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A Review on Environmentally-safe Corrosion deterrence of Metals in Various Media

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ABSTRACT

The present review gives a brief application of environmentally – safe corrosion inhibitors for various metals like aluminum, copper, mild steel, and zinc. Due to the enormous increase of industrial activities, a large amount of mineral acids are consumed. Therefore more number of metals gets corroded. These problems can be solved by using corrosion deterence. Although many chemical deterence are available most of them are highly virulent. So there is a need to explore a new class of corrosion inhibitors with good inhibition efficiency and that are environmentally - safe. Consequently, it can be achieved by using plant materials as corrosion inhibitors which are non-toxic, easily available and biodegradable.

Key words: Aluminum, Mild steel, copper, Zinc, Eco-friendly corrosion inhibitors, plant extract

Introduction:

Recently, a lot of investigations have been carried out in search of different types of corrosion inhibitors for various types of metals, in different media. Although chemical inhibitors (organic & inorganic) are available, they cause much damage to our surroundings. Therefore to overcome these problems, the area of research regarding the plant extracts as corrosion inhibitors is being concentrated much because of their renewability, low-cost, eco-friendliness and easy availability. The extract of leaves, stem, bark, root, fruit and seed consists of mixture of organic compounds and has the ability to function as effective inhibitors for metal in acid, alkaline and neutral media. The inhibition process occurs via the phytoconstituents present in the plant material on the surface of the metal, thus a protective film is formed therein corrosion process is prevented further.

A list of plant extracts as eco-friendly corrosion inhibitors is given below:

S.no	Metal/Medium	Inhibitor/ Corrosion parameters		Phytochemicals present	Methods adopted	Major findings	Ref no
1.	Aluminum alloy AA3003/ 0.4 M HCl and 0.5 M HCl	*Aspilia africana* leaf		Vitamin B	Gravimetric, Electrochemical, Quantum chemical computations & Molecular simulations	Both Physisorption and Chemisorption process occurred.	1
		Conc	100-700 mg/L				
		Temp	303-333 K				
2.	Aluminum/ 1 M HCl	Coconut coir dust		Lignins,Tannins,Cellulose, Pentosan,Furfural	Weight loss and Hydrogen evolution methods	Chemisorption IE - 80% at 60^{o}C –Weight loss method	2
		Conc	0.1 - 0.5 g/L				
		Temp	30^{o}C and 60^{o}C				
3.	Aluminum/ 2M HCl	*Chlomolaena odorata* L. leaf		Oils,Steroids, Triterpenes, Flavonoids	Gasometric and Thermometric techniques	Physisorption, IE - 92.16% (Gasometric) IE - 95.12%(Thermometric) at 7.5 %V/V	3
		Conc	10-50 %V/V				
		Temp	30^{o}C and 60^{o}C				
4.	Aluminum/ 0.5 mol/L HCl	*Cocos nucifera* L.		Amino acids, Ascorbic acid, Vitamin B1,Sorbitol,Fructose, Glucose,Malic acid, Phytohormone,Auxin,Cytokinin, Gibberellin,	Weight loss Method	Spontaneous adsorption IE - 93%	4
		Conc	0 -7.5 %V/V				
		Temp	30 ^{o}C				
5.	Aluminum alloy (7075)/ 3.5% NaCl	Date palm (*Phoenix dactylifera* L.) Fruit juice		Cellobiose,Glucose,Xylose, Fructose,Arabinose,	Potentiodynamic polarization and EIS	Physisorption Cathodic inhibitor	5
		Conc	100 - 2000 ppm				
		Temp	--				
6.	Aluminium and 6063 aluminium alloy/1.0 M H_3PO_4	*Garcinia indica*		Garcinol,Curcumin	Tafel Extrapolation and Electrochemical impedance techniques,	Mixed-type inhibitor, Chemisorption, IE of *Garcinia indica* extract was efficient for 6063 alloy when compared with Al (99.6%)	6
		Conc	100 - 500ppm				
		Temp	30-50^{o}C				
7.	Mild steel /1 M H_2SO_4	*Araucaria Columnaris* (Gum Exudates)		Polysaccharide(1,2-benzenedicarboxylic acid, bis(2-ethylhexyl) ester, diisooctyl-phthalate, phthalic acid, isobutyl and isopropyl ester)	Weight loss, Electrochemical method, SEM	Maximum inhibition efficiency is achieved at very lower concentration (400 ppm), Mixed type inhibitor	7
		Conc	50 - 600 ppm				
		Temp	303 - 323 K				

