Review of Plant-Based Corrosion Inhibitors as Natural Corrosion Preventives

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ABSTRACT

Corrosion is the gradual breakdown of metals and alloys. It's a major issue in both the private and public sectors, and we need to start working on it right away. Industries as varied as oil and gas, food processing, pharmaceuticals, shipping, automotive, aerospace, and more regularly experience losses on par with or greater than those described. To prevent corrosion from occurring in the first place, scientists are continuously improving corrosion-resistant materials and processes. To prevent corrosion from occurring in the first place, scientists are continuously improving corrosion-resistant materials and processes. Several methods for preventing rusting are currently available. When comparing the various methods of corrosion prevention, corrosion inhibitors are widely regarded as the most functional and cost-effective option. Because of the problems caused by conventional, harmful corrosion inhibitors, eco-friendly, cheap, readily available, biodegradable alternatives are urgently needed. Here The use of naturally occurring plant inhibitors has the potential to vastly increase both corrosion resistance and process efficiency. They pose no risk to human health or the environment, may be implemented with little to no financial outlay, and are adaptable to a broad variety of settings and materials. In this review, we analyzed the corrosion problem in the industrial sector, why plant-extracted inhibitors are a viable alternative to other options, how plant-extracted inhibitors function and impact metals, and where improvements can be made using plant-extracted inhibitors to keep or reduce the corrosion problem in the industrial sector. Several plant species are mentioned in relation to their potential use as corrosion inhibitors due to the presence of several naturally occurring phytochemicals in these plants. The current review not only discusses and defines the existing state and potential for utilizing plant extracts as corrosion inhibitors, but it also outlines the problems associated with such utilization.

Key word: corrosion , corrosion inhibitors , eco-friendly , plant extract , sustainable

1. Introduction

Metallic materials, especially alloys, are widely used in the construction industry due to their many desirable properties, including as their great mechanical power and low cost[1]. However, Metals and their alloys corrode when they react chemically or electrochemically with their environments. Corrosion is caused by a variety of causes, including as contaminants on the surface, changes in pressure and temperature, and the activity of the solutions. Researchers have found that corrosion is a significant cause of material failures in several industries. Corrosion poses a serious risk to the integrity of many materials and is to blame for a large portion of structural failures, many of which cause the catastrophic collapses seen in modern architecture. As an additional consequence, this causes significant financial strain if there is a need for maintenance, refurbishment, or replacement[2], [3]. The cost of preventing and remediating corrosion was estimated at $2.5 trillion in 2013, or 3.4% of worldwide Gross Domestic Product. This does not include the costs of ensuring the health and safety of people or the protection of the environment[4]–[6].

Several strategies have been implemented to reduce corrosion. Electrochemical (anodic and cathodic protection), protective coatings, and the addition of corrosion inhibitors are all methods used to halt the deteriorating effects of corrosion[7]. For instance, choro- mates and their derivatives are among the most well-known inorganic compounds for their potent inhibitory effects. However, environmental rules have limited their use because of their toxicity and negative impact on human life and ecosystems[8]–[10].

Plant extracts and other natural products are both accessible and inexpensive. Corrosion inhibitors made from naturally occurring substances are an exciting new option since they may be used to adsorb numerous chemicals onto different metal surfaces[11]. Therefore, there has been an increase in study and implementation of green chemistry in corrosion inhibitors in the twenty-first century. Extracts from various plant components have been the subject of a flood of research into their corrosion-inhibiting properties. Indeed, it has been shown that bioactive compounds found in plant extracts are just as effective as manufactured inhibitors. Motivated by the abundance of recent literature on the topic of green corrosion inhibitors[8], we felt it necessary to do a brief review of the topic so the purpose of the present investigation is to provide a synopsis of the most recent research on the topic of green and sustainable inhibitors, with a focus on natural plant extracts and their bioactive components that may increase their efficacy as anti-corrosive agents, updating the literature with new findings, and outlining potential future avenues for study.

