Green Corrosion Inhibitors for Mild Steel in H_2SO_4 Solutions (Period 2019-2022) - A Review

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Abstract
MS is the most commonly used alloy in industries, due to its remarkable features such as high thermal requirements, low cost, easy availability, high strength, durability and electrical conductivity. In recent years, scientists have focused on green inhibitors obtained from plants, fruit 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 on MS corrosion control by naturally occurring plant extracts as corrosion inhibitors in H_2SO_4 solutions.

Keywords: corrosion inhibition; EIS; H_2SO_4; MS; plant extracts; PDP; WL.

Introduction•

Corrosion is the gradual destruction or deterioration of a metal by chemical or electrochemical interaction with an environment that leads to wastage of a metal surface. It occurs due to the metals spontaneous need to revert to a more stable form as it is found in nature. Corrosion is a continuous process and cannot be completely stopped. It causes financial implications in terms of product losses and replacement, and environmental pollution. Several techniques have been applied in order to reduce metallic corrosion. The use of inhibitors is one of the most practical and efficient methods for metals protection against corrosion [1].

The problems associated with traditional organic and inorganic inhibitors, which limit their usage nowadays, include biotoxicity, environmentally unfriendly properties, high cost and non-availability on demand. The use of natural products to inhibit corrosion is of enormous interest, since they are environmentally friendly, ecologically acceptable, readily available, inexpensive, and can be used nowadays as green inhibitors. Generally, plant extracts contain heteroatoms such as O, P, N and S. Adsorption of these atoms depends mainly on functional groups, steric factors, electron density at the donor atoms and also on the inhibitor's

•The abbreviations list is in page 175.

electronic structure. A corrosion inhibitor is generally referred to as a chemical substance that when applied in small quantities to a corrosive medium reduces the corrosion rate of a metal or an alloy [2]. Inhibitors retard metal corrosion by adsorbing onto a metallic surface. This process is influenced by some factors, which include the inhibitor molecular size and concentration, nature of substituents, test solution nature and T [3, 4]. The use of inhibitors for the control of metallic corrosion is one of the most practical approaches for preventing this phenomenon, especially in acid solutions, to prevent unexpected metal dissolution and acid consumption [4]. Due to inhibitor molecules adsorption onto metal surfaces, a protective film is formed, thus hindering corrosion. A great number of corrosion inhibitors have been studied for MS in acidic media.

MS contains 0.05 to 0.25 by weight of carbon, hence known as low CS. It is extensively applied 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.

Acidic solutions are widely used in industry for removal of undesirable scale and rust in metal finishing. The most important areas of application are acid pickling, industrial acid cleaning and heat exchangers. H_2SO_4 is a strong acid, being used as a cleaner for rust, algae and scale from condensers and cooling towers [5].

Meanwhile, concerted efforts are being employed by scientists with a view to improve the life span of metallic and alloy materials, by finding suitable anti-corrosive compounds that can be used in various media to prevent metal dissolution.

Extraction methods

Various solvents have been used to obtain the desired concentration of active compounds from plant extracts. The efficient extraction of active compounds depends on the solvent used, among which the most common are water, ethanol, methanol, ethyl acetate, dichloromethane and hexane [6, 7]. Water could be the most convenient extraction solvent, since it is highly available, non-toxic, non-flammable and inexpensive [8].

T and immersion time

T has an important influence on the corrosion of metal surfaces. It is possible to modify the interaction between the corrosive medium and the metal surface in the presence of inhibitors. Some extracts exhibit an increasing IE(%) trend towards higher T [9]. However, other extracts have shown different behaviors. Thus, the evaluation of IE(%) as a function of T is important, since every extract could perform differently. Similarly, immersion time is another factor that could modify IE(%).

Characterization of techniques

A proper characterization of the extracts proposed as corrosion inhibitors is needed. Thus, several experimental techniques are available for this purpose. WL technique is based on the mass lost by corrosion, which is directly monitored to assess the CR. Polarization tests, such as PDP, are based on the evaluation and analysis of the current produced by a variable potential in a working electrode [10]. EIS technique is used to determine the impedance of a system in terms of the frequency of a variable potential. EIS shows more information, for example, mechanisms and different resistances of the system. Surface characterization is commonly addressed by means of spectroscopy and microscopy techniques. SEM provides a clear comparison between the metal surface with and without a corrosion inhibitor, as well as other morphological information. Similarly, AFM obtains information regarding the shape of the metal surface for comparison purposes and topography imaging. Complementary characterizations are usually done through FT-IR, to obtain information on the functional groups and vibrational modes on corrosion inhibitors. Similarly, UV-vis helps to elucidate functional groups, electronic transitions and optical band gaps. XPS is a quantitative technique that is capable of identify elemental compositions and analyze the outermost molecular layers of a material. QCC has been recently used to analyze the adsorption mechanism of inhibitors on a metal surface.

Types of inhibitors

There are three types of inhibitors according to mechanism of electrochemical action. Anodic inhibitors slow down the oxidation reaction by blocking anodic sites (seat of metal oxidation), which decrease the density of the metal dissolution current and shift the corrosion potential in the positive direction. Cathodic corrosion inhibitors decrease the corrosion potential towards lower values, inhibiting the reactions that take place at the cathode, such as oxygen reduction and hydrogen evolution, shifting the corrosion potential in a negative direction. Mixed-type inhibitors act on both cathodic and anodic reactions.

Plant extracts as MS corrosion inhibitors

Table 1 shows recent studies, by various authors, on structural MS corrosion inhibition by plant extracts.

Table 1: Natural products as corrosion inhibitors for MS in a H_2SO_4 solution.

Plant	Corrosive medium	Techniques used	Type of inhibitor	IE(%)	Ref.
AC bark	0.5 M H_2SO_4	WL, PDP, EIS, SEM, AFM, UV-vis, FT-IR	Mixed	91.13 WL, 93.85 PDP, 93.12 EIS	[11]
AC bark	1 M H_2SO_4	WL, OCP, PDP, SEM, UV, FT-IR	Mixed	93.96 WL, 98.91 PDP	[12]
AC pod	0.5 M H_2SO_4	WL, PDP, EIS, SEM, AFM, UV, QCC	Mixed	91.13 WL, 92.73 PDP, 94.98 EIS	[13]
AN	1 N H_2SO_4	WL, PDP, FT-IR	--	--	[14]
AN leaves and stems	0.5 M H_2SO_4	PDP, EIS, SEM, EDX, FT-IR, GC-MS	Mixed	AN leaves: 89.1 PDP, 88.8 EIS. AN stems: 80.0 PDP, 86.6 EIS	[15]
ASG	0.5 M H_2SO_4 + 0.08 M KBr and KI	PDP, EIS	-	81.60 EIS with KI and 68.4 EIS with KBr	[16]
ACL	0.5 M H_2SO_4	WL, PDP, EIS, FT-IR, SEM	Mixed	--	[17]
AE leaves	0.5 M H_2SO_4	WL, PDP, EIS, SEM, FT-IR, UV-Vis	---	96.0 WL	[18]
ANB	1 M H_2SO_4	WL, OCP, PDP, FT-IR, UV-Vis	Mixed	71.94 WL, 90.00 PDP	[19]
AV leaves	0.5 M H_2SO_4	WL, PDP, SEM	Mixed	88.9 WL	[20]

