2 REVIEW OF LITERATURE

The corrosion inhibition review analysis was done for MS/AA corrosion in acidic medium and AA corrosion in alkaline medium using green inhibitors as well as organic inhibitors.

2.1 Natural products and its inhibition efficiency on MS corrosion in acidic medium

Green inhibitors are having the ability to replace synthetic organic and inorganic inhibitors. The structure of the active ingredient in the plant species can influence the mechanism of corrosion inhibition action and thus many researchers have given in the literature **(Chigondo *et al*, 2016).** The active compounds present in the acidic solution are formed onium ions and the cathodic sites of the metal surface adsorb these ions to control the cathodic reaction **(Amitha Rani *et al*, 2012).** All the natural inhibitors are not containing the same active constituents but it can vary from one plant species to another but their structures are closely related. The nature of metal, testing media, the structure of inhibitor, and nature of phytochemical constituents present in the inhibitor, presence of additives, the temperature of the medium and concentration of the solution are responsible for the adsorption of the inhibitor **(Sastri, 2001).** It can be observed from the review summarized in the table focus on intensive research on the application of plant parts as green corrosion inhibitors for mild steel for the period of about decade.

Corrosion inhibition study is performed in sulphuric acid and hydrochloric acid and in some cases in both media and thus including real industrial scenarios, where metals are immersed in these acids are used **(Aribo *et al*, 2017, Finsgar, *et al*, 2014).** The research conducted in the industrial effluent medium reflects that the utilization of eco-friendly inhibitors in real effluent may lead to large scale implementation. Table 2.1 listed the examined green inhibitors for the acid corrosion of MS and techniques adopted.

Table 2.1. List of plant sources used for corrosion inhibition studies and adopted techniques

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
1.	*Datura stramonium*	MS/ HCl and H_2SO_4	I, II, III and SEM studies	97	**Bothi raja *et al*, 2007**
2.	*Zenthoxylum alatum plant*	MS/5% and 15% HCl	I, II, III.	96	**Chauhan *et al*, 2007**
3.	*Garcinia kola*	2M HCl and 1M H_2SO_4	Gasometric technique	88-96	**Oguzie *et al*, 2007**
4.	*Black pepper extract*	MS/HCl	I, II, III	98	**Quraishi *et al*, 2009**
5.	*Parthenium hystophrous L*	MS/1N Sulphuric acid	I, II, III	95	**Muhamath *et al*, 2009**
6.	*Murraya koenigii leaves*	MS/HCl	I, II, III	97	**Quraishi *et al*, 2010**
7.	*Neem (Azadirachta indica _ AZI) mature leaves*	MS/HNO_3	Gravimetric technique at 30 and 60^oC	81	**Sharma *et al*, 2010**
8.	*Gongronema latifolium (GL)*	Mild steel in H_2SO_4.	Thermometric and hydrogen evolution techniques.	90	**Eddy *et al*, 2010**
9.	*Atractylis serratuloides*	API 5L X52 steel/ 15% H_2SO_4	I, II	85	**Hameurlaine *et al*, 2010**
10.	Palmyra palm (*Borassus flabellifer)*	MS/ 0.5 M H_2SO_4 and 1 M HCl	I, II, III	98	**Vijayalakshmi *et al*, 2010a**
11.	*Cocos nucifera* shell extract	MS/ H_2SO_4 and HCl	I, II, III	95	**Vijayalakshmi et al, 2010b**
12.	*Emblica officinalis (EOL)*	Mild steel in 0.5M H_2SO_4	I, FT-IR	92	**Saratha *et al*, 2011**
13.	*Vernonia amygdalina*	Mild steel in HNO_3	I	51	**Nwabanne *et al*, 2011**
14.	*Kola plant and tobacco*	MS/0.5M HCl	I, Metallographic methods	96	**Loto *et al*, 2011**
15.	*Cassia Auriculata (CAF)*	MS/1 M HCl	I, II, III	95	**Rosaline Vimala *et al*, 2011**
16.	*Cocos nucifera coir dust*	MS/1 M HCl	I, Hydrogen evolution methods at 30 and 60^oC	90	**Eduok *et al,* 2012**
17.	*Nicotiana leaves*	MS/HCl	II, III	91	**Abd-El-Khalek *et al*, 2012**
18.	*Eucalyptus citriodora*	Al/MS/HCl	I	64	**Ezeokonkwo *et al,* 2012**