2. MECHANISM FOR CORROSION INHIBITION

Corrosion has a multifaceted mechanism that depends on the metal's chemical make-up, the surrounding environment, and the presence or absence of inhibitors. Corrosion inhibitors are chemicals that work by blocking or slowing the electrochemical reactions taking place on a metal's surface, therefore preventing or delaying corrosion. Inhibitors often take the form of chemicals that coat the metal's surface and keep it from coming into touch with the corrosive environment. Substances that alter the pH of the surrounding environment, making it less corrosive, and those that can prevent the flow of electrons in the electrochemical reaction are two further categories of inhibitors. The concentration of the inhibitor, the type of metal being inhibited, and the conditions to which the metal is exposed are all crucial considerations in determining the inhibitor's efficacy[12] .

To be considered sustainable, corrosion inhibitors need to be able to keep up with both current and future demands without compromising on any of the aspects that make them effective[13] [2]. Physisorption or chemisorption processes are hypothesized to underlie the inhibitory effect. As shown in Figure 1, physisorption occurs when inhibitor molecules have a weak polar connection with the charged metal surface. In contrast, chemisorption occurs when the molecules are held onto the metal surface by strong electrostatic forces[14]. In the corrosive media, the cathodic reactions are given by Equations (1) and (2). And the reduction reaction of hydrogen gas is given by Equation (3).

$$2H^+ + 2e^- \rightarrow H_2 \qquad (1)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \qquad (2)$$

$$2H^+ + 2e^- \rightarrow H_{ads} \rightarrow 2H_2 \qquad (3)$$

Adsorbed hydrogen ions on the metal surface catalyse reactions involving multiple hydrogen ions. The cathode surface then releases the hydrogen gas that has been holding it in place. Adsorption on an exposed metal surface causes inhibitor molecules to act as neutral molecules rather than hydrogen ions, as shown in Equation (4).

$$\text{Inhibitor} + n\,H_{ads} \rightarrow \text{Inhibitor}_{ads} + H_2 \qquad (4)$$

According to Equation (2), by displacement of water molecules on the metal surface as site blocking elements, green inhibitors have adsorption properties [15], [16].

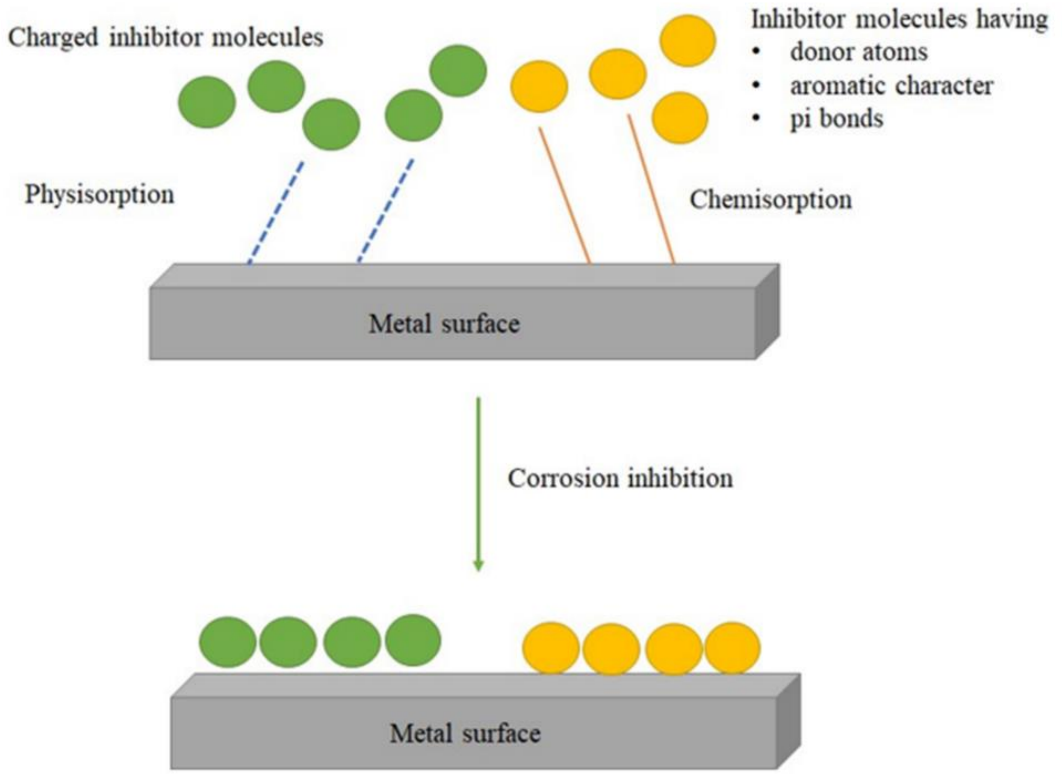

Figure 1 The mechanism for corrosion inhibition[17].

