Chapter 3
Review of Literature

3.1. Background of review

This chapter focuses on **research** and **collection of data** from various sources such as **journals, books, websites, conferences, thesis, seminar and others** should be reviewed whether it is appropriate before making references [1].

The study of **organic, inorganic, polymer, oil, gum, coating, coordination complex, industry and bakery waste, amino acid, protein, hetero cyclic compounds** as inhibitor for corrosion of metal and alloys specifically, mild steel in acidic media are reviewed [2-10]. The responsibility of an inhibitor is to form a barrier of one or a number of molecular layers against acid attack. Also review is the usage of plant materials for corrosion of metals such as **carbon, aluminium, copper, zinc, and alloys namely stainless steel and mild steel.** The ***reviewed*** (research) work carried out is presented below.

3.2. Inorganic Inhibitor

A number of inorganic elements (minerals) are essential for the growth of living things present in **almost all foodstuffs. Chromates, phosphate, selenium, tellurium, sulphur and arsenic, antimony** is among the most common substances used as inhibitors or incorporated in anticorrosive pre-treatments of aluminium alloys. Recently it is shown that addition of heavy metal ions such as **lead, manganese, cadmimum and lanthanide salts** exhibit excellent anti-corrosive properties [11].

Arena et al [12] also studied the inhibition of localized corrosion process in 3.56 g wt 5% NaCl for tin (Sn) after the addition of cerium solution. The optimum concentration among those which were studied was 1000 ppm $CeCl_3.7H_2O$ with 96% efficiency of protection.

3.3. Organic Inhibitor

Ambrish Singh, Eno E. Ebenso and **M.A Quraishi [13]** had reported Andrographispaniculata, Strychnousnuxyvomica and Moringaoleifera extracts showed inhibition efficiency above 98 %. The extracts of Andrographispaniculata, Strychnousnuxyvomica and Moringaoleifera were found to be mixed type of inhibitors.

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3.4. Polymer compounds

Several researches have been indicated that some polymers can be used as corrosion inhibitors because, through their functional group, they form complexes with metal ions and on the metal surfaces. For example gum arabic, were reported by **Umoren et al** [14] potential corrosion inhibitors for aluminum corrosion by gum arabic was attributed to the presence of arabinogalactan, oligosaccharides, polysaccharides, and glucoproteins since these compounds contain oxygen and nitrogen atoms which are the centers of adsorption.

Khairou and Sayed [15] have evaluated the inhibiting action of polyacrylamide, PVA, sodium polyacrylate, poly (ethylene glycol), pectin, and carboxymethyl cellulose on the corrosion of Cd in 0.5 M HCl solution.

3.5. Aluminium and its Alloys

Noor [16] has used an aqueous extract of Hibiscus sabdariffa leaves for inhibiting the corrosion of aluminium in alkaline solutions. Electrochemical measurements revealed that AEHSL acts as mixed-type inhibitor with an inhibition category that belongs to geometric blocking.

Corrosion behaviour of aluminium in the presence of an aqueous extract of hibiscus rosa-sinensis has been evaluated by **Rajendran et al** [17]. The formulation consisting of 8ml flower extract (FE) and 50 ppm of Zn^{2+} had 98 % inhibition efficiency.

Abdllah et al [18] investigated that the corrosion inhibition of non - toxic plant extract of Hibiscus teterifa on the corrosion of chill cast Al-Zn-Mg alloy in 0.5 Molar solution of NaOH was studied using weight loss method.

SEM-EDS characterization of natural products on corrosion inhibition of Al-Mg-Si alloy has been studied by **R. Rosliza and S. Izman** [19]. The corrosion protections and the mechanism of corrosion inhibitions of natural products for an Al-Mg-Si alloy in seawater were investigated at room temperature.

3.6. Copper

As early as 1967, **Cotton et al** [20] studied corrosion inhibition of Cu by benzotriazole and analogous compounds where one or two of the N atoms of benzotriazole are substituted by C or the labile H atom is replaced by a CH_3 group, i.e., indazole, benzimidazole, indole and methyl benzotriazole. Generally 5-membered heterocyclics, imidazole, 1, 2, 4-triazole, and pyrazole and their derivatives showed little inhibitive effect.

Walker [21] reviewed the use of BTAH as a corrosion inhibitor and the theory of its mode of protection of Cu in aqueous systems. BTAH is a good inhibitor for Cu and Brass when added to many neutral and alkaline solutions and acts as a weak buffer.