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
19.	Staminate Flower extract of Cocos Nucifera	MS/HCl	I, II, III	97	**Rajalakshmi *et al*, 2012**
20.	Cassia alata leaves extract (CALE)	MS/HCl	I, II, III, FTIR, SEM techniques.	88	**Leelavathi *et al*, 2012**
21.	*Piper longum fruit*	MS/HCl	I, II, III	97	**Singh *et al*, 2013**
22.	*Jathropha Curcas leaves*	MS/H_2SO_4	I, Thermometric measurements	93	**Odusote *et al*, 2013**
23.	*Ginkgo biloba leave*	MS/1 M HCl at 60°C,	I, II	83	**Chen *et al*, 2013**
24.	*Clerodendrumphlomidis plants leaves*	MS/0.5M HCl	I, SEM studies	96	**Pruthviraj et al, 2013**
25.	*Acalypha torta leaves (EAL)*	MS/1M HCl	I, II, III Chronoamperometric measurements and SEM.	91	**Krishnegowda *et al*, 2013**
26.	*Euphorbia falcata L. extract (EFE) was*	Carbon steel/1 M HCl	I, II, III, SEM	93	**El Bribri *et al*, 2013**
27.	*Eugenia Jambolana fruit peel (EJFP)*	MS/1N HCl	I	90	**Deepa rani *et al*, 2013**
28.	*Alpina galinga extract*	MS/ 0.5 N H_2SO_4	I, II, III	72	**Ananth Kumar *et al*, 2013**
29.	*Achyranthes aspera L.*	MS/0.5 M H_2SO_4	I	92	**Nwosu *et al*, 2013**
30.	*Dodonaea viscosa* Leaves (DVLE)	MS/ 1M HCl and 0.5M H_2SO_4	I, II, III UV, FTIR and SEM	95	**Leelavathi *et al*, 2013**
31.	*Leaves of Hibiscus sabdariffa*	1.2 N HCl and 1.2 N H_2SO_4	I	87	**Murthy *et al*, 2014**
32.	*Hyptis suaveolens leaf extract (HSLE)*	MS/1 M H_2SO_4	I, II, III, FTIR, SEM, XRD	95	**Muthukrishnan *et al*, 2014**
33.	*Mentha pulegium extract (MPE)*	MS/1M HCl	II, III	88	**Khadraoui *et al*, 2014**
34.	*Mollugo cerviana plant*	MS/1M HCl	I, II, III	93	**Arockiasamy *et al*, 2014**
35.	*Cucurbita maxima (LCM)*	MS/1N HCl	I, FTIR	98	**Anbarasi et al, 2014**
36.	*commiphora caudata*	MS/1MHCl and H_2SO_4	I, II, III	95	**Aejitha *et al*, 2015**
37.	*Red apple (Malus domestica) fruit extract*	MS/1M HCl	I, Electrochemical methods at 30–60°C.	87	**Umoren *et al*, 2015**

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
38.	*Eucalyptus globulus leaves*	Carbon steel in 1 M H_2SO_4	I	84	**Tezeghdenti *et al*, 2015**
39.	*Ankado leaves extract*	MS/1M HCl	I, II, III	96	**Desai, 2015**
40.	*Boscia senegalensis*	MS/1M HCl	I, II, SEM, FTIR	70	**Awe *et al*, 2015**
41.	*Polyalthia longifolia (PL) leaves*	MS/1N H_2SO_4	I, II, III and Temperature studies	92	**Shanmuga Priya, *et al*, 2015**
42.	*Thevetia peruviana*	MS/1 M HCl	I,II, III, Electrochemical frequency modulation techniques	90	**Fouda *et al*, 2016**
43.	*Phyllanthus amarus leaf extract (PAE)*	MS/1 M HCl	II, III	95	**Anupama *et al*, 2016**
44.	*Citrus aurantium leaves*	MS/1 M H_2SO_4	I	89	**Hassan *et al*, 2016**
45.	*Leaves and stem extracts of Sida acuta*	MS/1 M H_2SO_4	I, Hydrogen evolution, AAS, FTIR, UV techniques 30–60^oC	85	**Umoren *et al*, 2016**
46.	*Funtumia elastica (FE) leaves*	MS/ 0.5 M H_2SO_4	I, II, III	98	**Adindu *et al*, 2016**
47.	*Siam weed*	MS/1 M HCl	I, II, SEM and energy dispersive microscopy (SEM-EDS)	83	**Olusegun *et al*, 2016**
48.	*Banana peduncle extract*	MS/0.5M HCl solution	I, SEM, FTIR	98	**Orhorhoro *et al*, 2106**
49.	*Bauhinia purpurea (Fabaceae) extract*	Carbon steel in 1.0 $mol \cdot L^{-1}$ sulfuric acid	I, II	80	**De Barros *et al*, 2016**
50.	*Tagetes erecta stem (TES) extract*	MS/1 M HCl	I, II, III, FT-IR	97	**Subha *et al*, 2016**
51.	*Roasted coffee extract*	MS/1 M HCl	I, II, III, SEM	94	**Do Carmo Assumpcao de Souza *et al*, 2016**
52.	*Canna Indica* flower extract (CIFE	MS/ 1M HCl	I, II, III	95	**Mathina *et al*, 2016**
53.	*Tecoma capensis* flower extract	MS/ 1M HCl	I, II, III	95	**Prithiba *et al*, 2016**
54.	Podranea ricasoliana leaves	MS/ 1M HCl	I, II	96	**Nesrin Fathima *et al*, 2016**
55.	*Clove (Syzygium aromaticum) oil (CO)*	MS/1 M HCl	II, III	93	**El-Hajjaji *et al*, 2017**
56.	*Adathoda vasica, Eclipta alba and Centella asiatica*	MS/1 M HCl	II, III, SEM	99	**Shyamala *et al*, 2017**