3. DIFFERENT TYPES OF PLANT EXTRACT AS CORRIOSION INHIBITOR

Plant extracts are one green alternative to commercial corrosion inhibitors. Corrosion inhibitors are frequently made from plant extracts such as bark, leaf, fruit, peel, seed, root, flower, and sometimes the complete plant. Plant extracts have been discovered to be effective corrosion inhibitors for a number of metals including mild steel, aluminium, copper, and so on, without negatively impacting the environment [18]. This review part focuses on the use of plant extracts as corrosion inhibitors for alloys such as aluminium, copper, mild steel, carbon steel, and their alloys in corrosive conditions**.**

Studies on the effectiveness of plants as corrosion inhibitors on MS under a range of corrosive circumstances have been conducted extensively. Gorse extract, for instance, was found to be an effective corrosion inhibitor in a solution of 1 mol L-1 hydrochloric acid by Trindade and partners. SEM, electrochemistry, and weight loss measures were all used in the research (SEM). Gorse leaves were steeped in 600 mL of double-boiled distilled water for an hour in order to extract the inhibitor from the leaves. The filtrate was then filtered and kept in glass containers at 4 °C in a freezer for future use. Liotop brand containers with frozen filtrate were heated at 52°C to remove the sample's water content without altering its structure, producing a powder as a result of this process. It was discovered that the efficacy of inhibition increased from 72.5 % to 93.8 % at 800 mg L^{-1} for 2 and 48 hours of immersion time and concentration, respectively. It was discovered that the charge transfer resistance (R_{ct}) increased while the capacitance of the double layer decreased using electrochemical impedance spectroscopy, with efficiency reaching 96.6 percent at 1600 mg L1 [19].

For their study on the inhibitory effects of Ficus religiosa fruit extract and Armoracia rusticana, Haldar et al used a variety of techniques, including gravimetric measurements, electrochemical analysis, atomic force microscopy and SEM analysis, UV–visible and FTIR spectroscopy, and quantum chemical calculations. In order to conduct a test of the extract solution, the 0.5 M H2SO4 was diluted with (100, 200, 300, 400, and 500 mg/L) of Ficus religiosa fruits. Reagent-grade H2SO4 and distilled water were used to make the corrosive solution (0.5 M H2SO4). Inhibitor solutions in the range of 100–500 mg/L were produced in 0.5 M H2SO4. 0.5M H2SO4 was most soluble in Ficus religiosa extract (up to 500 mg/L). According to electrochemical studies and weight loss estimations, the fruit extract of Ficus religiosa has the highest inhibitory efficiency of 92.26 % at 500 mg L^{-1}, 298 K [20]. As for the Armoracia rusticana root, according to electrochemical analysis and weight loss estimates, An excellent inhibitory efficiency of up to 95.74 % was found for MS when 100 mg/L of Armoracia rusticana root extract was used in a 0.5M H2SO4 solution at 298 K. The inhibitor's adsorption follows the Langmuir adsorption isotherm [21].

Rosa canina fruit extract is used by Sanaei et al to prevent mild steel from corroding in a solution of 1 M HCl. An EIS and a potentiodynamic polarisation test were utilised to measure the inhibitory efficiency of the drug. Rosa canina fruit powder was created. Filtered and dried for three hours at 60°C, the extract included 0.04 percent Al, 0.05 percent P, 0.05 percent S, 0.09 percent C and 0.32 percent Mn by weight. The test solutions were made with distilled water. At concentrations of 0, 200, 400, 600, and 800 ppm, an extract of the Rosa canina fruit was added to solutions of 1 M HCl. Increased inhibitor concentration to 800 ppm and immersion time of 24 hours, according to the EIS investigation, significantly improved polarisation resistance, surface coverage, and inhibition efficacy. More than 86% of the corrosion was prevented when an inhibitor was used at 800 ppm [14].