Walker [22] studied the corrosion of Cu in acidic, neutral and alkaline solutions containing triazole, benzotriazole and naphthotriazole. Triazole was a poor inhibitor, while benzotriazole and naphthotriazole were better. Naphthotiazole gave the best protection.

3.7. Zinc metal

The inhibitive action of water extract of naturally occurring **Elettaria cardamomum** [23] plant against the corrosion of zinc in 1 M HCl solution was investigated by using weight loss, potentiodynamic polarization and electrochemical impedance spectroscopy. EC extract showed high inhibitory effect due to its adsorption on the metallic surface through its electron rich functional groups. The adsorption of the investigated water extract on a zinc surface follows Langmuir's adsorption isotherm.

3.8. Carbon steel

Johnsirani et al [24] studied that the inhibition efficiency of an aqueous extract of the (curcuma longa l) plant material rhizome powder has been used as a corrosion inhibitor in controlling corrosion of carbon steel in sea water by weight loss study. The result showed that 93 % IE was provided.

A. S. Fouda et al [25] have studied the aqueous extract of Propolis as corrosion inhibitor for carbon steel in aqueous solutions was investigated by weight loss and electrochemical measurements. Potentiodynamic polarization curves revealed that this extract acts as a mixed type inhibitor and the inhibition efficiency of up to 92 % can be obtained.

Denni Asra Awizar et al [26] have studied the Nano silicate extraction from rice husk ash as green corrosion inhibitor. Silica was extracted from rice husk ash (RHA) and used to produce corrosion inhibitor for carbon steel. The corrosion inhibition efficiency of nano silicate attained 99 % as measured using the potentiodynamic polarization and weight loss measurements after 6 hrs exposure.

3.9. Different Metals

Saleh and his co-workers [27] carried out an intensive study on the inhibition effect of aqueous extract of Opuntia ficusindica, Aloe Vera leaves and peels of orange, mango and pomegranate fruits on the corrosion of steel, aluminium, zinc and copper in both HCl and H_2SO_4 acid solutions using gravimetric and polarization measurement techniques.

Corrosion control by water-soluble extracts from leaves of economic plants has been studied by **Rehan** [28]. Water extracts from leaves of date palm, phoenix dactylifera, henna, Lawsoniainerims and corn, Zea mays, were tested as corrosion inhibitors for steel, aluminium, copper and brass in acid chloride and sodium hydroxide solutions using weight loss, solution analysis and potential measurements. The inhibitive action of the extract of Ficus nitida leaves toward general and pitting

corrosion of C-steel, nickel and zinc in different aqueous media was investigated by **El-Etre and El-Tantawy** [29] using weight loss, potentiostatic and potentiodynamic polarization techniques. They found that the presence of ficus extract in the corrosive media (acidic, neutral or alkaline) decreases the corrosion rates of the three tested metals.

The aqueous extract of the leaves of henna (lawsonia) is tested as corrosion inhibitor of C-steel, nickel and zinc in acidic, neutral and alkaline solutions, using the polarization technique was studied by **El-Etreand and El-Tantawy** [30]. The extract acts as a mixed inhibitor.

Yee [31] determined the inhibitive effects of organic compounds namely; honey and rosemarinus officinalis L on four different metals-aluminium, copper, iron, and zinc each polarized in two different solutions, that is, sodium chloride and sodium sulphate. The experimental approach employed potentiodynamic polarization method. Rosemary extracts showed some cathodic inhibition when the metal was polarized in sodium chloride solution.

3.10. Stainless Steel

The inhibitive effect of the extract of khillah (Ammivisnaga) seeds, on the corrosion of stainless steel in HCl solution was determined by **El-Etre** [32] using weight loss measurements as well as potentiostatic technique. The inhibitive effect of khillah extract was discussed on the basis of adsorption of its components on the metal surface.

N. A. Abdel Ghanyl et al [33] have investigated the inhibitive effect of some amino acids on the corrosion behaviour of 316 L stainless steel in sulphuric acid solution. Glycine, Leucine and Valine inhibit the corrosion process, but Arginine accelerates the corrosion phenomenon. Glycine has the highest inhibition efficiency, its efficiency increases with increasing the concentration to attain 84.2 % at 0.1 M.

3.11. Mild Steel

R. Saratha and V.G. Vasudha [34] studied the efficiency of acid extract of dry Nyctanthesarbortristis leaves as corrosion inhibitor for mild steel in 1 N H_2SO_4 solution. The leaves extract showed good corrosion inhibition type inhibiting both cathodic as well as anodic reactions.