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
57.	*Ginger roots extract (GRE)*	Carbon steel in 1 M HCl	I, II, III, AFM, UV-visible spectrophotometric methods, FT-IR	94	**Gadow *et al*, 2017**
58.	*Telfairia occidentalis rind extract*	MS/1 M H_2SO_4	I, Hydrogen evolution methods	89	**Akpan *et al*, 2018**
59.	*Neem leaf extract*	MS/0.1 M HCl	I, FTIR, and GC-MS analyses	93	**Okewale *et al*, 2018**
60.	*Piper guineense (uziza leaf) extract*	MS/2 M H_2SO_4	I		**Anuchi *et al*, 2018**
61.	*Black tea leaves extraction*	MS/0.1 M HCl	I, SEM, FTIR	97	**Hamdan *et al*, 2018**
62.	*Gongrone malatifolium*	MS/1 M HCl	Gasometric methods at 303K, 313K and 323K	77	**Onwumelu *et al*, 2018**
63.	*Lemon Balm extract*	MS/1 M HCl	II, III, SEM, UV, FTIR, Raman, AFM	95	**Asadi *et al*, 2018**
64.	*Parsley (Petroselium Sativum) leaves extract (PSL)*	MS/1 M HCl	I, II, III, SEM	92	**Benarioua *et al*, 2019**
65.	*Sweet melon (Cucumis melo L) peel (SM) extract in*	MS/1 M HCl	I, II	92	**Saeed *et al*, 2019**
66.	*Rosa canina fruit extract*	MS/1 M HCl	II, III	86	**Sanaei *et al*, 2019**
67.	*Ficus tikoua leaves extract*	MS/1 M HCl	II, III, FTIR	96	**Wang *et al*, 2019**

I = Mass loss; II= Potentiodynamic polarization method; III = Electrochemical impedance

2.2 Organic compounds used as Corrosion Inhibitors for MS corrosion in aggressive acid solution

Various organic compounds are reported as effective corrosion inhibitors for acidization industrial cleaning processes **(Khan *et al*, 2015).** The organic additives control the adsorption of chloride ions and the formation of a more resistant oxide film on the metal surface **(Musa *et al*, 2009).** The inhibition efficiency of these compounds depends on the structure of the organic inhibitors and nature of the adsorbed film on the metal surface. Organic compounds possessed nitrogen, oxygen, sulfur and phosphorus atoms and these compounds containing multiple bonds, active centres for the process of adsorption on metal surfaces, higher basicity and electron density are the responsible for acting as effective inhibitors for the corrosion of many metals and alloys (Table 2.2).

Table 2.2 List of organic inhibitors in acidic solution on mild steel corrosion

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
1.	Amino acids	MS/ H_2SO_4	II	73	**Abdel Rahim *et al,* 1997**
2.	Undecenoic acid hydrazide (UAH);2-mercaptobenzothiazole (MBT);and 2-hydrazinobenzothiazole (HBT)	Carbon steel/ 1N HCl	I, II	99	**Ali *et al,* 2002**
3.	Pyridoxol hydrochloride (PXO)	MS/2 M HCl	I, Hydrogen evolution techniques	72	**James *et al*, 2007**
4.	Poly (vinyl alcohol – aniline) PVAA composite	MS/1M HCl	I, II, III	92	**Karthikaiselvi *et al,* 2012**
5.	O-chlorophenyl-2-imidazoline (OCP2I)	MS/ H_2SO_4/HCl	I, II, III	91	**Nalini *et al*, 2011**
6.	Polyvinyl alcohol-anthranilic acid (PVAAA)	MS/1 M HCl	I, II, III	91	**Srimathi *et al,* 2011**
7.	p-nitrophenyl-2-imidazoline (PNP2I)	MS/0.5M H_2SO_4/1M HCl	I, II, III	80	**Nalini *et al,* 2013**
8.	2-(3-methyl-6-oxopyridazin-1(6H)-yl)accetohydrazide	MS/HCl	I, II, III	74	**Ghazoui *et al*, 2014**
9.	Sulphadoxine and pyrimethamine	MS/1 M HCl	II	46	**Akpan *et al*, 2014**
10.	Thiophene derivatives	Carbon steel/1 M HCl	I, II, Electrochemical frequency modulation, (EFM) and EIS techniques	98	**Fouda *et al,* 2014a**
11.	Poly (vinyl alcohol-o-methoxy aniline)	MS/1 M HCl	I, II, III	97	**Karthikaiselvi *et al*, 2014**
12.	N1,N1,N5,N5-tetrakis((3,5-dimethyl-1H-pyrazol-1-yl)methyl)naphthalene-1,5-diamine (BF5)	MS/1 M HCl	I, II, III	97	**ELouadi *et al*, 2015**
13.	Nicotinic acid N-oxide and isonicotinic acid N-oxide	MS/2N sulphuric acid	I, II, III, SEM and AFM, UV-Vis, FTIR, NMR	77	**Kavitha *et al*, 2017**

