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CORROSION INHIBITION OF MILD STEEL IN HYDROCHLORIC ACID MEDIUM USING PLANT EXTRACTS – A SUCCINCT REVIEW

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ABSTRACT

The intent of this paper is to establish the use of plant extracts as green inhibitors exclusively for mild steel corrosion inhibition in hydrochloric acid medium. Mild steel is used extensively as structural material in several applications owing to its workability and cost effectiveness. The expenditure of corrosion control in mild steel is enormous and hence corrosion inhibitors are widely used as an inexpensive way of protection. But, the hazards associated with chemical inhibitors pose threat to the environment. Eco-friendly products from plant sources hold promise for corrosion inhibition of metals in various medium. This paper discusses the preparation methods of the plant extracts, type of inhibition, technique of experimental study, effective concentration, inhibition efficiency, type of surface characterization carried out by several researchers with respect to mild steel. Precisely, current review consolidates the recent progress in the field of mild steel corrosion inhibition and facilitates the scope for further investigation.

KEYWORDS: Adsorbtion isotherm, Green inhibitors, Hydrochloric acid, Mild steel

1. INTRODUCTION

Mastery and use of iron and steel products is a measure that indicates the industrialization and development of a nation. All metals undergo the natural process of corrosion when put in to usage. Ulick R. Evans had said that, "Corrosion is largely an electrochemical phenomenon, (which) may be defined as destruction by electrochemical or chemical agencies…" As per IUPAC, "Corrosion is an irreversible interfacial reaction of a material (metal, ceramic, polymer) with its environment which results in consumption of the material or in dissolution into the material of a component of the environment". There are many forms of corrosion, viz., general attack corrosion, localized corrosion – pitting, crevice, filiform corrosion, galvanic corrosion, environmental cracking - stress corrosion cracking, corrosion fatigue, hydrogen-induced cracking, liquid metal embrittlement, flow assisted cracking- erosion-assisted corrosion, impingement, cavitation, inter granular corrosion, de-alloying, fretting corrosion, high temperature corrosion and microbial corrosion. At a given time, more than one type of corrosion attack can happen on a metal/alloy surface, depending upon its exposure to different environments at different points within the same structure. All corrosion cells have anode, cathode, electrolyte and metallic path for flow of ions and electrons. Theoretical features of corrosion and its control is covered systematically in several books: Uhlig (1963), Fontana (1986), and Schweitzer (1989).

Mild steel is low carbon steel where the main alloying constituent is carbon (0.16 to 0.29%). Cold rolled mild steel is work hardened at a temperature below its recrystallization temperature, which increases its strength via strain hardening up to 20%. Mild steel is neither brittle nor ductile, cheap and malleable, hence used in large quantities as structural element. It has density of 7.85 g/cm^3. The corrosion inhibition of mild steel is a very important phenomenon in industries. The surface of mild steel may have mill scale or corrosion products due to environmental attack. Before processing and fabrication, surface treatment is essential. The rust formed on the iron surface has wurztite –FeO, magnetite -Fe_2O_4 and hemaetite-Fe_2O_3, progressing towards the environment from metal surface.

Out of the various surface treatment processes, pickling is the major process adopted in many industries before fabrication of mild steel. Pickling is a surface treatment process, involving the treatment of metals with acid baths to remove rust, scale or any corrosion product on their surface. Apart from removal of unwanted corrosion product, the base metal is attacked by the pickling acid. To prevent corrosion of the base metal, chemical inhibitors are added to the pickling baths. Several chemical inhibitors are identified and used as pickling inhibitors. The conventional chemical inhibitors are toxic and pose threat to environment.

Corrosion inhibitors derived from plant sources offer eco friendly means to pickling baths. Exponential growth in this field of research has witnessed several plant extracts derived from leaves, roots, stems, flowers and husk that proved to be effective inhibitor in acid medium by gravimetric and electrochemical methods of corrosion testing.

Several acids have been tested and used in pickling baths, viz., hydrochloric acid, sulphuric acid, nitric acid, phosphoric acid, citric acid, acetic acid depending upon the scale and process condition. Hydrochloric acid is widely used in many industries as pickling bath, because of its faster rates of pickling, brighter pickled surface, efficient regeneration methods available, spent pickle liquid of lower volume, complete reaction of acid during pickling and cost effective compared to sulphuric acid.