Pigeon pea leaf (PPL) extract was used as an anti-corrosion agent for mild steel in an acidic environment by Anadebe et al who studied the corrosion inhibition process utilizing experimental, theoretical modeling, and optimization investigations (HCl solution). Gas chromatography-mass spectrometry (GC-MS) and FTIR spectroscopy were used to assess the extract's chemical makeup. The response surface methodology was applied to optimize inhibition efficiency using Design-Expert software (RSM). By examining the surface morphology with a scanning electron microscope, the researchers investigated the mild steel (SEM). They found that inhibition efficiency ranged from 87.13% to 91.1% to 90.77% using thermometric, gravimetrical, potentiodynamic, and electrochemical impedance spectroscopy techniques. A quadratic model was used to show the link between inhibition efficiency and the variables that influence it [22].

Olive leaf extract was used as a MS inhibitor in an alkaline chloride solution (pH 13) by Ben Harb et al. Polarization curves, EIS, and Mott-Schottky investigations were used to determine the anticorrosive effectiveness. It took six hours of Soxhlet extraction with methanol, dichloromethane, hexane, and the other four organic solvents to remove the solvent. Solidified rotavapor solutions were obtained by centrifugation of the acquired liquids. Anti-corrosion tests were then carried out on it. Researchers found that olive leaf extract is a mixed inhibitor in NaOH (0.1 M) and NaCl (0.5 M), with a strong influence on the anode process. EIS, polarization curves, and Mott-Schottky studies all yielded consistent findings. 91.9 % of the time, methanol extract is the best inhibitor. [23].

Regarding carbon steel, Eco-friendly Eucalyptus leaf methanolic extract in 1 M H2SO4 solution was examined by Tezeghdenti et al using weight-loss measures and several electrochemical methods for corrosion inhibition. The extraction was carried out for six hours using the Soxhlet method with methanol as the extraction solvent. The solubilized solution was heated and cooled and then concentrated until it became solid. This solid extract was used to investigate corrosion inhibition. Concentrations of up to 1.5 g L-1 were dissolved in 1 M H2SO4 at varied concentrations. The test solutions were made fresh for each experiment. According to the data, the inhibition efficiency value rises with the concentration of the inhibitor, reaching approximately 84% [24].

A new green corrosion inhibitor, MAPLE, was discovered by Jokar et al. in 1 M HCl solutions of carbon steel at varied concentrations (0.1–0.4 g/L) and temperatures (25–60°C). They used a sun-dried process to dry the MAPLE inhibitor, then powdered it and extracted it in stages with distilled water. A magnetic stirrer was used to mix 6.250 grammes of powdered leaves with 500 ml of distilled water for three hours at 70 °C. Two days of stirring at the same temperature resulted in the creation of a concentrated solution from filtered water. The dried dark brown gel had a high viscosity and was pulverized. It was done by conducting EIS and polarisation experiments using electrochemical impedance spectroscopy. At a temperature of 25 °C, 0.4 g/L MAPLE inhibited up to 93% of the test sample [25].

In order to preserve low-carbon steel from acid corrosion, Paul and his colleagues extracted a green inhibitor from papaya seed. The papaya seeds were ground and boiled for 15 minutes in 100 cc of a 5 M H2SO4 solution to extract 25 g. Less than 50 mL of solution was left when it was boiled down. Filtration had taken place. A total of 10 cc of the inhibitor solution was preserved. A range of inhibitor concentrations, from 200 to 1500 ppm, was used in the trials, which included solutions of 0.5 M H2SO4, 1 MH2SO4, and 3 M H2SO4. They measured the inhibitor's action using electrochemical impedance spectroscopy and found that an increase in polarisation resistance and impedance at the metal-solution interface is what causes papaya seed to limit corrosion. Corrosion resistance is proportional to both the acid concentration and the inhibitor concentration. Adsorption isotherms show that the corrosion inhibitor mechanism is based on physical adsorption, as revealed by the adsorption research. [26].