Amaranthus	4 N H_2SO_4	WL, PDP, SEM	Cathodic	--	[21]
AS	0.5 M H_2SO_4	WL, PDP, EIS, SEM, AFM	Cathodic	--	[22]
AO	0.5 M H_2SO_4	WL, PDP, EIS, SEM, AFM, FT-IR	Mixed	91.62 PDP, 93.27 EIS	[23]
AH-AO	0.5 M H_2SO_4	WL, PDP, EIS, SEM, GC-MS	Mixed	85.0 WL, 88.0 PDP	[24]
AF-F leaves	1 M H_2SO_4	WL, PDP, SEM, FT-IR	Mixed	85.49 WL, 88.39 PDP	[25]
PAM leaves	0.5 M H_2SO_4	WL, SEM, EDX	--	97.89 WL	[26]
PAM seeds	0.75 M H_2SO_4	WL, PDP, SEM, FT-IR	Mixed	74.55 WL, 68.37 PDP	[27]
AI leaves	1 M H_2SO_4	WL	--	86.0 WL	[28]
Berberine	1M H_2SO_4	WL, PDP, EIS, SEM, FT-IR, UV-Vis	Mixed	93.80 WL, 98.19 PDP, 98.02 EIS	[29]
BA	1M H_2SO_4	WL, PDP, EIS, ATR-FTIR, SEM, EDX	Mixed	95.92 WL, 98.14 PDP	[30]
BK leaf	1.2 M H_2SO_4	WL, FTIR, GC-MS, SEM, RSM, QCC	Mixed	93.0 WL, 87.6 PDP, 85.5 EIS	[31]
BM seeds	2 M H_2SO_4	WL, HE, PDP, EIS, SEM, DFT, FT-IR, QCC	Mixed	93.48 WL, 89.27 PDP, 88.43 EIS, 94.83 HE	[32]
BE seeds	2.0 M H_2SO_4	WL, SEM, FT-IR, DFT, QCC	--	96.0 WL	[33]
BE seeds	1.0 M H_2SO_4	WL, SEM, FT-IR, QCC, DFT	--	95.53 WL	[34]
CN	2 M H_2SO_4	WL, SEM, FT-IR, RSM	--	70.67 WL	[35]
CA leaves	0.5 M H_2SO_4	WL, PDP, EIS, SEM, AFM, FT-IR, UV-Vis	Mixed	93.81 WL, 96.46 PDP, 95.06 EIS	[36]
CB leaves	0.5 M H_2SO_4	WL, PDP, EIS, SEM	Mixed	85.71 WL, 86.60 PDP, 86.86 EIS	[37]
CB leaves	1 M H_2SO_4	WL	--	91.91 WL	[38]
CO stem	0.5 M H_2SO_4	WL, SEM	--	94.34 WL	[39]
CM leaves	1 M H_2SO_4	WL, PDP, EIS, SEM, FT-IR, EDX	Mixed	92.00 WL, 85.10 PDP	[40]
CNSA	1 M H_2SO_4	WL, PDP, FT-IR, UV-Vis	Mixed	96.40 WL, 97.03 PDP	[41]
CS stem	1 M H_2SO_4	WL, PDP	--	90.43 WL, 92.86 PDP	[42]
CP	0.5 M H_2SO_4	WL, PDP, EIS, SEM, UV-Vis. QMC	Mixed	98.09 WL, 84.09 PDP, 80.51 EIS	[43]
CuA leaf	1 M H_2SO_4	WL, SEM, EDX, AFM, XRD, RSM	--	92.39 WL	[44]
CR	0.5 M H_2SO_4	WL, PDP, EIS, GC-MS, FT-IR, AFM, DFT, QCC	Mixed	87.9 WL, 78.0 PDP, 77.0 EIS	[45]
DE	0.5 M H_2SO_4	OCP, PDP, EIS, GC-MS, AFM, SEM, EDX	Mixed	68.47 PDP, 85.96 EIS	[46]
EO	3 M H_2SO_4	WL, SEM, FT-IR, RSM.	--	82.93 WL	[47]
EH	1 M H_2SO_4	WL, PDP, EIS, FT-IR, SEM, EDX	Mixed	82.0 WL, 92.74 PDP, 86.28 EIS	[48]
Eucalyptus leaf	0.5 M H_2SO_4	WL, PDP, EIS, SEM, FT-IR	Mixed	--	[49]
EpO leaves	1 M H_2SO_4	WL		92.72 WL	[50]
FH	1 M H_2SO_4	WL, PDP, EIS, SEM, IR, UV-Vis	Mixed	86.56 WL, 85.14 PDP, 90.61 EIS	[51]
FPo and FPl	2 M H_2SO_4	WL	--	FPO- 45.85 WL. FPL- 23.71 WL	[52]
GMM	0.5 M H_2SO_4	WL, OCP, PDP, EIS, SEM, XPS, NMR, EPC, QCC	Mixed	95.4WL, 94.8 PDP, 95.4 EIS	[53]
Guava leaf	0.1, 0.3 and 0.5 M H_2SO_4	WL, FT-IR	--	98.81 WL, 96.82 RSM	[54]
GEAH	1 M H_2SO_4	WL, PDP, EIS, SEM, EDX, GC-MS, AFM and QCC	Mixed	78.57 WL, 95.89 PDP, 91.84 EIS	[55]
HBR leaves	0.5 M H_2SO_4	WL, PDP, EIS, SEM, EDX, FT-IR, ENA	Mixed	88.0 WL, 74.0 PDP, 82.0 EIS	[56]
Hibiscus leaves	0.5 M H_2SO_4	WL, FT-IR	-	89.39 WL	[57]
HP	0.5 M H_2SO_4	WL, FT-IR, SEM, GC-MS, UV-vis., MDS, QCC	--	95.11 WL	[58]
HSFS	0.5 M H_2SO_4	PDP, EIS, SEM, FT-IR, UV-Vis	--	90.0 WL	[59]
HSPE and honey	1 M H_2SO_4	PDP, GC-MS	Mixed	87.5 PDP	[60]