The present review exclusively focuses on the use of plant extracts as green inhibitors in hydrochloric acid medium for mild steel in the recent years by the researchers which discloses the potential of the green inhibitors for further research.

Table- I: List of plant extracts as green inhibitors in HCl medium for mild steel

S. No.	Plant	Extract	Type of Inhibition	Method	Extract concentration	Inhibition efficiency	Characterization Techniques	Adsorption Isotherm	Reference
1.	Henna extract and its constituents	Aqueous/1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	1.2g/L	90%	SEM, EDAX, GC-MS	Langmuir	A. Ostovari et al., 2009
2.	Piperaceae	Piperine isolation/ 1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	120 ppm	98%	----	Langmuir	M.A. Quraishi et al ., 2009
3.	Ochrosiaoppositifolia, leaves and bark	Alkaloid extracts/ 1MHCl	Mixed type	Electrochemical, molecular modeling	25 mg/L	95%	SEM, EDAX, FTIR	Langmuir	PandianBothi Raja, 2013
4.	Leaves of Citrus aurantiifolia	1M HCl	Mixed type	Weight loss, Electrochemical method	2.5% V/V	97%	SEM	Langmuir, Temkin, Freundlich, Frumkin and Flory-Huggins	R. Saratha et al., 2009
5.	JasminumnudiflorumLindl. leaves	Ethanol extract/ 1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	50 mg/L	98%	SEM, FTIR	----	Xiang-Hong Li et al., 2010
6.	Kalmegh(Andrographis paniculata) leaves	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	1200 ppm	98%	FTIR	----	Ambrish Singh et al., 2010
7.	UAE Neem (AzadirachtaIndica)	Soaking 6hours in distilled water	Physical adsorption	Weight loss, Electrochemical method,	2g/L	87%	----	Temkin	AyssarNahl´e et al., 2010
8.	Pericarp of the Fruit of Garcinia Mangostana	5% HCl	Mixed type	Weight loss, Electrochemical method, EIS	25% w/v	97%	SEM, FTIR	Temkin	K.P.Vinod Kumar et al., 2010
9.	Seed extract of Kuchla - Strychnos Nuxvomica	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	350 ppm	97%	FTIR	Langmuir	Ambrish Singh et al., 2010
10	Ocimium	Ethanol	-	Weight loss,	1.2%	98.67%	-	-	N.

.	sanctum/stem &leaves	extract/0.5N HCl		thermometric					Kumpawat et al., 2010
11.	Artemisia pallens/aerial parts	Methanolic extract/4N HCl	-	Weight loss, polarization studies, CHNS analysis	40 gl^{-1}	96.5%	SEM, FTIR	Langmuir	Patchiahkalaiselvi et al., 2010
12.	Fig leaves extract	Aqueous extract/2M HCl	Mixed type	Weight loss, Electrochemical method, EIS	200 ppm	87%	---	Langmuir	Taleb H. Ibrahim 2011
13.	Clematis gouriana/leaves	Ethanol extract/1M HCl	Mixed type	Weight loss, polarization, EIS	400 ppm	95.70%	SEM, FTIR	Langmuir	Gopiraman et al., 2011
14.	Areca catechu/Seeds	5% HCl	Mixed type	Weight loss, polarization and impedance studies	500 ppm	96.97%	SEM, FTIR	Temkin	K.P. Vinodkumar et al., 2011
15.	Pongamiapinnata/seeds	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical studies	400 ppm	98%	FTIR	Langmuir	Ambrish Singh et al., 2011
16.	Tinosporacrispa /stem	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical studies	800 ppm	87.77%	SEM	Langmuir	M. Hazwanhussin et al., 2011
17.	Xylopiaferruginea/leaves, Stem bark	10v% HCl/1M HCl	Mixed type	Electrochemical studies	100 V/V %	87%	SEM , FTIR	----	P.B. Raja et al., 2011
18.	Seeds of Punicagranatum (pomegranate)	Ethanol extract/ 1M HCl	Mixed type	Weight loss, Electrochemical studies, EIS, Quantum chemical c	600 mg/L	83%	----	----	Maduabuchi A. Chidiebere et al., 2012
19.	Partheniumhysterophorus plant leaves	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical studies, EIS	1100 ppm	84%	SEM, UV-VIS	Langmuir	GopalJi et al., 2012
20.	Ziziphusmauritiana leaves	Alcohol /0.5MHCl	Mixed type	Weight loss, Electrochemical method, EIS	2800ppm	87.52%	SEM	Langmuir	Shivakumar and Mohana,2012
21.	Safflower (Carthamus tinctorius	Aqueous extract/ 0.5M, 1M HCl	Mixed type	Electrochemical method, EIS	0.14g/L	92%	Optical Microscopy, SEM, EDAX, AFM, Neural network	Langmuir	M. Nasibi et al., 2013