8.	Aluminiumand AA5754 aluminium alloy/ 3% NaCl	*Laurus nobilis* L.oil Conc: 0 – 50 ppm Temp: 25 °C	1,8-cineole, Methyl eugenol, α-terpinyl acetate, Linalool, Sabinene	Weight loss method, Potentiodynamic polarization and Linear Polarization method, SEM	AA5754 alloy has better corrosion resistance in 3% NaCl solution than pure alloy	8
9.	Aluminum alloy (Al7075)/ 3.5% NaCl	L-Glutamine Conc: 0-2000 rpm Temp: --	Amino acid	Polarization and Electrochemical impedance studies	The critical electrode rotation rate for the best performance of inhibitor is 1000 rpm	9
10	Aluminium/0.5 mol/L HCl. KCl,KBr are added as additives	*Morinda tinctoria* leaves Conc: 0.5-7.0% Temp: 303-333k	Alkaloids,Flavonoids, Terpenoids,Steroids, Amino acids	Mass loss and electrochemical techniques,SEM	IE - 96.72% With immersion of 2 h. Langmuir adsorption. Physisorption	10
11	Aluminum & Aluminum silicon alloy/0.5 M HCl	Phoenix dactylifera Leaves Conc: 200-1000 ppm Temp: 20°C	Gallic acid, Protocatechuic acid, Ferulic acid, β-carotene, Lutein, Quercetin, Luteiolin	Potentiodynamic Polarization, EIS & EFM	Mixed type Cathodic inhibitor, Physisorption	11
12	Mild steel /1 M HCl	Galinsoga parviflora (Quick Weed) Conc: 2.5 – 6 % V/V Temp: 303-343 K	Alkaloids, Flavanoids, Saponins, Tannins, Phytosterol, Galinsosides	Weight loss, Potentiodynamic polarization and EIS	IE - 90% at 6 % V/V, Mixed-type inhibitor	12
13	Mild steel /1 M HCl	Bombax malabarieum seeds Conc: 0.005%, 0.05%, 0.15%,0.5%, 2.5% (V/V) Temp: 303-343 K	Arachidic acid,Cyclopropane, Lignoceric acid, Gossypol, Linoleic acid,Myristic acid, Palmitic acid, Oleic acid and Stearic acid	Weight loss, Potentiodynamic polarization and EIS	IE – 96.47% at 2.5 % V/V , Mixed-type inhibitor,	13
14	Copper/0.5 M Sulfuric acid	*Myrtus Communis* (oil extract) Conc: 25-100mg/L Temp: -	Limonene, Linalool, Pinene, 1,8-Cineole, Linanyl Acetate, And Terpineol,	Weight Loss, Potentiodynamic Polarization, EIS, SEM & AFM	Mixed-type inhibitor affecting both the Cathodic and anodic reactions	14
15	Copper/2.5 M HNO_3	Vitamin B1 hydrochloride (Thiamine Hydrochloride) Conc: 0.01-2.5 mM Temp: 30,35,40&45 ± 0.2 °C	--	Weight loss study	IE-69.9% at 2mM thiamine hydrochloride	15