IC	0.5 M H_2SO_4	WL, PDP, EIS, SEM, ENA, FT-IR and UV-Vis, QCC	Mixed	77.96 WL, 87.02 PDP, 90.33 EIS	[61]
JC	1.0 M H_2SO_4	WL, OCP, PDP	Mixed	92.05 WL, 91.34 PDP	[62]
JC leaves	4 M H_2SO_4	WL	--	71.3 WL	[63]
JT stem bark	1 M H_2SO_4	WL	--	75.61 WL	[64]
LD	5 M H_2SO_4	WL, GM, FT-IR	--	82.63 WL, 84.09 GM	[65]
LH	0.5 M H_2SO_4	WL, PDP	Mixed	--	[66]
LP	1 M H_2SO_4	WL, PDP, EIS, SEM, FT-IR, AFM	Mixed	--	[67]
LC peels	0.5 M H_2SO_4	WL, PDP, EIS, SEM, UV-Vis, FT-IR, XRD	Mixed	97.8 WL, 95.7 PDP, 97.8 EIS	[68]
MK	1 M H_2SO_4	WL, PDP, EIS, AAS, SEM, EDX, AFM, FT-IR, UV-Vis	Mixed	95.01 PDP	[69]
ME	0.4 and 2.5 M H_2SO_4	WL, GM	--	62.07 WL	[70]
MH extract	0.5 M H_2SO_4	WL, Colorometry, PDP, EIS, EDS, FESEM, FT-IR	Mixed	--	[71]
MAC	1 M H_2SO_4	WL	--	90.0 WL	[72]
MP peels	H_2SO_4	WL, PDP, EIS, FT-IR, UV-Vi., SEM, AFM, DFT	--	87.0 WL	[73]
MP stem extrude	1.0, 1.5 and 2.0 M H_2SO_4	WL		84.75 WL	[74]
NI leaves	1.3 M H_2SO_4	WL, PDP, EIS, SEM, FT-IR, QCC	Mixed	86.92 WL, 86.2 PDP, 86.0 EIS	[75]
NN leaves	1 M H_2SO_4	WL, PDP, EIS	Mixed	76.47 WL, 75.56 PDP, 69.47 EIS	[76]
OEL leaves	1 M H_2SO_4	PDP, EIS, SEM, FT-IR	Mixed	99.0 PDP, 96.0 EIS	[77]
OS leaves	1 N H_2SO_4	WL, PDP, EIS, SEM, GC-MS, DFT, FT-IR, UV-Vis	Mixed	92.6 WL	[78]
Pichia sp. biofilm	1 M H_2SO_4	WL, PDP, EIS, FT-IR, XRD, EDX, FE-SEM, XPS, AFM	Mixed	90.0 WL	[79]
PN leaves	0.5 M H_2SO_4	WL, PDP, EIS, SEM, RSM	Mixed	84.31 WL, 97.2 PDP, 85.34 EIS	[80]
PL bark	0.5 M H_2SO_4	WL	--	88.0 WL	[81]
RLE	0.5 M H_2SO_4	WL, PDP, EIS, SEM, QCC, FTIR, UV-Vis	Mixed	93.30 WL, 94.11 PDP, 92.19 EIS	[82]
RC plant	0.5 M H_2SO_4	PDP, EIS, SEM, AFM, FTIR	Mixed	74.0 PDP, 75.0 EIS	[83]
RR	1 M H_2SO_4	WL, PDP, SEM, EDX, FTIR	Mixed	87.51 WL, 93.24 PDP	[84]
Rice straw	1.5 M H_2SO_4	WL, SEM	--	86.42 WL	[85]
SR leaf	1 N H_2SO_4	WL, PDP, EIS, SEM, DFT, GC-MS, UV–Vis, FT-IR	Mixed	90.30 WL	[86]
SRB	1 M H_2SO_4	WL, PDP, UV-Vis, FT-IR	Mixed	93.75 PDP	[87]
Siam weed	1 M H_2SO_4	WL	--	95.0 WL	[88]
SX stem	1 M H_2SO_4	WL, PDP, SEM, FT-IR	--	93.14 WL, 98.14 PDP	[89]
SC leaves	1 M H_2SO_4 + KI	WL, GM, SEM	--	SC+ KI- 91.49 WL, 83.76 PDP	[90]
SA fruit	0.5 M H_2SO_4	WL, PDP, EIS, AFM, SEM	---	93.25 WL	[91]
TT leaves	0.4, 0.5, 0.6 and 2.5 M H_2SO_4	WL, GM	--	70.77 WL, 59.31 GM	[92]
TGL	0.5 M H_2SO_4	WL, PDP, EIS, AFM, SEM	Mixed	96.70 WL	[93]
TP leaves	1 N H_2SO_4	PDP, EIS, AFM, SEM, UV-Vis, FT-IR, NMR, GC-MS	Mixed	93.0 PDP	[94]
TC leaves	1 M H_2SO_4	WL	--	64.0 WL	[95]
TI leaves	1 M H_2SO_4	WL	--	92.47 WL	[96]
Thyme extract	0.5 M H_2SO_4	WL, PDP, EIS	Mixed	98.0 WL	[97]
TCd	0.5 M H_2SO_4	WL, PDP, RSM, BBD, EIS, SEM, AFM	Mixed	82.53 WL, 88.68 EIS	[98]
VA	1 M H_2SO_4	WL, PDP, FT-IR, QCC	Mixed	89.11 WL	[99]
XA	5 M H_2SO_4	WL, FT-IR, SEM	--	98.32 WL	[100]
ZM cobs	1 M H_2SO_4	WL, PDP	Mixed	89.68 WL, 94.05 PDP	[101]
AV and ST	1 M H_2SO_4	WL, PDP, SEM, FT-IR	Mixed	AV- 92.58, WL 88.06 PDP. ST- 90.79 WL, 83.22 PP	[102]
CT and JC	4 M H_2SO_4	WL, GM	--	CT- 49.59 WL, 68.9 GM. JC- 55.77 WL, 61.30 GM	[103]
Lavandula and RCu oil	5 M H_2SO_4	WL, PDP	--	96.35 WL, 90.00 PDP	[104]