							modelling		
22.	Leaves of Ptercarpussoyauxi	Ethanol extract/1M to 2.5M HCl	Physical adsorption	Weight loss	0.5 g/L	96%,60° C	----	Temkin, Langmuir	Iloamaeke et al., 2012
23.	Leaves of Vitexdoniana	Ethanol extract/1M to 2.5M HCL	Physical adsorption	Weight loss, Thermometric method	0.5 g/L	68%	----	Temkin, Langmuir	Onuegbu Theresa Uzoma et al., 2012
24.	Uncariagambir(gambir powder) Tinosporacrispa (stem) Rhizophoraapiculata(bark)	50% aqueous ethanol/1M HCl	Physical adsorption	Electrochemical method	1000 ppm	78%, 72%, 83%	---	----	Mohd Jain Kassim, Tan Kang Wei , 2012
25.	Two Indonesian green tea samples (Camellia sinensis)	acetone 70% / 1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	200 ppm	75%, 79%	SEM, EDAX, FTIR, HPLC	----	Nofrizal2012
26.	Black pepper, coffee, garlic, and yeast	Dissolved in 1N HCl	Mixed type	Electrochemical method,	200 ppm	70 to 90%	----	Frumkin, Temkin, and Langmuir	Subir Paul and BikashKar, 2012
27.	Ecboliumviride plant	Stem, roots ethanol extract/ 1M HCl	Anodic sites, physical adsorption	Weight loss, Electrochemical method, EIS	400 ppm	80%	SEM	Langmuir	S.L. Ashok Kumar et al., 2012
28.	Unripe fruit peel extract of Musa acuminata (Cultivar variety – Nendran)	1N HCl	Physical adsorption	Weight loss, Electrochemical method, EIS	2%	96%	----	Temkin, Langmuir	S. C. Murugavelet al., 2012
29.	Jeera (CuminumCyminum) dried seed powder	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical method, EIS Quantum chemical calculations	300 ppm	93%	UV - VIS	Langmuir	Ambrish Singh et al., 2012
30.	Acacia trees/exudates gum	Aqueous extract/1M HCl	Mixed type	Weight loss, Electrochemical method, hydrogen evolution	--	--	SEM , FTIR, XPS	--	M.A.Abu-Dalo et al., 2012
31.	Alstoniaanugustifoliavar.latifolia	Dichloromethane/1M HCl	Mixed mode of inhibition	Weight loss, Electrochemical studies	5 mg/L	Above 80%	SEM , FTIR	Langmuir	P.B.Raja et al., 2012
32.	Cocosnucifera Leaves	1M HCl	---	Weight loss, Hydrogen evolution measurements	0.5 g/L	80%	---	Langmuir	U. M. Eduok et al., 2012