16	AISI steel 4130/1M HCl	Taurine (2-aminoethanesulfonic acid) Conc: 12.5-250 ppm Temp: 25°C,45 °C, 65 °C	--	Potentiodynamic Polarization, EIS,AFM & Optical microscopy	Mixed-type inhibitors, Chemisorption	16
17	Carbon steel (ASTM 1015)/ 1.0 mol L^{-1} HCl	Antibacterial drugs (Penicillin G, Ampicillin & Amoxicillin Drugs) Conc: 0.1 to 10.0 mM Temp: 25-55 °C	--	Potentiodynamic polarization, EIS and Electrochemical noise (EN)	Mixed-type inhibitor	17
18	C38 Steel/ 1 M HCl	Black pepper extract and its piperine Conc: 0.008 – 2 g/L Temp: 40 - 70 °C	Piperine, Piperanine	Weight loss method	IE - 95.8 % at 2 g/L	18
19	C38 steel/0.5 M H_2SO_4	*Lavandula multifida* L Conc: 0.25-2 g/L Temp: 303-343 K	Carvacrol	Weight loss, Electrochemical Polarization & EIS methods	Mixed-type inhibitor, IE-72.2% at 2 g/L of oil at 298 K	19
20	Mild steel/ 1 M HCl	*Tagetes erecta* stem Conc: 0.001 -0.3 % V/V Temp: 30°C	β–caryophyllene (8.5%), terpinolene (18.4%),(E)–ocimenone (12.6%), (Z) β-ocimene (10.4%), piperitenone (10.4%),(Z)-ocimenone (5.5%),limonene (6.2%)	Chemical and Electrochemical studies, FTIR	IE - 97% at 0.3% V/V, Mixed- type inhibitor	20
21	Mild Steel/ 0.5 M,1 M,2 M HCl and H_2SO_4	Acacia trees (Exudate gum) Conc: 0.6 mg/L Temp: 30°C	Polysaccharides like 42% Galactosyl, 27% Arabinosyl, 15% Rhamnosyl, 14.5% Glucuronoysl 1.5% 4-O-methyl-glucuronosyl and Protein- polysaccharide (minor component)	Weight loss, Hydrogen evolution, Electrochemical polarization, SEM,FTIR,XPS	Mixed-type inhibitor, Inhibition efficiency increases in the presence of magnetic field	21
22	Mild steel/ 1 M HCl	*Alstonia anugustifolia* Var.*latifolia(A. latifolia)* Leaves Conc: 1-5 mg/L Temp: 30±2 °C	Indole alkaloids (Alstogustine 19-epialstogustine Alstopirocine)	EIS,SEM,FTIR	Mixed- type inhibitor, IE-84% for Impedance studies, IE-88% for Polarization studies	22

23.	Mild steel /0.5 M H_2SO_4	*Anacyclus pyrethrum* L. (leaves and stem, flowers,roots) Conc: 100-350 mg/L Temp: 25- 40 ^oC	Catechol tannins, saponins, alkaloids, flavonoids (absent in roots), amino acids	EIS, Potentiodynamic Polarization	IE-87.01% for leaves & stems, 88.88% for flowers, and 79.30% for roots, Chemisorption	23
24	C38 steel/ 1 M HCl	*Aniba rosaeodora* Conc: 25-200 mg/L Temp: 25 ^oC	Anibine	Potentiodynamic polarization,EIS, XPS, NMR	Mixed –type inhibitor, Anibine as the major constituent(EIS)	24
25	Mild steel /HCl	*Areca catechu* (Seed extract) Conc: 0-500 ppm Temp: 303-318 K	polyphenols (flavonols and tannins), alkaloids (Arecoline, Arecaidine, Guvacoline, and Guvacine), carbohydrates, fats, proteins, crude fiber, and mineral matters	Weight loss, polarization & impedence studies, FTIR,SEM	Mixed mode of inhibition	25
26	Mild steel/ 4 N HCl & Conc. HCl	*Artemisia pallens* Conc: 0.1-1.5 g/l Temp: 30 ± 1 ^oC	Tetrahydrofuran, Davanone, Linalool, Ethylcinnamate, Sesquiterpenoids, Terpenoids, Artemone	Weight loss, Polarization - 4 N HCl, Weight-loss, SEM & FTIR-Conc. HCl	IE-93% at 1.5 g/L in 4 N HCl IE-96.5% at 40 g/L in Conc. HCl	26
27	Mild steel/1 M HCl	*Aquilaria crassna* Leaves extracts crude extract(ME) and Aqueous Extract(AE) Conc (ME): 0-300 ppm Conc (AE): 0-60 ppm Temp: 27 ^oC	Saponins(higher presence), Flavanoids & Tannins(moderate presence), Alkaloids & Triterpenoids(Week presence)	Weight loss, Potentiodynamic polarization, EIS, XPS SEM,FTIR	Max IE at 300 ppm for ME 80.28% (Weight loss), 66%(EIS) , 67% (Potentiodynamic Polarization) and Max IE at 60 ppm for AE 69.98 % (weight loss), 60% (Potentiodynamic Polarization) and 59%(EIS) at 50 ppm	27
28	Mild steel/1 N HCl	Basella alba L. leaves Conc: 65 – 95 ppm	Alkaloids,Carbohydrates, Pseudo tannins, Chlorogenic acids,	Weight loss, Potentiodynamic	Maximum inhibition efficiency was	28