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
14.	Triazoles (Benzotriazole and Benzyl benzotriazole)	MS/HCl	I, II	98	**Desai *et al*, 2015**
15.	Thiocarbanilide	High carbon steel in 1 M H_2SO_4 and HCl acid solutions	I, II	80	**Loto *et al*, 2016**
16.	Heterocyclic Compound	Carbon steel type C38 in 15% HCl	I, II, III, Gasometrical method, X-ray diffraction (XRD)	92	**Meften, 2016**
17.	3-nitrobenzoic acid	MS/ 0.1 M H_2SO_4	I, II, III, SEM, FTIR Quantum chemical techniques	99	**Ameh *et al* , 2016**
18.	Synthesized Schiff's base	MS/1 M HCl	I, II, III	90	**Nithya *et al*, 2016**
19.	(E)-3-oxo-2-(m-toyldiazenyl) pentanenitrile compound (A), (E)-3-oxo-2-(phenyldiazenyl) pentanenitrile compound (B) and(E)-3-(phenyldiazenyl) pentane -2,4-dione compound (C)	SS 316L in 1 Molar hydrochloric	II, III,Electrical frequency modulation(EFM)	85	**Fouda *et al*, 2017a**
20.	Aromatic hydrazide derivative, 2-(3,4,5-trimethoxybenzylidene) hydrazinecarbothioamide (TMBHC)	MS/1 M HCl	II, III	95	**Preethi Kumari *et al*, 2017**
21.	Alkyl substituted 2,6-diphenyl piperidin-4-one with thiosemicarbazone	Mild-steel in 1N sulfuric acid	I, II, III	89	**Shanmuga Priya *et al*, 2018**
22.	(4-(3-mercapto-5,6,7,8-tetrahy dro-[1,2,4]triazolo[4,3-b][1,2,4,5]tetrazin-6-yl)phenol)	MS/1 M HCl)	II, III, Electrochemical frequency modulation (EFM) techniques	67	**Othman Ahmed *et al*, 2018**

I = Mass loss; II= Potentiodynamic polarization method; III = Electrochemical impedance

2.3 Biomass extracts as corrosion inhibitor for Aluminium corrosion in acid medium

Aluminium alloys are used in electronics due to its super purity nature **(Rosliza *et al*, 2010).** Acid solutions, widely used in industrial acid cleaning, acid descaling, acid pickling, and oil well acidizing, require the use of corrosion inhibitors in order to restrain their corrosion attack on metallic materials **(Ostovari *et al*, 2009).** The importance of the study lies in the fact that natural plant products are non-polluting, eco-friendly, economic, less toxic and easily available than synthetic organic compounds (Table 2.3).

1. Namrata Chaubey *et al*, 2018 investigated corrosion inhibition effect of *Papaya peel extract* (*PPE*) on aluminium alloy (AA) in 1 M HCl. The corrosion inhibition study was conducted using electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization techniques (PDP). The maximum inhibition efficiency obtained was 95.5% and 98.1% from EIS plot and PDP studies at higher concentration (2.0 g L^{-1}) of PPE. Potentiodynamic polarization results revealed that the cathodic type inhibition for PPE. Surface morphology of AA was performed by SEM and AFM. Quantum chemical study was supported well with the experimental results of the corrosion inhibition.

2. Obi-Egbedi *et al*, 2012, studied the corrosion inhibition of aluminium in 0.5 M H_2SO_4 by *Spondias mombin L.*using the standard gravimetric technique at 30–60^oC. The mechanism of inhibition was suggested by inhibition efficiency with temperature. The results revealed that the *S. mombin L*. extract acted as an inhibitor for acid-stimulated corrosion of aluminium. The Inhibition efficiency was increased with an increase in the concentration of the *S. mombin L*. extract but decreased with temperature. In addition, the IE (%) increased on the addition of potassium iodide. The inhibitor adsorption behaviour was correlated with Langmuir adsorption isotherm at all the concentrations and temperatures studied.