33.	Brugmansiasuaveolens (BS) and Cassia roxburghii (CR)/flowers	Ethyl acetate/1M HCl	Mixed type	Weight loss, Electrochemical studies, EIS	400 ppm	94.69%	SEM , FTIR	Langmuir	M. Gopiraman et al., 2012
34.	Chamomile (Matricariarecutita), flowers	Aqueous extract/1M HCl	Mixed type - predominantly anodic	Electrochemical studies, EIS	7.2 g/L	93.28%	optical microscopy,AFM,SEM	Langmuir	M. Nasibi et al., 2013
35.	A marine alga Caulerparacemosa	Methanol / 1M HCl, isolation of phytoconstituent	Mixed type	Weight loss, Electrochemical studies, EIS	25 ppm	80%	AFM, FTIR, Uvvis, NMR	Temkin	Chennappan Kamal and MathurGopalakrishnan Sethuraman,2012
36.	Andrographispaniculata, Murrayakoenigii, Aeglemarmelos, Strychnosnuxvomica, Moringa oleifera, Citrus aurantium, Terminaliaarjuna	1M HCl	Chemical adsorption	Theoretical approach, quantum chemical calculations	---	---	----	---	Singh et al., 2013
37.	Dodonaeaviscosa leaves	1MHCl	Mixed type	Weight loss, Electrochemical method, EIS	0.8%V/V	95%	SEM, EDAX, FTIR, UV	Temkin, Langmuir	Leelavathi et al., 2013
38.	Emilia sonchifolialeaves ,Vitexdonianaleaves	Ethanol extract/ 2.5M HCl	Physical adsorption	Gasometric method	0.5 g/L	65%	---	Temkin, Langmuir	Iloamaeke I. M, 2013
39.	Ochrosiaoppositifolia, leaves and bark	Alkaloid extracts/ 1MHCl	Mixed type	Electrochemical, molecular modeling	25 mg/L	95%	SEM, EDAX, FTIR	Langmuir	PandianBothi Raja, 2013
40.	Magnolia champaca stem	Aqueous extract/ 1MHCl	Physical adsorption	Weight loss, Electrochemical method, EIS	10 mL	75%	----	----	S. AnanthKumar et al., 2013
41.	Costusafer leaves	Ethanol extract/ 5M HCl	Physical adsorption	Weight loss, Hydrogen evolution	5 g/L	95%	----	Frumkin, Temkin, and Langmuir	Ikama E. Uwah et al ., 2013
42.	Eucalyptus camaldulenis	3 M HCl	Physical adsorption	Gravimetric method	10g/L	85%	-----	Langmuir	LubnaGhalibabdulkh

	leaves								aleq, 2013
43.	Leaves of Nicotianatabacum	1M HCl	Physical adsorption	Weight loss method	0.5v/v	95%	----	Temkin, Langmuir	Olasehinde, E. F. 2013
44.	Polyalthialongifolia (Asoka tree) leaves	1N HCl	Physical adsorption	Weight loss and temperature study	1.5%	87%	----	Temkin, Langmuir, Freundlich	Vasudha V G et al., 2013
45.	Aloes leaves extract	1.0 M HCl	Mixed type	Weight loss, Electrochemical method, EIS	800 ppm	72%	----	Langmuir	HuiCang et al., 2013
46.	Clerodendrumphlomidis plants leaves	0.5 M HCl	----	Weight loss	50 ppm	96%	SEM	----	Pruthviraj et al., 2013
47.	Morindatinctoria	Aqueous/ 1 M HCl	Physical adsorption	Weight loss, electrochemical methods, ,EIS calorimetric	15%	86%	SEM, FTIR	Langmuir	K. Krishnaveniet al., 2013
48.	Aloes leaves	Aqueous/ 1 M HCl	Mixed type	Weight loss, electrochemical methods, ,EIS	800ppm	72%	----	Langmuir	*HuiCang et al.,2013*
49.	Arganiaspinosa/ leaves	1M HCl	Mixed type	Electrochemical studies	---	---	---	---	Lailaafia et al., 2013
50.	Haloxylonscoparium/aerial parts	1M HCl	Mixed type	Electrochemical studies	55% v/v	90%	SEM	---	M. Allaouieta l., 2013
51.	Ochrosiaoppostifolia/leaves &bark	Dichloromethane/1M HCl	Mixed type	Weight loss, Electrochemical studies, molecular modeling studies	20-25 mg/L	---	SEM , FTIR	Langmuir	P.B. Raja et al., 2013
52.	Pisidiumgujava/ leaves	Aqueous /1M HCl	Mixed type	Electrochemical studies	10 ml	90%	SEM, AFM	Frumkin	K. Anupama et al., 2013
53.	Ptychotisverticillata/essential oil	1M HCl	Mixed type	Weight loss, Electrochemical studies, GC-MS analysis	0.5 g/L	86%	---	Langmuir	E. El ouariachi et al., 2013
54.	Opuntiaelatior fruit	Ethanol / 1M HCl	Mixed type	Weight loss, Electrochemical studies, EIS	50ppm	72%	FTIR, NMR, SEM, XRD	Temkin	C. Loganayagi, M. G. Sethuraman ET AL., 2014
55.	Red apple (Malusdomestica) fruit	0.5M HCl	Mixed type	Weight loss, Electrochemical studies, EIS	5 g/L	87%	SEM, Quantum Chemi	Temkin	SaviourUmoren et al., 2014