AC: *Acacia catechu*; ACL: *Adina cordifolia* leaves; ACo: *Acacia concinna*; AE: *Ailanthus excelsa;* AF-F: *Athyrium filix-femina*; AH-AO: *Artemisia herba-alba* oil; AI: *Azadirachta indica*; AV: *Aloe vera*; AN: *Acacia nilotica*; ANB: *Alnus nepalensis* bark; AO: *Artabotrys odoratissimus*; AS: *Annona squamosa*; ASG: *Acacia sengal* gum, BA: *Berberis aristata*; BE: *Brachystegia eurycoma*; BK: *Bitter kola;* BM: *Black mustard;* CA: *Citrus aurantifolia*; CB: *Commelina benghalensis*; CM: *Cordia millenii*; CN: chicken nail; CNSA: *Coriaria nepalensis* stem alkaloid; CO: *Corchorus olitorius*; CP: *Croton persimilis*; CR: *Cyperus rotundus*; CS: *Crotalaria spectabilis*; CT: *Cascabela thevetia*; CuA: *Cucumis anguria*; DE: *Delonix elata*; EH: *Equisetum hyemale*; EO: *Epiphyllum oxypetalum*; EpO: *Euphorbia heterophylla*; FH: *Ficus hispida*; FPl: *Ficus platyphylla*; FPo: *Ficus polita*; GEAH: gum exudate from *Araucaria heterophylla*; GMM*: Glycine max meal* (Soybean); HBR: *Hardwickia binata Roxb*; HP: *Honeycomb propolis*; HSFS: *Hymenaea stigonocarpa* fruit shell; HSPE: *Hyptis suaveolens poit extract*; IC: *Ixora coccinea*; JC: *Jatropha curcas*; JT: *Jatropha tanjorensis*; LC: *Litchi chinensis*; LD: *Landolphia dulcis*; LH: *Landolphia heudelotii*; LP: *Liriope platyphylla*; MAC: *Musa acuminate colla* (native banana); ME: *Milicia excelsa*; MH: *Mitracarpus hirtus*; MK: *Magnolia kobus*; MP: *Musa paradisica*; NI: *Napoleonaea Imperalis,* PAM: *Persea americana mill* (avocado); NN: *Nelumbo nucifera*; OEL: *Olea europaea L.*; OS: *Oxalis stricta*; PL: *Polyalthia longifolia;* PN: *Picralima nitida*; RC: *Rhus coriaria*; RCu: *Ricinus communis*; RLE: Radish leaf extract; RR: *Rhynchostylis ret*usa; SA: *Syzygium aromaticum*; SC: *Spondias cytheria*; SR: *Senegalia rugata;* SRB: *Shorea robusta* bark; SX: *Solanum xanthocarpum*; ST: *solanum tubersoum*; TC: *Terminalia catappa*; TCd: *Tinospora cordifolia*; TGL: *Tectona grandis L*; TI: *Terminalia ivorensis*; TP: *Tephrosia purpurea*; TT: *Talinum triangulare* (water leaf); VA: *Vernonia amygdalina* (bitter leaf); XA: *Xylopia aethiopica*; ZM: *Zea mays*.

Active phytoconstituents present in green inhibitors

In this review, most plant extracts were found to contain active phytochemicals such as tannins, flavonoids, saponins, alkaloids, phenols and glycosides. Some few plant extracts contain steroids, amino acids, carbohydrates, proteins, terpenes and β-sitosterol etc., which have a corrosion inhibitive effect.

Conclusions

This review paper has summarized the research works carried out by various researchers on MS corrosion in H_2SO_4 and on is inhibition by using different plant extracts and techniques. Many variables can be explored to evaluate a plant extract as corrosion inhibitor: concentration, extraction solvent, T and immersion time. In fact, plant extracts have numerous phytochemical constituents that are able to easily be adsorbed onto metals, thus inhibiting their CR by forming a passive film or an adsorbed layer that acted as a barrier. According to WL, PDP and EIS data, it is obvious that, with higher inhibitor concentration, CR decreases while IE(%) increases. An increase in T resulted in lower IE(%) of the tested products. Plants extracts can control metallic corrosion by inhibitory mechanisms (anodic, cathodic and mixed) in acidic environments. In this review, Langmuir's adsorption isotherm was found to be the most common. The effectiveness of the corrosion inhibitor was evaluated by WL, PDP and EIS. Other methods like SEM, FT-IR, UV-vis, RSM, AFM, GC-MS and EDX were also used to study the metals surfaces. Results obtained from WL data were in good agreement with PDP and EIS methods. This review may be useful to green corrosion chemists and researchers in the near future.

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Conceived and designed the analysis; collected the data; provided data or analysis tools; performed the analysis; wrote the paper.

Abbreviations
AAS: atomic absorption spectroscopy
AFM: atomic force microscope
BBD: box-Behnken design
CR: corrosion rate
CS: carbon steel
DFT: density functional theory
EDS: energy dispersive spectroscopy
EDX: energy-dispersive X-ray spectroscopy
EIS: electrochemical impedance spectroscope
ENA: electrochemical noise analysis
EPC: electro-phorosis characterization
FT-IR: fourier-transform infrared spectroscope
GC-MS: gas chromatography mass spectrometry
GM: gasometry method
H_2SO_4: sulfuric acid
HE: hydrogen evolution
IE(%): inhibition efficiency
KBr: potassium bromide
KI: potassium iodide
MDS: molecular dynamics simulation
MS: mild steel
NaCl: sodium chloride
NaOH: sodium hydroxide
NMR: nuclear magnetic resonance
OCP: open circuit potential
PDP: potentiodynamic polarization
QCC: quantum chemical calculations
QMC: quantum mechanical calculations
RS: Raman spectroscopy
RSM: response surface methodology
SE: synergistic effect
SEM: scanning electron microscopy
T: temperature
UV-vis: ultraviolet-visible spectroscope or ultraviolet-visible spectrophotometry
WL: weight loss
XPS: X-ray photoelectron spectroscopy
XRD: X-ray diffraction

References

1. Kumar S, Sharma D, Yadav P et al. Experimental and quantum chemical studies on corrosion inhibition effect of synthesized organic compounds on N80 steel in hydrochloric acid. Ind Eng Chem Res. 2013;52(39):14019-14029. https://doi.org/10.1021/ie4013 08v
2. James AO, Oforka NC, Abiola K. Inhibition of Acid Corrosion of Mild Steel by Pyridoxal and Pyridoxol Hydrochlorides. Int J Electrochem Sci. 2007; 2:278-284. https://doi.org/10.1016/S1452-3981(23)17073-8
3. Naderi AE, Jafari AH, Ehteshamzadeh M et al. Effect of carbon steel microstructures and molecular structure of two new Schiff base compounds on inhibition performance in 1 M HCl solution by EIS. Mater Chem Phys. 2009;115:852-858. https://doi.org/10.1016/j.matchemphys.2008.08.026
4. Galai M, El Gouri M, Dagdag et al. New Hexa Propylene Glycol Cyclotiphosphazene as Efficient Organic Inhibitor of Carbon Steel Corrosion in Hydrochloric Acid Medium. J Mater Environ Sci. 2016;7(5):1562-1575.
5. Sax NI, Lewis RJ. Sr. (eds.). Hawley's Condensed Chemical Dictionary, 11th edition, New York, Van Nostrand Reinhold Co., 1987.
6. Pham H, Nguyen V, Vuong Q et al. Effect of Extraction Solvents and Drying Methods on the Physicochemical and Antioxidant Properties of *Helicteres Hirsuta Lour* Leaves. Technologies. 2015;3(4):285-301. https://doi.org/ 10.3390/technologies3040285
7. Seal T. Quantitative HPLC analysis of phenolic acids, flavonoids and ascorbic acid in four different solvent extracts of two wild edible leaves, *Sonchus arvensis* and *Oenanthe lin*earis of North-Eastern region in India. J Appl Pharm Sci. 2016;6(2):157-166. https://doi.org/ DOI:10.7324/JAPS.2016.60225
8. Varma RS. Greener and Sustainable Trends in Synthesis of Organics and Nanomaterials. ACS Sustain Chem Eng. 2016;4:5866-5878. https://doi.org/10.1021/acssuschemeng.6b01623
9. Bahlakeh G, Dehghani A, Ramezanzadeh B et al. Highly effective mild steel corrosion inhibition in 1 M HCl solution by novel green aqueous Mustard seed extract: Experimental, electronic-scale DFT and atomic-scale MC/MD explorations. J Mol Liq. 2019;293:111559. https://doi.org/ 10.1016/j.molliq.2019.111559
10. Esmailzadeh S, Aliofkhazraei M, Sarlak H. Interpretation of Cyclic Potentiodynamic Polarization Test Results for Study of Corrosion Behavior of Metals: A Review. Prot Met Phys Chem Surf. 2018;54:976-989. https://doi.org/10.1134/S207020511805026X
11. Haldhar R, Prasad D, Bhardwaj N. Experimental and theoretical evaluation of *Acacia catechu* extract as a natural, economical and effective corrosion inhibitor for Mild Steel in acidic environment, J Bio Tribo Corros. 2020;6(3):76. https://doi.org/10.1007/s40735-020-00368-5
12. Karki R, Bajgai AK, Khadka N et al. *Acacia catechu* Bark Alkaloids as Novel Green Inhibitors for Mild Steel Corrosion in a One Molar Sulphuric Acid Solution. Electrochemistry. 2022;3:668-687. https://doi.org/10.3390/ electrochem3040044