3. The pure aluminium undergoes minimum corrosion in phosphoric acid medium than 6063 aluminium alloy. The corrosion rate increased with an increase in temperature in both metals. SEM and Energy dispersive X-ray (EDX) confirmed the film formed on the metal surface. The rate of corrosion of 6063 aluminium alloy was found to be higher than that of pure aluminium. A suitable mechanism was proposed for the corrosion of aluminium and 6063 aluminium alloy in phosphoric acid medium **(Prabhu *et al*, 2013a)**.

4. The corrosion inhibitive behaviour of *Aningeria robusta* extract for aluminium in 2 M HCl was examined by **Obot *et al,* 2011.** When the concentration of the extract and with temperature increased, the IE also increased. The inhibitor system followed Langmuir isotherm model.

5. Guedes *et al*, 2019 evaluated the tannin from bark of *A. mearnsii* acts as a suitable eco-friendly inhibitor for controlling the corrosion reaction of AA7075-T6 aluminum alloy in 0.1M HCl medium. The IE of the tannin from bark of *A.mearnsii* increased with the concentration and reached efficiencies of 95% and 97% as obtained by polarization and EIS techniques at 14 g L^{-1}. The results of PDP curves revealed that the tannin from inhibitor acted as a cathodic inhibitor. The adsorption on the AA7075- T6 alloy surface in HCl confirmed Langmuir Isotherm model. The EIS results revealed that the aluminium dissolution reaction was controlled by charge transfer from anodic to cathodic sites. The SEM images supported to prevent the aluminium alloy corrosion acidic solution by the tannin from bark of *A. mearnsii.*

6. This study reported the corrosion inhibition of AA8011 aluminium alloy in acidic solutions using *Newbouldia leaves* leaf extract by way of gravimetric measurements. The results revealed that the corrosion of aluminium was minimized by inhibitor in the test solutions and the inhibition efficiency depended on the concentration of the plant extract as well as the exposure time of the aluminium samples in H_2SO_4 solutions with the inhibitor solution. The experimental data fulfil Langmuir adsorption isotherm. The thermodynamic parameters results confirmed that the inhibitor molecules were spontaneously adsorbed onto the aluminium surface through physical adsorption mechanism (**Nnanna *et al*, 2011c)**

7. Raghavendra *et al,* 2018a studied *Areca leaves* extract as potential corrosion inhibitor for aluminium in 0.5 M HCl environment. 89.4% of IE obtained by mass loss method, 88.1% by PDP study and 97% by EIS technique. The positive ΔH^* values confirmed that the Al dissolution process was endothermic in nature. The negative ΔG°_{ads} values reflected that the adsorption reaction was spontaneous. The SEM and AFM morphology studies supported the results of weight loss, potentiodynamic polarization and impedance studies.

8. The corrosion inhibitive behaviour of leaf extracts of *Euphorbia hirta* and *Dialum guineense* on aluminium alloy (AA 8011) in 0.5M HCl solution was studied by

Anozie *et al*, 2011 using the gravimetric technique at 30° and 60°C. The results revealed that both extracts worked as excellent inhibitors. The temperature study and activation parameters were used to deduce the inhibition mechanisms. Both leaf extracts obeyed Langmuir adsorption isotherm. The obtained thermodynamic results confirmed that the adsorption process on aluminium surface was physical adsorption.

9. Loto *et al*, 2014 was evaluated *Green tea* as an effective natural corrosion inhibitor for aluminium in 0.8 M H_2SO_4 by using potential and weight loss methods. The IE of the plant extract increased with increase in the inhibitor concentration. The mechanism of adsorption of plant extract molecules on the metal surface was physiosorption which was confirmed by the values of Gibb's free energy of adsorption. An overview of the role of plant extracts on acid corrosion of Al is depicted in Table. 2.3.

10. The inhibition efficiency of acetone extract of *Red onion* skin on aluminium in hydrochloric acid solutions evaluated by **James *et al*, 2009** using weight loss techniques. The concentration of inhibitor and temperature influenced the values of IE of the inhibitor. The IE increased with increasing the inhibitor concentration but decrease with temperature. Physical adsorption mechanism was suggested for the inhibition and Langmuir adsorption isotherm was obeyed. Quercetin was responsible for the inhibitory action of red onion skin. Red onion skin acted as an inhibitor of aluminium corrosion in 2 M HCl solution.

Table 2.3. Role of green inhibitors on acid corrosion of Aluminium.