							cal Calculations, Molecular Dynamics Simulation		
56.	Anibarosaeodora's wood	Acid-base extraction, alkaloid extract/ 1M HCL	Mixed type	Electrochemical studies, EIS	200 mg/l	91%	NMR, XPS	Langmuir	M. Chevalier et al. 2014
57.	Leaves and twigs of *Acalyphaindica*	Alcoholic extract / 1M HCl	Chemical adsorption	Weight loss method	0.9 %	94 %	FTIR	Temkin	*A.Srinivasulu etal, 2014*
58.	Agar wood leaves	methanol /aqueous extracts/1M HCl	Mixed type	Weight loss, Electrochemical method	300 ppm	80%	SEM , FTIR	Temkin, Langmuir	L. Y. S. Helen et al., 2014
59.	7 hydroxy flavone - a representative natural compound	1M to 3M HCl	Physical adsorption	Weight loss, Electrochemical method	200 ppm	82-90%	SEM	Langmuir	D. Kesavan et al., 2014
60.	Shorea Robusta leaves	Aqueous extract/ 1M HCl	Physical adsorption	Weight loss	5 g/L	95%	----	Langmuir	Pinky Sisodia, et al., 2014
61.	Calotropis gigantean leaves	1M HCl	Mixed type	Weight loss, Electrochemical method	1.25 %	96%	----	Temkin	P. S. Desai, 2014
62.	Fruit extract of Terminaliachebula	Ethanol/ 1M HCl	mixed type	Weight loss, Electrochemical method	800 mg/L	89%	Molecular modeling	Langmuir	E. E. Oguzie et al., 2014
63.	Anibarosaeodora's wood, anibine alkaloid extract	Acid- base extraction/1M HCl	Mixed type	Electrochemical method, EIS, Phytochemical screening	200 mg/L	91%	NMR, XPS	Langmuir	M. Chevalier et al., 2014
64.	Kigeliapinnata leaves	Ethanol extract/ 1M HCl	Mixed type	Weight loss, Electrochemical method	125 ppm	85%	SEM, XRD, FTIR, GC-MS, UV-VIS	Langmuir	P. Muthukrishnan, et al., 2014
65.	Mollugocervianaplant	methanol /1M HCl	Mixed type	Weight loss, Electrochemical method	500 mg/L	89%	SEM	Langmuir	P. Arockiasamy et al., 2014
66.	Gum extrudates of Albiziaferrugin ea,Khayasenega	0.1M,2.5 M HCL	Physical adsorption	Weight loss, Gasometric	0.5 g/L	83%, 67%	FTIR, GC-MS	Langmuir	Paul OchejeAmeh, 2015

