peter A, Sharma S. Use of *Azadirachta indica* (AZI) as green corrosion inhibitor against mild steel in acidic medium: anti-corrosive efficacy and adsorptive behaviour. Int J Corros Scale Inhib. 2017;6(2):112-31.
56. Faiz M, Zahari A, Awang K et al. Corrosion inhibition on mild steel in 1 M HCl solution by *Cryptocarya nigra* extracts and three of its constituents (alkaloids). RSC Adv. 2020;10(11):6547-62.
57. Anupama K, Ramya K, Shainy K et al. Adsorption and electrochemical studies of *Pimenta dioica* leaf extracts as corrosion inhibitor for mild steel in hydrochloric acid. Mater Chem Phys. 2015;167:28-41. https://doi.org/10.1016/j.matchemphys.2015.09.013
58. Slepski P, Gerengi H, Jazdzewska A et al. Simultaneous impedance and volumetric studies and additionally potentiodynamic polarization measurements of molasses as a carbon steel corrosion inhibitor in 1 M hydrochloric acid solution. Constr Build Mater. 2014;52:482-7. https://doi.org/10.1016/j.conbuildmat.2013.11.059
59. Ibrahim T, Alayan H, Mowaqet Y. The effect of Thyme leaves extract on corrosion of mild steel in HCl. Prog Org Coatings. 2012;75(4):456-62. http://doi.org/10.1016/j.porgcoat.2012.06.009
60. Dehghani A, Bahlakeh G, Ramezanzadeh B. Green Eucalyptus leaf extract: A potent source of bio-active corrosion inhibitors for mild steel. Bioelectrochemistry. 2019;130:107339. https://doi.org/10.1016/j.bioelechem.2019.107339
61. Srivastava K, Srivastava P. Studies-on plant materials as corrosion inhibitors. Br Corros J. 1981;16(4):221-3.
62. Pradeep K, Mohana K. Phytochemical screening and corrosion inhibitive behavior of *Pterolobium hexapetalum* and *Celosia argentea* plant extracts on mild steel in industrial water medium. Egypt J Pet. 2014;23(2):201-11. http://doi.org/10.1016/j.ejpe.2014.05.007

63. Muthukrishnan P, Prakash P, Jeyaprabha B et al. Stigmasterol extracted from *Ficus hispida* leaves as a green inhibitor for the mild steel corrosion in 1 M HCl solution. Arab J Chem. 2019;12(8):3345-56. http://doi.org/10.1016/j.arabjc.2015.09.005
64. Nnanna L, Owate I, Oguzie E. Inhibition of Mild Steel Corrosion in HCl Solution by *Pentaclethra macrophylla* Bentham Extract. Int J Mater Eng. 2014;4(5):171-9.
65. Okoronkwo A, Olusegun S, Olaniran O. Acid extract of *Gliricidia sepium* leaves as green corrosion inhibitor for mild steel in HCl solutions. African Corros J. 2015;1(1):1-5.
66. Rahman M, Gul S, Umair M et al. Anticorrosive Activity of *Rosemarinus Officinalis* Leaves Extract Against Mild Steel in Dilute Hydrochloric Acid. Int J Eng. 2016;3(03):38-43. http://www.ijirae.com/volumes/Vol3/iss3/08.MRAE10085.pdf
67. Akinbulumo O, Odejobi O, Odekanle E. Thermodynamics and adsorption study of the corrosion inhibition of mild steel by *Euphorbia heterophylla L.* extract in 1.5 M HCl. Results Mater. 2020;5:100074. https://doi.org/10.1016/j.rinma.2020.100074
68. Sharmila A, Prema A, Sahayaraj P. Influence of *Murraya koenigii* (curry leaves) extract on the corrosion inhibition of carbon steel in HCL solution. Rasayan J Chem. 2010;3(1):74-81.
69. Alibakhshi E, Ramezanzadeh M, Haddadi S et al. Persian Liquorice extract as a highly efficient sustainable corrosion inhibitor for mild steel in sodium chloride solution. J Clean Prod. 2019;210:660-72. https://doi.org/10.1016/j.jclepro.2018.11.053
70. Iloamaeke I, Onuegbu T. Corrosion Inhibition Of Mild Steel by *Pterocarpus Soyauxi* Leaves Extract In HCl Medium. Int J Plant Anim Environ Sci. 2012;2(3):22-8. http://ijpaes.com/admin/php/uploads/192_pdf.pdf
71. Patel N, Hrdlicka J, Beranek P et al. Extract of *Phyllanthus fraternus* leaves as corrosion inhibitor for mild steel in H_2SO_4 solutions. Int J Electrochem Sci. 2014;9(6):2805-15.