Fouda et al, conducted chemical and electrochemical tests on Tilia cordata extract to determine its efficacy as a green inhibitor for carbon steel in 1 M HCl solutions. Leaves of the Tilia cordata plant contain the inhibitor. The dried leaves were obtained from "Al Nakyti," an Egyptian plant provider, and ground into small bits before being combined with 250 ml of distilled water in a 1000 ml and heated for 30 minutes before cooling in a dark spot. Use filter papers to remove contaminants from the crude extract following the extraction procedure. Tilia cordata exhibits corrosion-inhibiting properties with a maximum efficacy of 96 % when the extract concentration is 300 mg L^{-1}. The charge transfer resistance (Rct) value increases as the extract concentration rises, while the capacitance of the double layer (C_{dl}) and corrosion current (i_{corr}) values drop. [27].

Ginkgo leaf extract was found to inhibit the corrosion of X70 steel in 1M HCl by an electrochemical study conducted by Qiang et al (GLE).For the Ginkgo leaf extract, researchers at Chongqing University used fresh leaves that had been cleansed and dried for 50 hours at 333 K. At 353 K, 20 g of powder was refluxed for three hours in 80% alcohol. This was followed by the use of a filter, petroleum ether to remove the grease, and an extracting funnel to extract the solution. Once the solution had been concentrated, it was dried for 24 hours at 333 K in a vacuum dry oven before being concentrated again. In the end, a dark brown solid residue (about 2 g) was collected and stored in a desiccator. Up to 90.0 % efficiency values were found at 298 K, and 91.3 % at 308 K, and 92.2 % at 318 K for 200 mg/L GLE in the polarisation test [28].

Using a variety of methods, including weight loss, PDP, EIS, UV–visible spectrophotometry, and surface assessment techniques including SEM and EDAX, Mobin and his colleagues evaluated the anticorrosion behaviour of LCS in a 1 M HCL solution using Bromelain (pineapple stem extract). An increase in inhibitor concentration and an increase in electrolyte temperature lead to an increase in Bromelain inhibition effectiveness of 97% at 1000 ppm and 338 K, respectively. In electrochemical impedance investigations, the addition of bromelain to an acid solution decreases the capacitance of the double layer (C_{dl}) while increasing the charge transfer resistance (R_{ct}). A decrease in C_{dl} values and an increase in R_{ct} values can be attributed to bromelain molecules adhering to the LCS surface, slowing the rate of corrosion. [29].

Second only to iron, aluminium is the most widely used metal. Using PDP, EIS, and weight loss measurements, Singh et al studied the corrosion-inhibiting action of Piper longum seed extracts in a 1 M NaOH solution. It was done by reboiling 100 grams of dry ingredients in 500 millilitres of distilled water for five hours. Filtration was performed on the refluxed solution to remove any contaminants. According to these findings, extract concentration has an effect on inhibition. At a 400 mg L^{-1} extract concentration, the inhibition efficiency increases dramatically and reaches 94%.[30].

Black pepper extract (BPE) was studied by Ladha et al in a 1M hydrochloric acid (HCl) media, and the inhibitor efficiency was determined using gravimetric, polarisation, and impedance techniques.. For the BPE stock solution, pulverised black pepper seeds were steeped in methanol for 90 minutes, then stored and filtered for 24 hours. When the inhibitor concentration was increased, they found that the inhibition efficiency increased and peaked at 99.6 % at 0.243 gL^{-1}. [31].

Deyab has employed rosemary extract to keep biodiesel's aluminium from corroding. Weight loss and polarisation methods were used to determine the effectiveness of corrosion inhibitors. You can create the extract by grinding and soaking 10 grammes of Rosemary leaves for 48 hours at 313 degrees Celsius in an ethanol solution of 95 %. It was chilled and filtered after 48 hours. The ethanol was subsequently removed from the sample by evaporating the filtrates at 352 K. In order to remove any remaining ethanol solution, the remaining extract was dried in an oven at 323 K for three hours. An extraction yield of 11.3 % was estimated. Dissolving 0.1, 0.2, 0.3, 0,4, and 5 grammes of the extract powder in 10 mL of 95 % ethanol and adding biodiesel until a total volume of 1.0 litres was reached were used to determine the concentrations of the extract solution in the samples. Physical adsorption has been shown to play a role in the increase in inhibition with increasing extract content and reduction in temperature. [32].