	lensis								
67.	Tiliacoraacuminataleaf extract	Ethanol/ 1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	320 ppm	93 %	SEM, EDAX, FTIR, UV-VIS	Langmuir	R. Karthik et al., 2015
68.	Leaves of Moringa oleiferaand lettuciaedibeliais	ethanol extract/1N, 2N HCl	----	Weight loss	8 ml	95%	----	----	J. ArockiaSelvi et al., 2015
69.	Leaves of MimusopsElengi Linn	Aqueous extract/1N HCl	Mixed type	Weight loss, Electrochemical method, EIS	20 ppm	97.6%	SEM, FTIR	----	M. Karuppasamy et al., 2015
70.	Sennaitalica leaves	1M HCl	Mixed type	Weight loss, Electrochemical method, EIS, Electrochemical Frequency Modulation	600 ppm	92.6%	SEM, EDAX	Freundlich	Ameena Mohsen Al-Bonayan, 2015
71.	Cladodes of opuntiaficusindica, pectin extract	ethanol extract/1M HCl	Cathodic type	Weight loss, Electrochemical method, EIS,	1 g/L	94%	----	----	H. Elmsellem et al.,2015
72.	Opuntiaficus-indica	Aqueous extract/1M HCl	Cathodic type	Weight loss, Electrochemical method, EIS,	300 ppm	75 %	SEM, FTIR	Langmuir	J. P. Flores-De los R´ıos et al, 2015
73.	Gliricidiasepium	1M HCl	Physical adsorption	Weight loss, Phyto chemical screening	5% v/v	80%	SEM, EDAX, FTIR, AAS	Langmuir	Okoronkwo, A. E. et al., 2015
74.	Ficushispida leaves	Ethanol/ 1M HCl	Mixed type	Weight loss, Electrochemical method, EIS,	250 ppm	90%	SEM, XRD, DR FTIR, GC-MS,	Langmuir	P. Muthukrishnan et al., 2015
75.	Boscia senegalensis	Ethanol/ 1M HCl	Mixed type	Weight loss, Electrochemical method, EIS, Phytochemical screening, Theoretical modeling and simulation	0.5g/L	81%	SEM, EDAX, FTIR	Freundlich	Awe et al., 2015
76	Athamantasicul	Methanol/ 1M	Mixed type	Weight loss,	5mL/L	91%	----	----	A.

.	a oil	HCl		Electrochemical method, EIS					Bouyenzeret al., 2015
77.	Azadirachtaindica gum Vs substituted piperidin-4-one derivatives	1M HCl	Mixed type	Weight loss, Electrochemical method, EIS,	0.008 g/L	73%	FTIR	----	BrindhaThirumalairaj, MallikaJaganathan, 2015
78.	Acanthuusmontanus (leaves, stem and root	1M HCl	Physical adsorption	Gravimetric method	800 mg/L	75%	----	Langmuir	NkechiEmeaIbisi et al., 2016
79.	Canna Indicaflowers	1M HCl	Mixed type	Weight loss, Electrochemical method, EIS	0.7 v/v	90%	SEM	----	Mathina et al., 2016
80.	Fresh leaves of neem tree, MoringaOleifera and bitter leaf	Ethanol extract/2M HCl	Mixed type	Weight loss method	70:30	----	----	----	S. Aji et al., 2016
81.	Cucumissativus peel extract	1MHCl	Physical adsorption	Electrochemical method, EIS	50%	82%	FTIR	Langmuir	Ghadah M. Al-Senani, 2016
82.	Ficusasperifolia-Miq (Moraceae)	Ethanol extract/5M HCl	----	Weight loss	0.5%	50%	AAS, SEM	Langmuir, Freundlich, Temkin	Fadare, et al., 2016
83.	Leaves of Prosopisjuliflora	1M HCl	Physical adsorption	Weight loss	30 mg/L	90%	----	Langmuir	Mustapha BalarabeIdris et al., 2016
84.	TerminaliaChebulaFruit	0.5M HCl	Physical adsorption	Weight loss, Electrochemical method, EIS	700 ppm	92%	SEM, FTIR	Langmuir	Dr. A. Leema Rose et al., 2016
85.	Allium sativum	Ethanol extract/0.5M HCl	Mixed type	Weight loss, Electrochemical method	100%	----	----		Cleophas A. Loto et al., 2016
86.	Pancratiumfoetidum, Pomplant	Methanol extract, dichloromethane extract/ 1MHCl	Mixed type	Weight loss, Electrochemical method, EIS	1g/L	84%, 93%	----	Langmuir	Bendaif et al., 2016
87.	Stem of African marigold	1M HCl,	Mixed type	Weight loss, Electrochemical method, EIS	0.3 v/v	93%	FTIR	----	R. Subha et al., 2016
88.	Thevetiaperuviana plant	Aqueous/1M HCl	synergism	Weight loss, Gasometric, Electrochemical method, EIS, Electrochemical Frequency Modulation	300 ppm	90%	SEM EDAX	Temkin	A. S. Fouda et al., 2016
89.	Hunteriaumbellata seed husk	1M HCl	Physical adsorption	Mass loss	5% v/v	90%	AAS, SEM,	Langmuir	K.K. Alaneme