S. No	Inhibitor	Metal	Medium	Method	IE (%)	Ref
11.	*Bassia muricata extract*	Al	1.0 M H_2SO_4	I, II, III, Electrochemical frequency modulation (EFM), SEM, AFM	90	**El-Katori *et al*, 2019**
12.	*Cnidoscolus aconitifolius*	Al	1M HCl	I, Hydrogen Evolution techniques at 303, 313 and 333 K	37	**Ugi *et al*, 2014**
13.	*Carica papaya Leaves*	Al	1.0 M H_2SO_4	I, I at 303 K, 313 K and 323 K, FTIR, SEM	72	**Kasuga *et al*, 2018**
14	*Thymus algeriensis extract*	2024 aluminium alloy	1 M HCl	I, II, III, Gasometric techniques.	79	**Khadraoui *et al*, 2015**
15.	*Cassia fistula leaves*	Al	0.5 M H_2SO_4 at 30 °C	I, II, III	96	**Omotosho *et al*, 2018**

S. No	Inhibitor	Metal	Medium	Method	IE (%)	Ref
16.	*Dendrocalamus brandisii leaves extract*	Al	HCl, H_3PO_4 solution	I, II, III	91	**Li *et al*, 2012a**
17.	*Leaf extracts of Sansevieria trifasciata*	Al	2M HCl and 2M KOH solutions	Gasometric technique	94	**Oguzie, 2007**
18.	*Polygonatum odaratum*	Al	1 M HCl	I, II, III, FTIR, SEM, and EDX	95	**Prabakaran *et al*, 2018**
19.	*Tecoma extract*	Al	1 M H_2SO_4	I, II, III, Electrochemical frequency modulation techniques, SEM	90	**Fouda *et al*, 2017b**
20.	*Raphia hookeri*	Al	HCl	I, Thermometric techniques	56	**Umoren *et al*, 2009**
21.	*Trigonellafoenum-graecum L*	Al	1M HCl	II, III	87	**Ennouri *et al*, 2017**
22.	*Ananas sativum*	Al	HCl	I, Hydrogen evolution methods	96	**Ating *et al*, 2010**
23.	*Breadfruit peel*	Al	0.5M H_2SO_4	I	85	**Orie *et al*, 2015**
24.	*Pawpaw leaves*	Al	HCl	Thermometric, I, II, SEM, FTIR	84	**Omotioma *et al*, 2017**
25.	*Commiphora pedunculata (CP) gum*	AA 3001	HCl	I, Thermometric methods	73	**Ameh *et al*, 2014**
26.	*Dryopteris cochleata leaves*	Al	H_2SO_4	I, II, III, XRD and SEM	95	**Nathiya *et al*, 2017**
27.	*Tender arecanut seed (TAS) extract*	Al	0.5 M HCl	I, II, III	94	**Raghavendra *et al*, 2016**

I = Mass loss; II= Potentiodynamic polarization method; III = Electrochemical impedance

2.4 Organic Inhibitors used as corrosion inhibitor for Al corrosion in acidic and alkaline solution

Inhibitors are used to minimize metal dissolution and reduce acid consumption. Many organic compounds reported as Al corrosion inhibitors in acidic medium. Though most of the organic compounds are having excellent inhibitive performance, their high cost and toxicity are the main drawbacks in the use of these compounds as corrosion inhibitors. The inhibitive action of the organic compounds are attributed to the adsorption of the compounds on the metal surface (Table 2.4 and Table 2.6).

Table 2.4 : Role of organic inhibitors for Al corrosion in acid solution

S.No	Inhibitor	Metal	Medium	Method	IE (%)	Ref
1.	Amine Modified Epoxy Resin	Al	1MHCl	I	92	**Oki *et al*, 2013**
2.	Pyrazolo carbothio amide derivatives	Al	2M HCl	Electrochemical frequency modulation (EFM), II, III,Mass reduction (MR) techniques	78	**Fouda *et al*, 2017c**
3.	Molybdate or permanganate species	2024 aluminium alloy	sulphuric acid	II, III, SEM	-	**Moutarlier *et al*, 2005**
4.	Phenyl sulfonylacetophenoneazo derivatives (PSAAD)	Al	0.5 M HCl	II, III, Electrochemical frequency modulation	88	**Shalabi *et al*, 2015**
5.	Cefadroxil drug	Al	HCl	I, II, SEM, DFT	93	**Silvère *et al*, 2018**
6.	Schiff's bases with additive Na_2SO_4	Al	H_2SO_4	I	95	**Sethi *et al*, 2009**
7.	Novel phthalocyanines	Al	0.1 M HCl	II, III	83	**Ozdemir *et al*, 2011**
8.	Substituted N-arylpyrroles	Al	HCl	II, III	98	**Metikos-Hukovic *et al*, 2002**
9.	Permanganate and phosphate anions	2024 aluminum alloy	H_2SO_4	II, III, SEM	99	**Mohammadi *et al*, 2013**
10.	Some Chalcone derivatives	Al	0.5 M HCl	I, II, III, Electrochemical frequency modulation (EFM)	96	**Fouda *et al*, 2014b**

I = Mass loss; II= Potentiodynamic polarization method; III = Electrochemical impedance

2.5 Inhibitive action of the Inhibitors for Al corrosion in alkaline solution

The corrosion of aluminium in alkaline solution is unfavourable to Al/air battery which can decrease the efficiency of battery and sometimes it may cause an explosion as a result of hydrogen buildup. The use of green inhibitors is the best practice for reducing aluminium corrosion in alkaline medium. Few researchers reported that lowering the corrosion rate by adding chemical compounds in alkaline solution. Nevertheless, most of the organic compounds are harmful, costly and not secure for the environment. In this connection, green inhibitors are used to reduce corrosion of Al in alkaline solution (Table 2.5).