Corrosion inhibition effects of Papaya peel extract (PPE) in 1 M HCl were studied by Chaubey et al. A combination of EIS and potentiodynamic polarisation was utilised to measure corrosion in the system (PDP). The inhibitor was made from Carice papaya peels, which were collected, cleaned with tap water, dried in an oven at 50°C, and ground into a powder. Steeping time was five hours for the five grammes of powder that were placed in 500 millilitres of HCl solution. After that, the mixture was chilled and filtered. After drying, the precipitate was weighed to determine its mass. The filtrate solution was maintained at a constant volume of 1000 millilitres per litre. At higher concentrations (2.0 g L-1) of PPE, the observed maximal inhibitory efficiency from the EIS plot and PDP experiments is 95.5% and 98.1%, respectively [33].

Copper and its alloys have a wide range of industrial and technological applications hence corrosion of copper and its alloys is of interest to researchers. It was found that copper corrosion was inhibited in 0.5 M NaCl solution by the use of olive leaf extract as a potentiodynamic polarizer and electrochemical impedance spectroscopy. They dried olive leaves at 25 °C for a month without light. At 75 °C, the deionized water and powdered leaves were blended and swirled for an hour. It was filtered through filter paper after cooling and kept in a freezer at 4 °C for future use once the combination cooled. The filtrate's pH was found to be 5.8 following processing. The obtained leaf extract was diluted in 0.5 M NaCl solutions in order to determine the effects. For the maximum inhibitor concentration, the inhibition efficiency reached 90% after 24 hours of immersion. [34].

An experimental copper-zinc alloy solution containing 16 ppm sulfuric acid was treated with myrrh extract for the first time, by Gadow and colleagues, as a corrosion inhibitor using myrrh extract. It was determined via a gravimetric approach, electrochemical tests, an AFM scanning electron microscope, UV spectroscopy, and FTIR analysis. The extract was made by soaking myrrh in methanol for five days. Methanol was removed from the myrrh solution extracts by filtering and distilling the solution at 40 °C for a second time before being concentrated to dryness. A concentration of 1000 ppm was obtained by dissolving 1 g of the extract in 1000 ml of water. Corrosion inhibition efficiency rose with myrrh content, reaching 67% at 300 ppm and 25 °C in the end. [35].

Papaya leaf extract (PLE) was employed by Tan et al as an environmentally friendly copper inhibitor in H2SO4 corrosion media. Electrochemical methods, SEM, X-ray photoelectron spectroscopy, and AFM experiments were used to determine the inhibitor's efficiency. An ultra-pure water extraction method was used to meticulously wash the fresh papaya leaves obtained in Sanya, Hainan Province (China), dry them for 24 hours in an oven set to 333 K, and then grind them up and transfer 100 grammes of the resulting papaya powder to an 8-liter beaker. To remove the papaya leaf residue, 1 L ultrapure water was added to the beaker and boiled until it evaporated to 200 mL. It was then necessary to boil and concentrate the filtered PLE. When the heating was finished, the extract had a volume of about 50 mL. Refrigerate for 10 hours or until extract had frozen to the bottom of tiny beaker containing PLE It was subsequently placed in a freeze-drying box (FD-1) for twenty-four hours, generating amber-colored powdered lactate (PLE) with an overall weight of 5.23 grammes. It was then placed in a desiccator to dry. It was found that PLE was an excellent corrosion inhibitor in a specified temperature range, based on the findings of the experiments [36].Table lists a summary of studies used in this review.

Table 3.1 summary of plant extract as corrosion inhibitor

NO	extracted plant part	metal type	Solution	Method Of Evaluated	Efficiency	Reference
1	Papaya leaves extract	cu	H2SO4	EIS measurement Electrochemical	95.5%	[36]
2	Olive leaf extract	Mild steel	NaOH (0.1 M) + NaCl (0.5 M)	electrochemical techniques;	91.9%	[23]