							FTIR		et al., 2016
90.	Santalum album leaves	Aqueous/1N HCl	Mixed type	Weight loss, Electrochemical method, EIS	30 ppm	83%	SEM, FTIR	----	Sivakumar P.R. , Srikanth A. P et al., 2016

2. DISCUSSION

From the table the following assertions are made:

2.1 Plant extracts

Various parts of plants which include leaves, stems, roots, barks, extrude, oils, fruit peels and husks have been utilized and tested for corrosion inhibition in HCl medium. Among them leaves are widely chosen**.** Plant extracts are prepared in aqueous, alcoholic and acid medium. Few authors have identified the phytochemical constituents in the plant extract. Very few have carried out separation of the active constituent and its characterization and further corrosion testing.

2.2 Conventional methods of testing plant extracts

Quantitative weight loss method has been carried out as a calibration standard for electrochemical means of corrosion, as it is simple, versatile and direct. The effects of acid concentration, inhibitor concentration, and immersion time on corrosion rate and inhibition efficiencies are arrived from this method. Further, the weight loss study is also employed to study the effects of temperature on the above factors which have led to the determination of reaction kinetics and thermodynamic parameters showing the spontaneity of the process. Adsorption isotherms are tested to prove the physical adsorption of the plant extract on the metal surface from the findings of weight loss method.

Electrochemical methods of corrosion testing involving linear polarization and Tafel plots using sophisticated potentiostat instruments give an instantaneous corrosion rate which tracks the type of inhibition as anodic, cathodic or mixed type. The electrochemical impedance study proves the adsorption of plant extracts by increase in double layer capacitance values from blank.

Surface investigations carried out by FTIR of the corrosion product and plant extract shows the functional groups responsible for inhibition.. The metal surface is visualized at several magnifications utilizing SEM which proves the adsorption of inhibitor to form a protective layer on the metal surface. UV- VIS and AAS methods are employed to understand the concentration of iron in the acid medium during the study relating to corrosion rate.

2.3 Add-on methods of testing plant extracts

Gasometric method - hydrogen gas evolution, thermometric method- temperature studies are also carried out to support weight loss method of testing. Phyto- chemical screening of the plant extract, isolation of the active constituents from the plant extracts, testing synergism with chemical compounds are also tested by few authors to prove inhibition efficiency of plant extracts in hydrochloric acid medium. Theoretical study of corrosion inhibition has been carried out by molecular modeling and quantum chemical calculations using well established software. Analytical tools such as EDAX, HPLC, NMR, XPS, and XRD are also utilized to substantiate the mechanism of corrosion inhibition and adsorption of the plant inhibitor on the metal surface.

3. CONCLUSION

Present review substantiates and proves the performance of plant extracts as effective green inhibitors for mild steel in hydrochloric acid medium**.** Customary mass loss methods, supported by electrochemical studies are carried out to establish the inhibition efficiencies of the plant extracts. Surface morphological studies using SEM and FTIR spectra helps in validating the physical and chemical adsorption of the inhibitor on the surface of the mild steel. However, standardization of the plant extract to make it suitable for industrial pickling baths remains a challenge. Stability of the plant extracts is seldom discussed notwithstanding its paramount concern. The inhibitor action which is generally attributed to the process such as

adsorption and charge transfer supported by molecular modeling and quantum chemical computations proves inadequate to crack the exact mechanism involved in corrosion inhibition and hence the search for detailed mechanism continues. Identifying the active constituent in the plant extract for inhibition remains an opportunity for further research. Confirming the experimental results by incorporating statistical tools would give better inference and insight in this field.

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