72. Haddadi S, Alibakhshi E, Bahlakeh G et al. A detailed atomic level computational and electrochemical exploration of the *Juglans regia* green fruit shell extract as a sustainable and highly efficient green corrosion inhibitor for mild steel in 3.5 wt% NaCl solution. J Mol Liq. 2019;284:682-99. https://doi.org/10.1016/j.molliq.2019.04.045
73. Kumar D, Khan F. Corrosion Inhibition of Mild Steel by Extract of *Bryophyllum Pinnatum* Leaves in Acidic Solution. Chem Mater Res. 2015;7(5):69-77. www.iiste.org
74. Michael N. The Corrosion Inhibition of Mild Steel in Sulphuric Acid Solution by Flavonoid (Catechin) Separated from *Nypa Fruticans Wurmb* Leaves Extract. Sci J Chem. 2014;2(4):27.
75. Zucchi F. Plant extracts as corrosion inhibitors of mild steel in HCl solutions. Surf Technol. 1985;24:391-9.
76. Zheng X, Gong M, Li Q et al. Corrosion inhibition of mild steel in sulfuric acid solution by loquat (*Eriobotrya Japonica* Lindl) leaves extract. Sci Rep. 2018;8(9140):1-15. http://doi.org/10.1038/s41598-018-27257-9
77. Durodola S, Adekunle A, Olasunkanmi L et al. Inhibition of Mild Steel Corrosion in Acidic Medium by Extract of *Spilanthes uliginosa* Leaves. Electroanalysis. 2020;1-32.

78. Hussein H, Sultan A, Intisar A et al. Mechanical Properties of Carbon Steel Using of *Allium Ampeloprasum* Extract as Corrosion Inhibitor. Int J Mech Eng Technol. 2015;6(1):34-41.
79. Abhulimen E. An investigation on the optimal concentration of oil palm (*Elaeis guineensis*) leaves extract as corrosion inhibitor of carbon steel in deaerated saline solution. MOJ Appl Bionics Biomech. 2018;60(2):109-13.
80. Nnanna L, Uchendu K, Nwosu F et al. *Gmelina Arborea* Bark Extracts as a Corrosion Inhibitor for Mild Steel in an Acidic Environment. Int J Mater Chem. 2014;4(2):34-9. https://doi.org/10.5923/j.ijmc.20140402.03
81. Oruene D, Isaac O, Nkoi B. The Inhibition Effect of Breadfruit Leaf Extract on Mild Steel Corrosion. J Newviews Eng Technol. 2021;3(1):34-43.
82. Aliyu A, Salisu L, Akilu A et al. Mild Steel Corrosion Inhibition by *Euphorbia heterphylla* Extract in 0.5 M Hydrochloric Acid Solution. J Mater Environ Sci. 2021;12(3):431-41.
83. Olasehinde E, Ogunjobi J. Investigation of the Inhibitive Properties of *Alchornea laxiflora* Leaves on the Corrosion of Mild Steel in HCl: Thermodynamics and Kinetic Study. J Am Sci. 2015;11(1s):32-9.
84. Chinonso A, Chidiebere A, Ibe F et al. Protecting Mild Steel from Acid Corrosion Using Extract from *Ocimum gratissimum* Leaves. Int Lett Chem Phys Astron. 2017;73:9-21. https://doi.org/10.18052/www.scipress.com/ILCPA.73.9
85. Gupta D, Das A, Neupane S et al. Study of *Jatropha Curcas* Extract as a Corrosion Inhibitor in Acidic Medium on Mild Steel by Weight Loss and Potentiodynamic Methods. J Nepal Chem Soc. 2020;41(1):87-93.
86. Omotosho O, Ajayi O, Fayomi O et al. Assessing the deterioration behaviour of mild steel in 2 M sulphuric acid using *Bambusa glauscescens*. Int J Appl Eng Res. 2011;2(2):406-18.
87. Hernandesa I, Cunhaa, D, Araujo C et al. Application of an Aqueous Extract of Cotton Seed as a Corrosion Inhibitor for Mild Steel in HCl Media. Mater Res. 2021;24(1):1-10.
88. Bhuvaneswari T, Vasantha V, Jeyaprabha C. *Pongamia Pinnata* as a Green Corrosion Inhibitor for Mild Steel in 1 N Sulfuric Acid Medium. Silicon. 2018:1-14.
89. Anbarasi K, Vasudha V. Influence of eco friendly plant material (*Cucurbita maxima*) on mild steel corrosion. Anti-Corrosion Methods Mater. 2016:1-13.