Oguzie [35] studied that the corrosion inhibition of mild steel in 1 M HCl and 1 M H_2SO_4 by leaf extracts of Occimum viridis (OV) using the gasometric technique. Synergistic effects increased the inhibition efficiency in the presence of halide additives namely KCl, KBr, KI. Comparative analysis of the inhibitor adsorption behaviour in 1 M HCl and 1M H_2SO_4 as well as the effect of halide (KCl, KBr, KI) additives were also studied.

Gunavathy et al [36] investigated the inhibition efficiency of acid extract of dry musa acuminate bract as corrosion inhibitor for mild steel in 1 N HCl. Potentiodynamic polarization curves revealed that inhibitor performed as a mixed type of inhibitor.

C.B. Pradeepkumar et al [37] studied the inhibition effect of plumeriarubra extracts on the corrosion of mild steel in industrial water medium by mass loss, potentiodynamic polarization and electrochemical impedance spectroscopy methods. Potentiodynamic polarization studies revealed that PR extracts act as a mixed type inhibitor.

3.12. Recent study

Recently, studies on the use of some researchers to drugs are heterocyclic; hence, they have great potentials of competing with plant extracts. The field of extracting eco-friendly corrosion inhibitors has been promising and effective. It has been observed that the natural inhibitors could potentially serve as effective substitute for the chemical inhibitors, since some studies showed that their inhibition efficiency is significantly better than that of synthetic inhibitors. Modern studies have tested different extracts for corrosion inhibition applications. The examples are numerous such as coffee beans and chickpeas [38], Chenopodium Ambrorsioides [39], Garcinia Kola [40], Musa Acuminata [41], Cannabis [42], Mexican Argemona [43], Lavandula Dentata [44], Aframomum Melegueta [45], Osmanthus Fragan [46], Neolamarckia Cadamba (Bark, Leaves) [47], Murraya Koenigii [48], Coptis Chinensis [49], Hibiscus Sabdariffa [50], Artemisia Oil [51], Musa Species [52], Hibiscus Rosa-Sinensis Linn [53], Opuntia-Ficus-Indica (Nopal) [54], Tobacco [55], Curcuma Longa [56], Onion Juice [57], Vernonia Amygdalina [58], Mangrove Tannin [59], Punica Granatum [60] used as green inhibitor**.**

Available literature has shown that the naturally occurring plant extract such as Phoenix Dactylifera Fruit Juice [61], Rain Water Containing Garlic [62], Olive Mill Waste Water [63], MorindaTinctoria [64], Creosote Bush (Larrea Tridentata) [65], Prosopis Laeviagata [66], Lanvandula Stoekas [67], Caffeine [68], Purine and Adenine [69], Vitamin B1 [70], Vitamin C [71], Pteroyl L Glutamic acid (Vitmin M) [72], Citric acid [73], Benzoic Acid [74], Peptin [75], Vitamin B1, B6 and C [76], Lignin Terpolymer **[**77], Cassava Starches [78], Carrageenan [79], Chitosan [80], Cassia Fistula [81], Bougainvillea Spectabilis [82], Mirabilis Jalapa [83], Amodiaquine [84], Benincasa Hispida [85], Dodonaea Viscosa [86], Cassia Alata [87], Cocos Nucifera [88], Frontiers Ofeco [89], Cocos Nucifera [90], Cocos Nucifera-Coconut Palm-Petiole [91], Polyvinyl alcohol-Anthranilic acid composite [92], Ortho Cholophenyl 2-Imidazoline [93], 3,4,5-Trimethoxyphenyl-2-Imidazolines [94], Cyamopsis Tetragonaloba [95], Borassus Flabellifer Linn [96], Bakery Waste [97], Dicycloimine Hydrochloride [98], Poly (Vinyl Alcohol Aniline) water soluble composite [99], Polyvinyl alcohol-Sulphanilic acid water soluble composite [100], Ervatamia Coronaria [101], Cocos Nucifera [102], Poly (Vinyl Pyrrolidone-Aniline) [103], Poly Ethylene Glycol Aniline Composite [104], Carbon prepared from agro waste in the removal of dye [105], Myristica Frangans [106], Dyeing with a natural dye on silk-annatto seeds dye [107], Abrus Precatorus [108], Chloro Quine Phosphate [109], Amodiaquine [110], Phaseolus Aureus [111], Poultry waste [112], Aquatic waste- fish scales [113], Ficus Benghalensis [114] were used as corrosion inhibitor for the protection of metal surface**.**