13. Haldhar R, Prasad D, Bhardwaj N. Surface adsorption and corrosion resistance performance of *Acacia concinna* pod extract: An efficient inhibitor for mild steel in acidic environment. Arab J Sci Eng. 2020;45:131-141. https://doi.org/10.1007/s13369-019-04270-2
14. Jimoh I, Usman B. Corrosion Inhibition Potential of Ethanol Extract of *Acacia nilotica* Leaves on Mild Steel in an Acidic Medium. Port Electrochim Acta. 2021;39:105-128. https://doi.org/10.4152/pea.202102105
15. Mahgoub FM, Hefnawy AM, Abd AEH. Corrosion inhibition of mild steel in acidic solution by leaves and stem extract of *Acacia nilotica*. Desalin Water Treat. 2019;169:49-58. https://doi.org/10.5004/dwt.2019.24681
16. Emmanuel J, Buchweishaija J. Synergistic Effects of Halide Ions and *Acacia senegal* Gum on the Corrosion Inhibition of Mild Steel in Sulfuric Acid Solution. Tanz J Sci. 2021;47(2):686-697. https://dx.doi.org/10.4314/tjs.v47i2.24
17. Seshian BD, Pandian BR, Durai U. *Adina Cordifolia* as a corrosion inhibitor – a green approach against mild steel corrosion in 0.5 M sulphuric acid medium. Pig Resin Technol. 2020;49(1):63-70. https://doi.org/10.1108/prt-01-2019-0004
18. Bhuvaneshwari DS, Padmavathy S, Baluchamy T et al. *Ailanthus excelsa* as biogenic inhibitor for mild steel corrosion in 0.5 M H_2SO_4 medium and antifoulant against fouling bacteria. Mater Today Commun. 2021;28:102461. https://doi.org/10.1016/j.mtcomm.2021.102461
19. Dhakal K, Bohara DS, Bist BB et al. Alkaloids extract of *Alnus nepalensis* Bark as a Green Inhibitor for Mild Steel Corrosion in 1 M H_2SO_4 Solution. J Nepal Chem Soc. 2022;43(1):75-88. https://doi.org/10.3126/jncs.v43i1.46999
20. Ayoola AA, Fayomi OSI, Akande IG et al. Inhibitive Corrosion Performance of the Eco-Friendly *Aloe Vera* in Acidic Media of Mild and Stainless Steels. J Bio- Tribo-Corros. 2020;6:67. https://doi.org/10.1007/s40735-020-00361-y
21. Srivastava M. Mild Steel Corrosion Inhibition in 4 N Sulphuric Acid by a Green Inhibitor. Port Electrochim Acta. 2020;38(2):99-106. https://doi.org/10.4152/pea.202002099
22. Karthikeyan S, Abuthahir S, Begum S et al. Corrosion Inhibition of Mild Steel in 0.5 M H_2SO_4 Solution by Plant Extract of *Annona squamosa*. Asian J Chem. 2021;33(9):2219-2228. https://doi.org/10.14233/ajchem.2021.23386
23. Rathod MR, Minagalavar RL, Rajappa SK. Effect of *Artabotrys odoratissimus* extract as an environmentally sustainable inhibitor for mild steel corrosion in 0.5 M H_2SO_4 media. J Indian Chem Society. 2022;99(5):100445. https://doi.org/10.1016/j.jics.2022.100445
24. Boumhara K, Harhar H, Tabyaoui M et al. Corrosion inhibition of mild steel in 0.5 M H_2SO_4 solution by *Artemisia herba-alba* oil. J Bio Tribo Corros. 2019;5(1):8. https://doi.org/10.1007/s40735-018-0202-8

25. Tomilawo BA, Olasehinde EF, Ani JU et al. Corrosion Control of Mild Steel in Sulphuric Acid by *Athyrium filix-fem*ina Leaf Extract Green Inhibitor. Chem Sci Rev Lett. 2020;9(36):869-885. https://doi.org/10.37273/chesci.CS0320510701
26. Mu'azu K, Aliyu MM, Mohammed AT et al. Ethanol Extract of Avocado Leaf as Corrosion Inhibitor for the Protection of Mild Steel in Acidic Environment. J Mater Environ Sci. 2022;13(11):1343-1354. https://doi.org/10.6084/m9.figshare.21699587
27. Gusti DR, Lestari I, Farid F et al. Protection of mild steel from corrosion using methanol extract of avocado (*Persea americana mill*) seeds in a solution of sulfuric acid. IOP Conf. Series: J Phy: Conf Series. 2019;1282:012083. https://doi.org/10.1088/1742-6596/1282/1/012083
28. Waidi YB, Philip OY. Investigating the Efficacy of *Azadirachta Indica* (Neem) Leaf on Mild Steel Corrosion in 1 M Sulphuric Acid (H_2SO_4). Amer J Sci Eng Technol. 2022;7(3):121-129. https://doi.org/10.11648/j.ajset.20220703.18
29. Karki N, Neupane S, Gupta DK et al. Berberine isolated from *Mahonia nepalensis* as an eco-friendly and thermally stable corrosion inhibitor for mild steel in acid medium. Arab J Chem. 2021;14(12):1-15. https://doi.org/10.1016/j.arabjc.2021.103423
30. Karki N, Neupane S, Chaudhary Y et al. *Berberis A*ristata: A Highly Efficient and Thermally Stable Green Corrosion Inhibitor for Mild Steel in Acidic Medium. Analyt Bioanalyt Electrochem. 2020;12:970-988. https://doi.org/www.abechem.com/article_43505.html
31. Anadebe VC, Nnaji PC, Okafor NA et al. Evaluation of *Bitter Kola* Leaf Extract as an Anticorrosion Additive for Mild Steel in 1.2 M H_2SO_4 Electrolyte. South Afri J Chem. 2021;75:6-17. https://doi.org/10.17159/0379-4350/2021/v75a2
32. Al-Moubaraki AH, Al-Malwi SD. Experimental and theoretical evaluation of aqueous black mustard seeds extract as sustainable-green inhibitor for mild steel corrosion in H_2SO_4 acid solutions. J Adhes Sci Technol. 2022;36:1-31. https://doi.org/10.1080/01694243.2022.2062955
33. Ozoemena CP, Charles M, Ugwuoke MC. Experimental and theoretical studies on the corrosion inhibitive properties of mild steel in 2 M H_2SO_4 acid solution by ethanolic extract of *Brachystegia eurycoma* seed. Asian J Sci Technol. 2019;10(12):10532-10544.
34. Ozoemena CP, Akpan GJ, Ugwuoke MC. Corrosion inhibition and adsorption characteristics of ethanolic extract of *Brachystegia eurycoma* seed on the corrosion of mild steel in 1 M H_2SO_4 acid solution. FUW Trends Sci Technol J. 2020;5(2):382-388.
35. Olawale O, Bello JO, Ogunsemi BT et al. Optimization of chicken nail extracts as corrosion inhibitor on mild steel in 2 M H_2SO_4. Heliyon. 2019;5(11):1-9. https://doi.org/10.1016/j.heliyon.2019.e02821