1. Namrata chaubey *et al*, 2015c reported that few plants leaves extract such as *Cannabis sativa (CS), Rauwolfia serpentina (RS), Cymbopogon citratus (CC), Annona squamosa (AS) and Adhatoda vasica (AV)* on the corrosion of aluminium alloy (AA) in 1 M NaOH. The corrosion study was carried out by using mass loss, EIS, potentiodynamic polarization and LPR techniques. RS showed maximum inhibition efficiency (97%). Potentiodynamic polarization study confirmed that all the investigated inhibitors are mixed-type.

2. The stem bark extracts namely *Moringa oleifera (MO), Terminalia arjuna (TA) and Mangifera indica (MI)* on the corrosion behaviour of Aluminium Alloy (AA) in 1M NaOH was analysed by **Namratha chaubey *et al*, 2017**. Corrosion inhibition study was conducted using mass loss, EIS, PDP measurements. MO extract showed the maximum inhibition efficiency (%) of 85.3%. PDP study confirmed that all the studied inhibitors are of mixed-type inhibitors. Langmuir's adsorption isotherm was fitted for all the inhibitors. SEM and AFM studies confirmed the protective film of inhibitor molecule on AA surface.

3. Abdel-Gaber *et al*, 2008 explored *Damsissa* extract as an effective corrosion inhibitor for the alkaline corrosion of aluminium. This inhibitor solution controlled the liberated hydrogen gas and anodic dissolution of aluminium in alkaline media. The chloride ions inhibited the anodic dissolution of aluminium below the pitting potential.

4. Corrosion inhibition of Al corrosion in 2M NaOH medium using *cetyl trimethyl ammonium bromide* (CTAB) and lupine seed extract was investigated by **Abdel-Gaber *et al*, 2010** using PDP and gasometric method. Potentiodynamic polarization (PDP) technique confirmed that inhibitor was controlled the anodic dissolution of aluminium and the hydrogen gas evolve at the cathodic sites of the aluminium surface. The results revealed that excellent agreement between the kinetic–thermodynamic model and Flory–Huggins isotherm. Gasometry method revealed that the Inhibitive effect of the surfactant increased at composition around its critical micelle concentration (cmc).

5. Singh *et al*, 2016 investigated that *Piper longum seed* extracts were used as green inhibitor for Al corrosion 1 M NaOH using EIS and PDP and mass loss method. 94% maximum IE(%) obtained at 400 mg L^{-1} extract concentration.PDP results confirmed that the inhibitor acted as a mixed-type inhibitor. Langmuir adsorption isotherms model was more suitable for the studied inhibitor.

6. Akalezi *et al*, 2012 observed that corrosion inhibition efficiency of *Bucolzia coriacea* (BC) and *Cninodoscolus chayansa (CC)* plants extracts for Al using gas volumetric technique. The obtained inhibition efficiency not only depend on concentration but also the nature of the plant extract. A molecular modeling study was used to assess the structure, electronic reactive parameters of the plant extracts in relation to their effectiveness as corrosion inhibitors.

7. Nnanna *et al* 2016, determined the performance IE (%) of AA 8011 in alkaline medium using an eco-friendly inhibitor *Palisota hirsute*. The IE increased with an increase in the concentration of the inhibitor solution. Langmuir adsorption isotherm was fitted for the observed experimental values and confirmed that the adsorption was single layer adsorption of inhibitor molecules on AA 8011 surface. The value of Gibb's free energy of adsorption obtained suggested that the spontaneous physical adsorption of the plant extract molecules on aluminium surface.

8. Qudah, 2015 found that *Cleome droserifolia Leaves* extract performed as an excellent natural inhibitor for dissolution of Al in 1M NaOH medium. The maximum IE(%) was 78.8% at 35ºC. The E_a values were less in the presence of inhibitor solution than in the absence of the inhibitor. The well-filtted adsorption model was Temkin adsorption isotherm.

9. The corrosion inhibition behaviour of bitter leaf (*Vernonia amygdalina*) extracts as a green corrosion inhibitor for aluminium silicon alloy in 0.5 M solution of caustic soda using mass loss method. The inhibition efficiency of 87% was observed at 0.5% concentration of the extract. The adsorption of inhibitor molecules followed physical adsorption which influenced the mechanism of inhibition **(Ayeni *et al*, 2012)**.

10. Geetha *et al*, 2013 a reported the inhibitive effect of *Solanum trilobatum leaves* extract on the corrosion of aluminium in 1M NaOH solution using weight loss, hydrogen evolution, PDP and EIS methods. The results revealed that the inhibitor showed 94% efficiency. Potentiodynamic polarisation studies proved that the inhibitor acted as a mixed type inhibitor. Langmuir adsorption isotherm was correlated with the experimental values.