The various plant extract exhibited excellent corrosion inhibitors which include, Cinnamomum Zeylancium [115], Elettaria Cardamomum [116], Emblica Officinalis [117], Eucalyptus Globulus [118], Paniala (Flacourtia Jangomas) [119], Garcinia Kola [120], Glycine max oil [121], Brugmansia Suaveolens [122], Cassia Roxburghii [123], Andrographis Paniculata [124], Strychnous Nuxvomica [125], Moringa Oleifera [126], Nyctanthes Abortristis [127], Phyllanthus Amarus [128], Acacia trees [129], Aloes extract [130], Polyalthia Longifloia of hydrochloric acid [131]. Polyalthia Longifloia of sulphuric acid [132], Honey [133], Cassia Acutifolia [134], Ziziphus Spina-Christi [135], Lupines Termis [136], Brassica Nigra [137], Trigonella Foenum-Graecum [138], Jatropha Curcas [139], Jatropha Curcas Oil [140], Allium Sativum [141], Juglans Regia [142], Pogostemon Cablin [143], Vitex Negundo [144], Tamarind [145], Tea Leaves [146], Pomegranate Juice and Peel [147], Terminalia Bellerica [148], Eucalyptus Oil [149], Gum Exudate [150], Musa Sapientum Peel [151], Auforpio Turkiale [152], Azydracta Indica [153], Mango/Orange Peels [154], Argemome Mexicana [155] act as eco-friendly corrosion inhibitors**.**

Also, the extract of Garlic [156], Carrot [157], Castor Seed [158], $CeCl_3$ and Mercapto benzothiazole [159], Vanillin [160], Rosmarinus Officinalis-Netural Phenol [161], Sulphates/Molybdates and Dicharomates as passivators [162], Amino and Polyaminoacids-Aspartic Acid [163], Pyridine and its selected derivatives [164], Rutin and Quercetin [165], Polybutadieonic Acid [166], Saccharides-Mannose and Fructose [167], Vernonia Amygdalina [168], Prosopis-Cineraria [169], Tannin Beetroot [170], Saponin [171], Acacia Concianna [172], Opuntia [173], Metal Chelates of Citric Acid [174], Black Radish [175], Garcinia Mangostana [176], Ipomea Involcrata [177], Soya Bean [178], Terminalia Catappa [179], Caffeic Acid [180], Gossypium Hirsutum [181], Carmine and fast green dye [182], Aniline and its derivatives [183], Cyperuc Esculentus L. Oil [184], Dacroydes Edulis [185] were also to be used as corrosion inhibitors.

The use of natural products as corrosion inhibitors are Telfaria Occidentalis [186], Occimum Basilicum [187], Anacardium Occidentale [188], Zenthoxylium Alatum [189], Mimosa Tannin [190], Prunus Cerasus [191], Menthe Pulegium [192], Magnifera Indica [193], Carica Papaya [194], Datura Metel [195], Natural Artemisia Oil [196], Jojoba Oil [197], Khillah Extract [198], Eclipta Alba [199], Eggplant Peel [200], Tectona Grandis [201], Nettle Extract [202], Withania Somnifera [203], Wrighiatinctoria [204], Cleroden drumphlomidis [205], Ipomoeatriloba [206], Alpha Amlose [207], Plumeria Rubra [208], Lavandula Stoeches [209], Lebbeck [210], Albizia Lebbeck [211], Raphia Hookeri [212], Pelto-Phorum Pterocarpum [213], Abutilon Indium [214], Amrican Marigold [215], Tegetes Erecta [216], Dimethylaminobenzylidene Acetone [217], Techoma Stans [218], Coffea Arabica [219], Crossandra Infundibuliformis [220], Vitis Vinifera [221], Ricinus Communis [222], Citrus Aurantifolia [223], Biodiesel-Oil Gloom [224], Uranyl Hydrazinesulfinates and Sulphite Hydrazinates [225], Solaum Verbascifolium [226], Michelia Champaca [227], Paisam Sativum [228], Pongamia Pinnata Biodisel-Diesel Blends [229], Jatropha Oil [230], Long Chain Amines [231], Tegetes Errecta [232], Solanum Elaegnifolium [233], Lycopersicion Esculentum [234], Sapodilla [235],

Macrotyloma Niflorum [236], 4-Hydroxy Coumarin [237], Pisonia Grandis [238], Manihot Esculentum [239], Methylene Blue [240], Sida Rhombifolia [241], Nerium Oleander [242], Artocarpus Hetrophyllis [243], Nerium Indicum [244], Erythrina Suberosa [245], Calenduler Officinals [246], Autaborrys Odorcitissimus [247], Hexadecyl Amine and Octa Decyl Amine [248], Trichodesma Indium Linn R.Br [249], Juniperus [250], Lawsonia Extract (Henna) [251], Natural Amino Acid [252] act as excellent corrosion inhibitors**.**