36. Haldhar R, Prasad D, Bhardwaj N. Extraction and experimental studies of *Citrus aurantifolia* as an economical and green corrosion inhibitor for mild steel in acidic media. J Adhes Sci Tech. 2019;(11):1169-1183. https://doi.org/10.1080/01694243.2019.1585030
37. Ahamed KR, Farzana BA, Diraviam SJ et al. Mild Steel Corrosion Inhibition by the Aqueous Extract of *Commelina benghalensis* Leaves. Port Electrochim Acta. 2019;37(1):51-70. https://doi.org/10.4152/pea.201901051
38. Odidika CC, Ajiwe VIE, Eboagu CN et al. Corrosion Inhibition and Adsorption Properties of *Commelina benghalensis* Leaves Extract on Mild Steel in 1 M H_2SO_4 Solution. Sci J Analyt Chem. 2020;8(2):86-92. https://doi.org/10.11648/j.sjac.20200802.18
39. Oyewole O, Oshin TA, Atotuoma BO. *Corchorus olitorius* stem as corrosion inhibitor on mild steel in sulphuric acid. Heliyon. 2021,7:1-7. https://doi.org/10.1016/j.heliyon.2021.e06840
40. Olasehinde EF, Tomilawo BA, Abata EO et al. Assessment of Corrosion Inhibitory Potential of *Cordia millenii* Leaves Extract on Mild Steel in Acidic Medium. Int J Adv Mater Res. 2019;5(1):20-30.
41. Oli HB, Magar JT, Khadka N et al. *Coriaria nepalensis* Stem Alkaloid as a Green Inhibitor for Mild Steel Corrosion in 1 M H_2SO_4 Solution. Electrochemistry. 2022;3:713-727. https://doi.org/10.3390/electrochem3040047
42. Bohara DS. Effect of *Crotalaria spectabilis* Stem Extracts on the Corrosion Inhibition of Mild Steel in 1 M Sulphuric Acid Solution (M.Sc.). Amrit Campus, Tribhuvan University, Nepal. 2019.
43. Vidhya K, Thomas JK, Raphael VP. Green Corrosion Inhibition Properties of *Croton Persimilis* Extract On Mild Steel in Acid Media. J Bio- Tribo-Corros. 2021;7(3):121. https://doi.org/10.1007/s40735-021-00554-z
44. Chung I, Kim SH, Prabakaran M. Evaluation of Phytochemical, polyphenol composition and anti-corrosion capacity of *Cucumis anguria* L. leaf extract on metal surface in sulphuric acid medium. Protect Metals Phys Chem Surf. 2020;56:214-224. https://doi.org/10.1134/S2070205120050
45. Anitha R, Unnisa CBN, Hemapriya V et al. Anti-corrosive potential of *Cyperus rotundus* as a viable corrosion inhibitor for mild steel in sulphuric acid. Pig Resin Technol. 2020;49(4):295-304. https://doi.org/10.1108/PRT-11-2019-0101
46. Mahalakshmi D, Unnisa CBN, Hemapriya V. Anticorrosive potential of ethanol extract of *Delonix elata* for mild steel in 0.5 M H_2SO_4 - a green approach. Bulgar Chem Commun. 2019; 51(1):31-37.
47. Emembolu L, Onukwuli O, Okafor V. Characterization and optimization study of *Epiphyllum oxypetalum* extract as corrosion inhibitor for mild steel in 3 M H_2SO_4 solutions. World Sci News. 2020;145:256-273.
48. Karki N, Neupane S, Chaudhary Y et al. *Equisetum hyemale*: a new candidate for green corrosion inhibitor family. Int J Corros Scale Inhib. 2021;10(1):206-227. https://doi.org/10.17675/2305-6894-2021-10-1-12

49. Abdel-Gaber AM, Rahal HT, Beqai FT. Eucalyptus leaf extract as a eco-friendly corrosion inhibitor for mild steel in sulfuric and phosphoric acid solutions. Int J Indust Chem. 2020;11(2):123-132. https://doi.org/10.1007/s40090-020-00207-z
50. Odidika CC, Ajiwe VIE, Eboagu NC et al. Corrosion Inhibitive Action of *Euphorbia heterophylla* Leaves Extract on Mild Steel in 1 M H_2SO_4 Solution. Open Sci J Analyt Chem. 2020;5(1):1-8.
51. Muthukrishnan P, Prakash P. Adsorption and Charge Transfer Resistance Behavior of *Ficus hispida* Leaf Extract on Mild Steel Against Acid Attack. J Fail Analyt Prev. 2020;20(5):1-7. https://doi.org/10.1007/s11668-020-00996-6
52. Adah CA, Adejo SO, Gbertyo JA et al. Comparative studies of inhibitive properties of *Ficus p*olita and *Ficus p*lat*yphyll*a on corrosion inhibition of mild steel in acidic media. Ovidius Uni Annals Chem. 2021;32(1):40-45. https://doi.org/10.2478/auoc-2021-0006
53. Limaa KC, Paivaa VM, Perrone D et al. Glycine max meal extracts as corrosion inhibitor for mild steel in sulphuric acid solution. J Mater Res Technol. 2020;9(xx):12756-12772. https://doi.org/10.1016/j.jmrt.2020.09.019
54. Ezeamaku UL, Eze OI, Nzebude CP et al. Examining the Unique Properties of Guava Leaf Extract as a Corrosion Inhibitor. Int J Eng Sci Invent. 2020;9(1):Series I;08-18.
55. Sathiyapriya T, Rathika G, Dhandapani M. In depth analysis of anticorrosion behaviour of ecofriendly gum exudate for mild steel in sulphuric acid medium. J Adhes Sci Tech. 2019;33(22):1-19. https://doi.org/10.1080/01694243.2019.1645261
56. Vasanthajothi R, Saratha R, Kadirvelu K. Mild steel green inhibition by *Hardwickia binata* Roxb leaves extract in acid medium. J Adhes Sci Tech. 2020;35(24):1-17. https://doi.org/10.1080/01694243.2020.1801248
57. Gaidhania KY, Khurpadeb PD, Nandi S. *Hibiscus* leaves extract: A green corrosion inhibitor. J Indian Chem Soc. 2020;97:865-869.
58. Idris IA, Bello AU, Usman B. Experimental and Theoretical Evaluation of Corrosion Inhibition of Honeycomb Propolis Extract On Mild Steel in Acidic Media. J Mater Environ Sci. 2022;13(05):576-59.
59. Policarpi E, Spinelli A. Application of *Hymenaea stigonocarpa* fruit shell extract as eco-friendly corrosion inhibitor for steel in sulfuric acid. J Taiwan Instit Chem Eng. 2020;116:215-222. https://doi.org/10.1016/j.jtice.2020.10.024
60. Ikpambese KK, Yaji M. Inhibitive effect of *Hyptis suav*eolens (l) poit extract and natural honey on corrosion of mild steel in H_2SO_4 solution. Annals– Int J Eng. 2020;4:99-106. https://www.researchgate.net/publication/347661957
61. Thomas VK, Kakkassery JT, Raphaelb VP et al. *Ixora coccinea* extract as an efficient eco-friendly corrosion inhibitor in acidic media: Experimental and theoretical approach. Current Chem Lett. 2021;10:139-150. https://doi.org/ 10.5267/j.ccl.2020.12.001