Table 2.5: Plant sources studied for corrosion inhibitors in alkaline corrosion of Al

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
11.	H_3PO_4 and HCl	Al/H_3PO_4 and HCl	II, III, SEM, EDX	-	**Prabhu *et al*, 2017**
12.	*Aqueous extract of Hibiscus sabdariffa leaves*	Al/0.5 M NaOH.	II, III	85	**Noor, 2009a**
13.	*Leaves extract of Senna auriculata (SL)*	Al/1N NaOH	I, Gasometric method, SEM analysis, Electrochemical techniques at 30-60°C.	76	**Sirajunnisa *et al*, 2014a**
14.	*Leaf extracts of Ziziphus jujuba*	Al/1N NaOH	I, II, III, Gasometric technique, SEM	76	**Sirajunnisa *et al*, 2014c**
15.	*Kalmegh leaf extract (KLE)*	Al/1 M NaOH	II, III, SEM, AFM	83	**Namrata Chaubey *et al*, 2016**
16	*Pisum sativum (PS), Solanum tuberosum (ST), and Citrus reticulata (CR)*	Al/1 M NaOH	II, III, SEM, AFM	95	**Namrata Chaubey *et al*, 2015a**
17.	*Senna*	Al/0.25 M NaOH	II, III, FT-IR	90	**Noor *et al*, 2017**
18	*Tridax procumbens leaves*	Al/0.5 NaOH	II, III, SEM	93	**Kiruthiga *et al*, 2015**
19	*Mesembryanthemum nodiflorum* leaves extract	Al/ 1M NaOH	I	95	**Al-Shboul *et al*, 2014**
20.	*Xylopia aethiopica Seed Extract*	Al/0.75 M KOH	I	85	**Nwosu *et al*, 2014**
21.	*Leaf extract of Euphorbia hirta*	Al/HCl and NaOH	I	88	**Nnanna *et al*, 2011a**
22.	*Euphorbia hirta and Dialum guineense leave extracts*	Al/0.25M NaOH	I	88	**Nnanna *et al*, 2011b**
23.	*Neolamarkia Cadamba (NC) bark*	Al/1 M NaOH	I, II, III, EIS, SEM	87	**Namrata Chaubey et al, 2015b**

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
24.	*Vitex negundo (VNL) leaves*	Al/1N NaOH	I, II, III, SEM	73	**Sirajunnisa *et al*, 2014b**
25.	*Plumbago europaea extract*	Al/1.0M NaOH	I	97	**Bataineh*, et al* , 2013**
26.	*Adathoda vasica leaves*	Al/1N NaOH	I, II, III, SEM	78	**Prabha *et al*, 2012**
27	*Cyanodon dactylon leaves*	Al/1N NaOH	I, II, III, Gasometric techniques, SEM	76	**Prabha *et al*, 2014**
28	*Vitex Negundo Leaves*	Al/1N NaOH	II, III	80	**Geetha *et al*, 2013b**

2.6. Organic compounds as corrosion Inhibitor for Aluminium Alloy in Alkaline medium

S.No	Source	Metal/Medium	Techniques Utilised	IE (%)	References
1	Smart epoxy coatings	AA2024/0.5 M NaCl	II,III SEM, Optical micrograph	-	**Snihirova *et al*, 2013**
2.	Fluorescein	1M NaOH	Galvanostatic, I	54	**Dhayabaran *et al*, 2004**
3.	Benzamide (BA), Sulfanilamide (SA), and Thioacetamide (TA)	Al/0.1 M NaCl	II, III SEM	98	**Zor *et al*, 2010**
4	Gelatin	Aluminum and Aluminum silicon alloys	II, III, Cyclic voltammetry	65	**Abdallah *et al*, 2016**
5	Ni in $LaNi_5$	$LaNi_{3.55}$ and $Co_{0.75}$ $Mn_{0.4}$ $Al_{0.3}$ /6 M KOH	II	-	**Wang *et al*, 2003**
6	Vinyl siloxane	Al/Neutral chloride	SEM,EDX, FTIR	-	**Petrunin *et al*, 2014**
7.	Chromate, molybdates, and tungstate	Al/0.5M NaCl	II, SEM,EDX, XPS	-	**Zein El Abedin, 2001**
8.	Pyridine	Al/2M NaCl	II	78	**Klisikic *et al*, 1997**
9	Phenyltrimethoxysil ane (PTMS)	Aluminum alloy AA7075/ aqueous solutions of NaCl	I, II	99	**Younis *et al*, 2012**

I = Mass loss;   II= Potentiodynamic polarization method; III = Electrochemical impedance

Literature survey details followed by materials and methods employed in the present study in Chapter 3.