90. Ajayi S, Ademosun O, Okoro ER et al. Corrosion Inhibitory Properties of *Biden Pilosa* Plant Extract on Mild Steel in Acidic Media. J Phys: Conference Series. 2019:1-10. https://doi.org/10.1088/1742-6596/1378/4/042005
91. Nnenna W, Adeola S, Msenhemba M et al. *Synsepalum Dulcificum* Leaves Extract as Green Inhibitor for Mild Steel Corrosion in Hydrochloric Acid. Chem Search J. 2021;12(1):47-54.
92. Noor E. Temperature Effects on the Corrosion Inhibition of Mild Steel in Acidic Solutions by Aqueous Extract of Fenugreek Leaves. Int J Electrochem Sci. 2007;2:996-1017.
93. Afandi M, Saud S, Hamzah E. Green-based corrosion protection for mild steel in 3.5% NaCl and distilled water medias: *Jatropha curcas* and Roselle extracts. J Met Mater Miner. 2020;30(2):91. https://doi.org/104.10.14456/jmmm.2020.25

94. Ebuka D, Stephen A, Abechi E. Corrosion inhibition studies of mild steel using *Acalypha chamaedrifolia* leaves extract in hydrochloric acid medium. SN Appl Sci. 2019;1(1089):1-11. https://doi.org/10.1007/s42452-019-1138-4
95. Omotosho O, Ajayi O, Ajanaku K et al. Environment Induced Failure of Mild Steel in 2 M Sulphuric Acid Using *Chromolaena Odorata*. J Mater Environ Sci. 2012;3(1):66-75.
96. Lebe N, Wisdom J, Tochukwu E et al. Inhibitive Effect of *Costus Afer* Extracts on Mild Steel Corrosion in Acidic Medium. Int J Eng Technol. 2016;7:60-7. https://doi.org/10.18052/www.scipress.com/IJET.7.60
97. Nwosu F, Nnanna L, Okeoma K. Corrosion inhibition for mild steel in 0.5 M H_2SO_4 solution using *Achyranthes aspera* leaf extract. African J Pure Appl Chem. 2013;7(2):56-60. https://doi.org/10.5897/AJPAC2012.0073
98. Oyewole O, Aondoakaa E, Abayomi T et al. Characterization and optimization study of *Ficus exasperata* extract as corrosion inhibitor for mild steel in seawater. World Sci News. 2021;151:78-94.
99. Achebe C, Ilogebe A, Chukwuneke J et al. The Effects of Inhibition on Corrosion of Mild Steel in H_2SO_4 Using Ethanol Extract of *Vernonia Amygdalina*. Int J Eng Sci. 2015;4(8):28-36.
100. Chukwueze G, Asadu C, Onu C et al. Evaluation of the Corrosion Inhibitive Properties of Three Different Leave Extracts on Mild Steel Iron in Sulphuric Acid Solution. J Eng Res Reports. 2020;12(3):6-17. https://doi.org/10.9734/JERR/2020/v12i317080
101. Madawa N, Tuaweri T, Mebine P et al. Corrosion Inhibition of Mild Steel C1026 Pipeline in Na_2SO_4 Using Green Inhibitors. Int J Eng Sci Invent. 2021;10(1):15-22. https://doi.org/10.35629/6734-1001011522
102. Awe F, Idris S, Abdulwahab M et al. Theoretical and experimental inhibitive properties of mild steel in HCl by ethanolic extract of *Boscia senegalensis*. Cogent Chem. 2015;1:1-14. https://doi.org/10.1080/23312009.2015.1112676
103. Okafor P, Uwah I, Ekerenam O et al. *Combretum bracteosum* extracts as eco-friendly corrosion inhibitor for mild steel in acidic medium. Pigment Resin Technol. 2009;38(4):236-41. DOI: https://doi.org/10.1108/03699420910973323
104. Ishmael V, Ajiwe E, Ejike C. Corrosion Inhibition of Mild Steel in Sulphuric Acid by Methanol Leaf Extracts of *Milicia Excelsa*. Open Sci J Analyt Chem. 2019;4(2):13-9.
105. Saeed M, Saleem M, Niyazi A et al. Carrot (*Daucus Carota*) Peels Extract as an Herbal Corrosion Inhibitor for Mild Steel in 1 M HCl Solution. Mod Appl Sci. 2020;14(2):97-112. https://doi.org/10.5539/mas.v14n2p97
106. Akalezi C, Enenebaku C, Oguzie E. Inhibition of acid corrosion of mild steel by biomass extract from the *Petersianthus macrocarpus* plant. J Mater Environ Sci. 2013;4(2):217-26.