62. Gupta DK, Anita Kafle KM, Kumari DA 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. https://doi.org/10.3126/jncs.v41i1.30493
63. Ajayi OM, Odusote JK, Yahya RA. Inhibition of mild steel corrosion using *Jatropha curcas* leaf extract. J Electrochem Sci Eng. 2014;4(2):67-74. https://doi.org/10.5599/jese.2014.0046
64. Abakedi OU, Sunday MV, James MA. Mild steel corrosion inhibition in acidic medium by *Jatropha tanjorensis* stem bark extract. Int J Chem Stud. 2021;9(3):09-13.
65. Emole PO, Onwuka KE, Okafor PC. Investigation of Corrosion inhibition potentials of *Landolphia dulcis* Extract on Mild Steel in Acidic Medium. Sci Res J. 2022;10(3):1-13. http://dx.doi.org/10.31364/SCIRJ/v10.i3.2022.P0322906
66. Agiriga, CE, Oguzie E, Chidiebere A et al. Corrosion inhibition action of *Landolphia heudelotii* on mild steel in acidic media. Pig Resin Technol. 2020;49(5):387-392. https://doi.org/10.1108/PRT-02-2019-0015
67. Chung IM, Venkatesan H, Kim SH et al. *Liriope platyphylla* extract as a green inhibitor for mild steel corrosion in sulfuric acid medium. Chem Eng Commun. 2019;208(1):1-17. https://doi.org/10.1080/00986445.2019.1692001
68. Singh MR, Gupta P, Gupta K. The litchi (*Litchi Chinensis*) peels extract as a potential green inhibitor in prevention of corrosion of mild steel in 0.5 M H_2SO_4 solution. Arab J Chem. 2019;12:1035-1041. http://dx.doi.org/10.1016/j.arabjc.2015.01.002
69. Chung IM, Malathy R, Priyadharshini RK et al. Inhibition of mild steel corrosion using *Magnolia Kobus* extract in sulphuric acid medium. Mater Today Commun. 2020;25:101687. https://doi.org/10.1016/j.mtcomm.2020.101687
70. 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.
71. Ragul R, Ravichandran·A, Murugesh A. Adsorption and Inhibitive Action of *Mitracarpus Hirtus* extract towards the corrosion of Mild steel in H_2SO_4 medium. J Bio- Tribo-Corros. 2020;6:65. https://doi.org/10.1007/s40735-020-00360-z
72. Leizoua KE, Ashraf MA. Evaluation of corrosion inhibitive properties of native banana (*Musa acuminate colla*) on mild steel in 1 M sulphuric acid (H_2SO_4). Acta Mech Malaysia. 2022;5(1):24-30. http://doi.org/10.26480/amm.01.2022.24.30
73. Ji G, Singh SK, Prakash R. Influence of the maturity of *Musa paradisica* peels on mild steel corrosion in sulfuric acid. J Adhes Sci Technol. 2021;36(1):1418-1438. http://doi.org/10.1080/01694243.2021.1970372

74. Idemudia OS, Maliki M. Studies on the Inhibitive Action of *Musa Paradisiaca* Stem Extrude on Corrosion of Mild Steel in an Acidic Medium. Int J Sci Technol. 2020;8(4):9-15. https://doi.org/10.24940/theijst/2020/v8/i4/ST2004-011
75. Emembolu LN, Onukwuli OD, Umembamalu CJ et al. Evalution of the corrosion inhibitory effect of *Napoleonaea Imperalis* leaf extract on mild steel in a 1.3 M H_2SO_4 medium. J Bio- Tribo- Corros. 2020;6(4):article 128. https://doi.org/10.1007/s40735-020-00422-2
76. Mushira BA, Riaz AK. Exploring *Nelumbo n*ucifera aqueous leaves extract as a green corrosion inhibitor for mild steel in acid medium. Int J Basic Appl Res. 2019;9(3):555-565. https://doi.org/ 10.5937/zasmat2303274N
77. 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. ISSN: 2028-2508.
78. Sannaiah PN, Alva VP, Bangera S. An experimental, theoretical and spectral approach to evaluating the effect of eco-friendly *Oxalis stricta* leaf extract on the corrosion inhibition of mild steel in 1 N H_2SO_4 medium. J Iranian Chem Soc. 2021;19(5):1-19. https://doi.org/10.1007/s13738-021-02422-6
79. Tamilselvi B, Bhuvaneshwari DS, Padmavathy S et al. Corrosion inhibition of *Pichia sp.* biofilm against mild steel corrosion in 1 M H_2SO_4. J Mol Liq. 2022;359(20):119359. https://doi.org/10.1016/j.molliq.2022.119359
80. Ezeugo JNO. A design and an optimization of an eco-friendly extract for inhibition of mild steel corrosion in sulphuric acid media. J Chem Technol Metall. 2019;54(4):810-825.
81. Adams SM, Aigbodion VS, Suleiman IY et al. Thermodynamic, kinetic and adsorptive parameters of corrosion inhibition of mild steel using *Polyalthia longifolia* bark extract in 0.5 M H_2SO_4. Int J Sci Eng Inven. 2019;5(11):1-7. https://doi.org/10.23958/ijsei/vol05-i11/177
82. Li D, Zhang P, Guo X et al. The inhibition of mild steel corrosion in 0.5 M H_2SO_4 solution by radish leaf extract. RSC Adv. 2019;9:40997-41009. https://doi.org/10.1039/C9RA04218K
83. Hijazi KM, Abdel-Gaber AM, Younes GO et al. Comparative study of the effect of an acidic anion on the mild steel corrosion inhibition using *Rhus Coriari*a plant extract and its quercetin component. Port Electrochim Acta. 2021;39:237-252. https://doi.org/10.4152/pea.2021390402
84. Chapagain A, Acharya D, Das AK et al. Alkaloid of *Rhynchostylis retusa* as Green Inhibitor for Mild Steel Corrosion in 1 M H_2SO_4 Solution. Electrochemistry. 2022;3:211-224. https://doi.org/10.3390/electrochem3020013
85. Oyewole O, Abayomi TS, Oreofe TA et al. Anti-corrosion using rice straw extract for mild steel in 1.5 M H_2SO_4 solution. Result Eng. 2022,16;100684. https://doi.org/10.1016/j.rineng. 2022.100684