3	Rosa canina fruit extract	Mild steel	1M HCL	electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization test	86%	[14]
4	pigeon pea leaf extract	Mild steel	HCL	thermometric, gravimetric, potentiodynamic polarization	87.13% 91% 92.1%	[22]
				electrochemical impedance spectroscopic techniques	90.7%	
5	Pineapple stem extract	Low carbon steel	1M HCl	weight loss, potentiodynamic polarization measurement (PDP), electrochemical impedance spectroscopy (EIS)	97.6%	[29]
6	Ficus religiosa	Mild steel	H2SO4	Electrochemical and gravimetric	92.26%	[20]
7	GINKO LEAFT EXTRACT	Steel	HCl	electrochemical measurements	90%	[28]
8	Papaya peel extract	Aluminum	HCl	electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization techniques (PDP	95.5% 98.1%	[33]
9	Armoracia rusticana	Mild steel	0.5 M H2SO4	Weight loss measurements, Tafel polarization and electrochemical impedance spectroscopy (EIS) measurements	95.74%	[21]
10	myrrh extract	copper–zinc alloy	NaCl	gravimetric method, electrochemical measurements, AFM, UV spectroscopy and FTIR	67%	[35]
11	Gorse aqueous	Mild steel	HCl	weight-loss measurements, potentiodynamic polarization curves, electrochemical impedance spectroscopy	93.8% 96.6%	[19]
12	Aqueous extract of Tilia cordata	Carbon steel	HCl	electrochemical techniques	96%	[27]
13	Black pepper extract	Aluminum	HCl	weight loss study electrochemical techniques	99.6%	[31]
14	Rosemary leaves	Aluminum	Biodiesel	Weight loss and polarization methods were	The inhibition efficiency of Rosemary extracts increases with in-creasing the concentration of the extract but decreases with in-	[32]

to be continued...

…continuation

					creasing temperature.	
15	Olive leaf extract	Copper	NaCl	potentiodynamic polarization and electrochemical impedance spectroscopy	90%	[34]
16	Piper longum extract	Aluminum	NaOH	potentiodynamic polarization, electrochemical impedance spectroscopy (EIS) methods, and weight loss measurements	94%	[30]
17	Papaya seed	Carbon steel	H2SO4	Electrochemical impedance spectroscopy	N/A	[26]
18	MORUS ALBA PENDULA LEAVES	Carbon Steel	HCl	electrochemical impedance spectroscopy (EIS) and polarization test	93%	[25]
19	Eucalyptus globulus leaves	Carbon steel	1 M H2SO4	weight loss measurements electrochemical methods.	84%	[24]

4. THE ECONOMIC IMPACT OF CORROSION

One of the greatest challenges to industry is corrosion, which can lead to a wide range of issues and even a financial meltdown. The manufacturing and production processes are becoming increasingly complex and expensive. In addition, the repercussions of corrosion issues are known, which has led to a rise in awareness in recent years[37]. Significant monetary losses are incurred all around the world due to corrosion. According to the World Corrosion Organization, for instance, corrosion causes annual losses of 150 million tonnes, or five tonnes per second, of steel output [38]. Furthermore, the oil and gas industry has recently suffered enormous economic losses as a result of corrosion reactions' issues. Corrosion significantly impacts the various stages of oil production and transportation, resulting in a substantial economic dilemma within the oil sector [18]. For example, a recent survey indicated that several innovative oil and gas businesses allocated an annual expenditure of around $1.372 billion towards issues associated with corrosion [39]. According to the source[40] , an estimated amount of $589 million was allocated for the construction and maintenance of surface pipelines and other oil facilities. Additionally, $463 million was dedicated to the procurement of downhole tubing, while $320 million was invested in capital expenditures associated with corrosion control. The use of corrosion inhibitors is just one of the various strategies that have been developed to combat corrosion. Only a small fraction of these corrosion inhibitors are safe for the environment. The eco-friendly plant extract and organic green corrosion inhibitor market is predicted to grow by 7.0% by 2026. The eco-friendly plant extract and organic green corrosion inhibitor market is predicted to grow by 7.0% by 2026. There are numerous effective green inhibitors, including Phoenix clactylifera, Azadirachta, Pongamia glabra and Annona squamosal, Acacia arabica, Vanillin, and Reduced saccharide fructose and mannose, with efficiencies of 97%, 98%, (89-95)%, (93-97)%, (82-91)%, and 92%, respectively[18], [41]. Additionally, a lot of leaves fall daily all around our surroundings, and typically they are burned, which results in environmental pollution. Corrosion inhibitors are valuable products that can be made for relatively little money, and this waste material might be converted into them[38] .