107. Olusegun S, Okoronkwo E, Okotete A. Gravimetric and electrochemical studies of corrosion inhibition potential of acid and ethanol extract of siam weed on mild steel. Leonardo J Sci. 2016;(29):25-42.
108. Kalla A, Benahmed M, Djeddi N et al. Corrosion inhibition of carbon steel in 1 M H_2SO_4 solution by *Thapsia villosa* extracts. Int J Ind Chem. 2016;7(4):419-29. https://doi.org/10.1007/s40090-016-0094-8
109. Chauhan L, Gunasekaran G. Corrosion inhibition of mild steel by plant extract in diluted HCl medium. Corros Sci. 2007;49(3):1143-61.

110. Arockiasamy P, Thenmozhi G, Franco M et al. Evaluation of Corrosion Inhibition of Mild Steel in 1 M Hydrochloric Acid Solution by *Mollugo Cerviana*. Int J Corros. 2014;2014:1-7. https://doi.org/10.1155/2014/679192
111. Premkumar P, Kannan K, Natesan M. Thyme extract of *Thymus vulgar* leaves as volatile corrosion inhibitor for mild steel in NaCl environment. Asian J Chem. 2008;20(1):445-51.
112. Ostovari A, Hoseinieh SM, Peikari M et al. Corrosion inhibition of mild steel in 1 M HCl solution by henna extract: A comparative study of the inhibition by henna and its constituents (lawsone, gallic acid, α-d-glucose and tannic acid). Corros Sci. 2009;51(9):1935-49.
113. Uwah I, Okafor P, Ebiekpe V. Inhibitive action of ethanol extracts from *Nauclea latifolia* on the corrosion of mild steel in H_2SO_4 solutions and their adsorption characteristics. Arab J Chem. 2013;6(3):285-93. http://doi.org/10.1016/j.arabjc.2010.10.008
114. Dickson O, Goodluck O, Onyekpe B et al. Effect of inhibitor concentration on the potency of *Stylosanthes gracilis* extract as corrosion inhibitor for AISI 304l in sulphuric acid solution. Sci African. 2021;11(e00714):1-4. https://doi.org/10.1016/j.sciaf.2021.e00714
115. Edoziuno F, Adediran A, Odoni B et al. Influence of Wormin Mebendazole on the Corrosion of Mild Steel in 1.0 M Sulphuric Acid. Results Eng. 2020:100192. https://doi.org/10.1016/j.rineng.2020.100192
116. Ameer M, Fekry A. Corrosion inhibition of mild steel by natural product compound. Prog Org Coatings. 2011;71(4):343-9. DOI: http://doi.org/10.1016/j.porgcoat.2011.04.001
117. Chaudhari H, Vashi R. The study of henna leaves extract as green corrosion inhibitor for mild steel in acetic acid. J Fundam Appl Sci. 2016;8(2):280. https://doi.org/10.4314/jfas.v8i2.8
118. Noyel S, Prasad R, Manivannan R. *Psidium guajava* leaf extract as green corrosion inhibitor for mild steel in phosphoric acid. Int J Electrochem Sci. 2015;10(3):2220-38.
119. Li X, Deng S, Li N et al. Inhibition effect of bamboo leaves extract on cold rolled steel in Cl_3CCOOH solution. J Mater Res Technol. 2017;6(2):158-70. http://doi.org/10.1016/j.jmrt.2016.09.002
120. Singh M, Gupta A. Corrosion behaviour of mild steel in formic acid solutions. Mater Chem Phys. 1996;46(1):15-22. https://doi.org/10.1016/0254-0584(96)80124-6
121. Yadav M, Gope L, Kumari N et al. Corrosion inhibition performance of pyranopyrazole derivatives for mild steel in HCl solution: gravimetric, electrochemical and DFT studies. J Mol Liq. 2016;216:78-86. http://doi.org/10.1016/j.molliq.2015.12.106
122. Satapathy A, Gunasekaran G, Sahoo S et al. Corrosion inhibition by *Justicia gendarussa* plant extract in hydrochloric acid solution. Corros Sci. 2009;51(12):2848-56. https://doi.org/10.1016/j.corsci.2009.08.016
123. Alibakhshi E, Ramezanzadeh M, Bahlakeh G et al. *Glycyrrhiza glabra* leaves extract as a green corrosion inhibitor for mild steel in 1 M hydrochloric acid solution: experimental, molecular dynamics, Monte Carlo and quantum mechanics study. J Mol Liq. 2018;255:185-98. https://doi.org/10.1016/j.molliq.2018.01.144