86. Sannaiah PN, Prasad AVD, Bangera S. An integrated electrochemical and theoretical approach on the potency of *Senegalia rugata* leaf extract as a novel inhibitor for mild steel in acidic medium. J Appl Electrochem. 2022;52(2):1-18. https://doi.org/10.1007/s10800-021-01631-4
87. Bajgai AK, Karki R, Magar JT et al. *Shorea robusta* Bark Extract as a Novel Green Inhibitor for Mild Steel Corrosion in 1 M H_2SO_4 Solution. Amrit Res J. 2022;3(1):29-45. https://doi.org/10.3126/arj.v3i01.50494
88. Ayoola AA, Joseph EP. Corrosion Inhibitive Effects of *Siam* Weed Extract on Mild Steel in 1 M H_2SO_4 Medium. J Modern Mech Eng Techn. 2020;7:47-52. https://doi.org/10.31875/2409-9848.2020.07.6
89. Thapa O, Magar JT, Oli HB et al. Alkaloids of *Solanum xanthocarpum* Stem as Green Inhibitor for Mild Steel Corrosion in One Molar Sulphuric Acid Solution. Electrochem. 2022;3:820-842. https://doi.org/10.3390/electrochem3040054
90. Obike AI, Abraham EK, Iwuagwu M et al. Green Corrosion inhibition behavior of *Spondias cytheria* leaves extract and its Synergism with Chloride Ions on Mild Steel in H_2SO_4. Sch Int J Chem Mater Sci. 2021;4(5):66-72. https://doi.org/10.36348/sijcms. 2021.v04i05.003
91. Saxena A, Prasad D, Haldhar R. Use of *syzygium aromaticum* extract as green corrosion inhibitor for mild steel in 0.5 M H_2SO_4. Surface Rev Lett. 2019;26 (06):1850200. https://doi.org/10.1142/S0218625X18502001
92. Vincent IEA, Chinedu EE. *Talinum triangulare* (water leaf) methanol leaf extract as corrosion inhibitor on mild steel surface in H_2SO_4. Coll Surf Sci. 2020;5(1):6-12. https://doi.org/10.11648/j.css.20200501.12
93. Karthikeyan S, Abuthahir SSS, Begum AS et al. Inhibition of mild steel corrosion in 0.5 M sulfuric acid by an aqueous extract of leaves of *Tectona grandis* L. plant. Int J Corros Scale Inhib. 2021;10(4):1531-1546. https://doi.org/10.17675/2305-6894-2020-10-4-10
94. Karunanithi BK, Chellappa J. Adsorption and inhibition properties of *Tephrosia Purpurea* as corrosion inhibitor for mild steel in sulphuric acid solution. J Dispers Sci Technol. 2019;40:1441-1450. https://doi.org/10.1080/01932691.2018.1516150
95. Pramudita M, Sukirno M, Nasikin M. Performance of *Terminalia Cata*ppa Leaves Extract as Bio Corrosion Inhibitor for Mild Steel in H_2SO_4 Solution. The 9th AIC 2019 on Sciences & Engineering (9thAIC-SE) IOP Conf. Series: Mater Sci Eng. 2020;796:1-6. https://doi.org/10.1088/1757-899X/796/1/012059
96. Jane MN, Nakara TM. Determination of the corrosion inhibition effect of *Terminalia ivorensis* leaves extract on galvanized and mild steel in sulfuric acid media. American J Phys Chem. 2019;8(1):11-16. https://doi.org/10.11648/j.ajpc. 20190801.12
97. Golshani Z, Moezabad HC, Amiri M et al. Effect of Thyme extract as an ecofriendly inhibitor for corrosion of mild steel in acidic media. Mater Corros. 2021;73(3):460-469. https://doi.org/10.1002/maco.202112769

98. Kannanaikkal VT, Thomas KJ, Raphael V et al. *Tinospora cor*difolia Extract as an Environmentally Benign Green Corrosion Inhibitor in Acid Media: Electrochemical, Surface Morphological, Quantum Chemical and Statistical Investigations. Mater Today Sustain. 2021;13:100076. https://doi.org/10.1016/j.mtsust.2021.100076
99. Daniel EF, Ebeagwu MC, Okafor PC et al. Exploring the Efficacy of Phytoconstituents from *Vernonia amygdalina* on Mild Steel Protection in Acid Environment: Combined Experimental and Theoretical Study. J Bio-Tribo- Corros. 2021;7(3):126. https://doi.org/10.1007/s40735-021-00562-z
100. Giwa AA, Adetunji AT, Wewers F. Assessment of Negro pepper (*Xylopia aethiopica*) fruit extracts as corrosion inhibitors for Mild steel. J Mater Environ Sci. 2020;11(7):1100-1111.
101. Obagboye FO, Thompson SO, Ogundele OD et al. Effect of concentration, contact time and temperature on inhibitory potential of green inhibitors case study: *Zea* mays cobs extract on mild steel. Int J Current Res Appl Chem Chemical Eng. 2019;3(1): 20-30.
102. Parajuli D, Sharma S, Oli HB et al. Corrosion Inhibition Efficacy of Alkaloid Extract of *Artemesia Vulgaris* and *Solanum Tuberosum* in Mild Steel Samples in 1 M Sulphuric Acid. Electrochemistry. 2022;3(3):416-433. https://doi.org/ 10.3390/electrochem3030029
103. Adekunle AS, Adeleke AA, Ikubanni PP et al. Comparative Analyses of the Inhibitive Influence of *Cascabela thevetia* and *Jatropha c*urcas Leaves Extracts on Mild Steel. Nat Env Poll Tech. 2020;19(3):923-933. https://doi.org/10.46488/NEPT.2020.v19i03.003
104. Loto CA, Loto RT. Effects of *Lavandula* and *Ricinus communi*s oil as inhibitors of mild steel corrosion in HCl and H_2SO_4 media. Procedia Manufact. 2019;35:407-412. https://doi.org/10.1016/j.promfg.2019.05.060