		Temp -	Steroidal glycosides, Coumarin and Flavonoids	polarization, EIS, SEM	81.28% at the inhibitor concentration 95 ppm	
29	Mild steel/ 1 M HCl	*Caulerpa racemosa* Conc 0-25 ppm Temp 303-323 K	Sesquiterpenes Caulerpin an alkaloid Reducing sugars Galactose,glucose, arabinose xylose, mannose, rhamnose,amino acids	Weight loss, EIS,UV,IR,NMR & AFM	Mixed-mode of inhibition IE- 83%	29
30	Mild steel/ 0.5 M H_2SO_4	*Centella asiatica* (leaves) Conc 0-1200 ppm Temp 30 - 60 ^oC	Triterpene acids (Asiatic, Terminolic, Centic, Centillic Centoic Acid) Alkaloids(hydrocotylin), volatile fatty oils(glycerites of palmitic,stearic, lignoceric, oleic,lynoleic and linolenic acids), glycosides(asiaticoside A, asiaticoside B, madecassoside, centellic acid),and flavonoids(3-glucosylquercetin, 3-glucosylkaempferol and 7-glucosylkaempferol	Gravimetric, EIS,SEM	IE-95.08% for 1200 ppm at 303 K, Mixed-type inhibitor	30
31	Mild steel/1 M HCl & 0.5 M H_2SO_4	*Chlorophytum borivilianum* root Conc 300 - 500 mg/L Temp 35 – 55 ^oC	Saponins	Weight loss, EIS, SEM,FTIR,UV-Visible spectroscopy	Mixed –type inhibitor	31
32	Mild steel/ 1 M HCl	Clematis gouriana Leaves Conc 0 – 400 ppm Temp 300 - 330 K	Magnoflorine, Aporphine alkaloid,	Weight loss, Potentiodynamic polarization, EIS,FTIR SEM,EDS	IE-95.70%. Possibility of both physisorption and chemisorption	32
33	Mild steel/1 M HCl & H_2SO_4	*Ervatamia coronaria* (leaf extract) Conc 10-50 ppm Temp 303-323K	Ervatinine-An alkaloid,indole Alkaloids,Tri-terpenoids	Weight loss,EIS SEM, XRD	Mixed mode inhibitor	33
34	Mild steel/ 2 M HCl	Fig leaves Conc 0 – 1000 ppm	-	Weight loss Measurement,	IE-87% for concentration above 200 ppm,	34