The expenses associated with corrosion can be somewhat ascribed to the various attempts made to enhance the aesthetic appeal of engineering tools, structures, and designs[42]. Metal corrosion has a discernible economic impact that may be categorized into two main types: direct and indirect. While the primary focus of many analyses revolves around the explicit expenses associated with corrosion, it has been documented that the indirect ramifications of corrosion yield significantly more severe outcomes. The tendency to overlook the indirect costs associated with corrosion can be attributed to the challenges involved in accurately estimating these costs[43] [15]. Repairing, storing, and replacing damaged metallic items, as well as converting alloys into metals and vice versa, all contribute directly to the costs associated with corrosion. The direct cost of corrosion could be measured by the money spent on preventative measures like nickel plating and galvanizing[44]. Several new chemical compounds were synthesized, characterized, and applied as corrosion inhibitors, adding to direct costs. However, the corrosion barrier also indirectly causes a number of other expenditures and complications. Scale and rust pollution, for example, diminishes the quality of materials by blocking and fouling the joints and valves of pipelines. As a result of their toxicity, the leakage of transported petroleum-based gases and liquids generates a wide range of environmental hazards[45]. Figure 2 shows the monetary costs of corrosion.

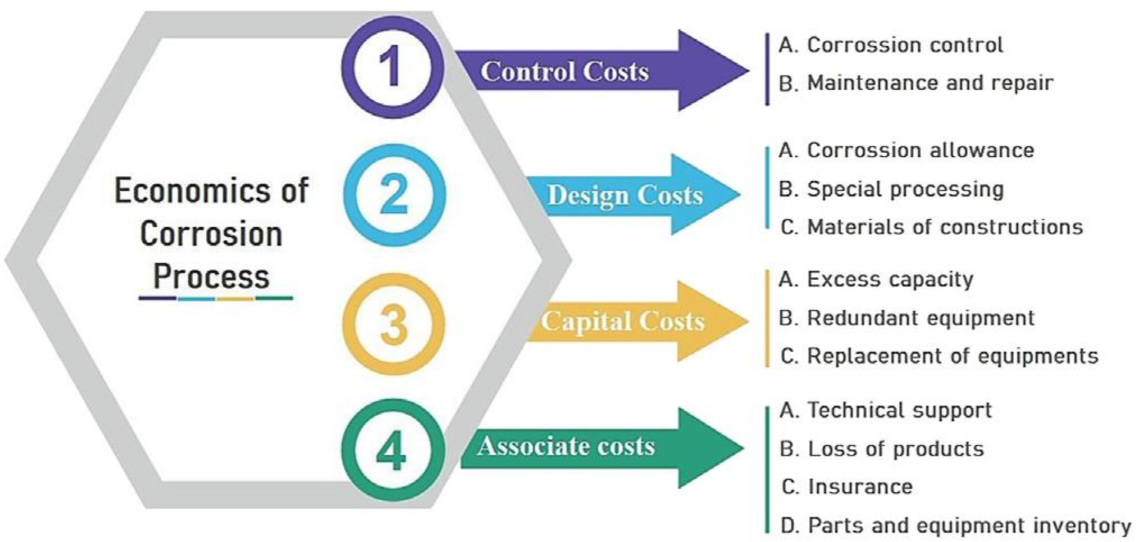

Figure 2 The economic costs of corrosion[11].

5. CONCLOSION

Corrosion is a common problem that shortens the lifespan of metals. It can be reduced in a number of ways. However, these processes often produce waste that is both dangerous and expensive. hence there is a lot of demand on scientists to discover a long-term solution to the problem of corrosion on various engineering installations. Researchers are paying more attention to plant inhibitors because of their relative advantages. When discussing the use of plant-based extracts as inhibitors of corrosion in metallic parts, it is important to do so from the perspective of sustainability, which takes into account the economic, safety, and environmental implications of the X-rays of inhibitors. The use of plant-based corrosion inhibitors appears to be an excellent solution to these issues. Its production processes are economical and efficient, and it only uses safe, non-toxic materials. However, the synthesis processes associated with plant extraction and their possible application in metal still require more investigation. The results are in, and plant-based inhibitors are not just a sustainable solution but also have wide-ranging practical implications.

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