The inhibitive action of plant extract of naturally occurring Curcumin Dye [253], Metformin [254], Ocimum Tenuiflorum Syn [255], Chromolaena Odarata L [256], Ananas Sativum [257], Hibiscus Teterifa [258], Azadirachia Plants [259], Ambrosia Maritime L [260], Ficus Religeosa [261], Rosemary [262], Ginseng [263], Nelumbo Nucifera [264], Oxystelma Esculentum [265], Policourea Guianensis [266], Nypa Fruticans Wurmb [267], Brassica-Juncea-Cruciferae [268], Prosopis Juliflora [269], Mangifera Indica [270], Piper Nigrum L [271], Ocimum Sanctum Linn [272], Parthenium Hysterophorus [273], Alfa Alfa [274], Adenanthera Pavonina [275], Phaseolus Lunatus [276], Sesbania Grandiflora [277], Eugenia Caryophyllata [278], Zea Mays [279], Cashew Nut Shell Liquid [280], Acacia Seyal VarSeyal [281], Red Onion Skin [282], Calotropis Procera and Calotropis Gigantea [283], Propolis [284], Propolis Laevigata [285], Swertia Aungustifolia [286], Pachylobus Edulis [287], Sansevieria Trifasciata [288], Psidium Guajava [289], Rice Husk Ash [290], Rosmarinus Officinalis L [291], Salvia Judica [292], Salvia Officinalis [293], Santalum Paniculatum [294], Senna Auriculata [295], Sesamum Indium [296], Solanum Nigrum [297], Solanum Torvum [298], Solanum Tuberosum [299], Chelidonium Majus [300], Lycium Shawii [301], Teucrium Oliverianum [302] have been shown to be effective corrosion inhibitor for metal in acid environment.

To prevent the corrosion of metal in acid medium, inhibitor such as Ochradenus Baccatus [303], Anvillea Garcinii [304], Cassia Italic [305], Artemisia Sieberi [306], Carthamus Tinctorius [307], Tripleurospermum Auriculatum [308], Rhizophora Racemosa [309], Fenugreek [310], Olea Europaea [311], Cotula Cinerea, Retama Retam and Artemisia Herba [312], Rauvolfia Serpentine **[**313], Lupinus Albus [314], Nauclea Latifolia [315], Ammi Visnaga [316], Embilica Uflicianalis, Terminalia Chebula and Terminalia Bellirica [317], Mentha Pulegium [318], Zanthoxylum Alatum [319], Thyme, Coriander, Hibiscus, Anis, Black Cumin and Garden Cress [320], Centella Asiatica [321], Combretum Bracteosum [322], Banana Peels [323], Medicago Sativa [324], Oxandra Asbeckii [325], Aegle Marmelos [326], Anna Squamosal [327], Heinsia Crinite [328], Syzygium Cumini [329], Piper Longum [330], Citrus Aurantium [331], Bacopa Monnieri [332], Terminalia Arujna [333], Delonix Regia [334], Piper Guinensis [335], Poinciana Pulcherrima [336], Cassia Occidentalis [337], Datura Stramonium [338], Acorus Calamus [339], Ajowan Seeds [340], Allium Cepa [341], Anacyclus Pyrethrum L [342], Aningeria Robusta [343], Argemone Mexicana [344], Asafoetia [345], Ficus Virens [346], Ocimum Basilicum [347], Caparis Deciduas [348], Asparagus Racemosus [349], Azadirachta Indica [350], Trachyspermum Coptium [351], Camellia Sinensis [352], Cassia Auriculata [353] and many oils extracted from different parts of plants [354]. Some researchers have used the inhibitors extracted from both plant leaves and fruits [355]. Many of

these natural substances proved their ability to serve as corrosion inhibitors for the corrosion of different types of metals.

The diverse set of research summarized and discussed indicates ongoing intensive research being carried out to tackle the problem of metal corrosion. Although it is realized that the preceding discussion are not infinitive the literature provided in this review reveal concerted efforts directed at the search for more green inhibitors as alternatives to the fossil origin toxic corrosion inhibitor. One main drawback is even with the growing interest in the search for green inhibitor the amount of research being undertaken is not significant compared to the effect of corrosion to the economy given the current consumption of mild steel. However, regardless of the drawback mentioned, this review has shown that the use of the green corrosion inhibitors is the way forward in the search for safer and environmentally secure protection against metal corrosion. The use of green inhibitors also has been the potential of being cost effective due to the renewability of its resources.

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