		Temp	25±2°C		Electrochemical techniques	Physisorption,	
35	Mild steel/ 2.5 M H_2SO_4	Gnetum Africana (Ethanol extract) Conc 0.1 0.5 g/L Temp 303 – 333 K		Alkaloid,Saponin, Tannin,Terpene, Anthraquinone,Flavonoid, Cardiac glycoside, Phlobatanins, Amino acids	Weight loss, Gasometric, Thermometric methods, FTIR	Physisorption	35
36	Mild steel/1M HCl & H_2SO_4	*Hydroclathrus clathratus* (marine alga) Conc 100 - 500 ppm Temp 303 - 323K		N-[2-hydroxy-1-(hydroxymethyl)pentadecyl]eicosanamide, Uracil, 1-(2-deoxy-b-D-ribofuranosyl)-5-methyl-1,2,3,4-tetrahydropyrimidine-2,4-dione, and 2-phenylamino-1,4-naphthoquinone	Weight loss, EIS, SEM & AFM	Mixed-mode of inhibition, IE-65.28% for 1M HCl IE-77.64% for 1 M H_2SO_4(Impedance studies) IE-76.6% for 1M HCl IE-85.02% for 1M H_2SO_4 (Polarization studies) at 500 ppm	36
37	Mild steel/1 M H_2SO_4 and 1 M HCl	*Kigelia pinnata* Leaves Conc 25 -125 ppm Temp 308 K,313 K,318 K,323 K & 328 K		Saponins, Tannins, Phenolic acids, Flavonoids, Alkaloids, and Carbohydrates	Weight loss,Tafel polarization,EIS, X-ray diffraction, SEM,FTIR,UV-Visible Spectroscopy	The inhibitor inhibits the corrosion reaction in both acid environments and inhibition efficiency follows the order H_2SO_4 > HCl	37
38	Mild steel/ 1 M HCl and 0.5 M H_2SO_4	*Syzygium cumini* seed Conc 60 - 600 ppm Temp 308–338 K		Ellagic acid, Gallic acid, Quercetin, Cafeic acid	Weight loss, EIS,	The inhibition efficiency is slightly better in HCl solution, Mixed –type inhibitor	38
39	6063 Aluminium alloy / 1 M phosphoric acid	*Coriandrum sativum* L. seed extract Conc 100 - 500 ppm Temp 30°C to 50°C		Linalool (Major constituent)	Potentiodynamic polarization, EIS,SEM	Mixed inhibitor,Results obtained by Tafel polarisation method and EIS method were in good agreement with one another. SEM studies confirmed the corrosion inhibition of the alloy due to the adsorption of the inhibitor	39
40	Carbon steel/ 1 M HCl	*Sesbania sesban* Conc 0.2 - 2 g/l Temp 25°C to 65°C		--	Weight loss and Potentiodynamic Polarization techniques	IE - 91.08%, Mixed type inhibitor	40

Abbreviations:

NMR: Nuclear Magnetic Resonance Spectroscopy
EIS: Electrochemical Impedance Spectroscopy
AFM: Atomic Force Microscopy
SEM: Scanning Electron Microscopy
FTIR: Fourier Transform Infrared Spectroscopy
EDS: Energy Dispersive Spectrum
EFM: Electrochemical Frequency Modulation

Conclusion:

From the review article, it can be seen that the common phytoconstituents responsible for corrosion inhibition are saponins, alkaloids, flavonoids, and phenolic compounds. The major techniques adopted to evaluate the corrosion inhibition efficiency are : Weight –loss method, Electrochemical impedance studies, Thermometric method, Gasometric method. The surface morphology techniques used are scanning electron microscope (SEM), Energy - dispersive X-ray analysis (EDAX) and Fourier transform infra-red spectroscopy which confirms the formation of protective film on the corroded metal therein to stop the corrosion process.

All the plant materials have been evaluated as corrosion inhibitors in the laboratory level, unless it is being used in industries the research is not of much use. Hence transfer of technology is essential. These plant materials as corrosion inhibitors may be tested in various industries, where chemical inhibitors are already in use. To apply the plant materials as inhibitor in the industries the inhibitors should be standardized for which the reliability and reproducibility tests should be carried out. Hence more research could be carried out using plant material as corrosion inhibitors in the applied field.

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