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Curcumin and Curcumin Derivatives as Green Corrosion Inhabitor-A Review

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Corrosion is a phenomenon in which metal is degraded when it is exposed to the environment. This deterioration of the metal leads to many impacts such as structural damage and material failure, leakage, environmental contamination, economic loss, *etc*. This has made to find a solution so as to protect the material and corrosion inhibitor are one among several corrosion control strategies. These are typically molecules which adsorb onto the surface of the substrate and avoid its interaction with the environment thereby inhibiting the corrosion. These inhibitors are applied in many systems such as heat exchangers, storage tanks, boilers, cooling towers, pipes, *etc*. Chromate being such a type of inhibitor is discriminated due to its non-environmentally friendly nature. Instead, the scientific community is in search of high performing green inhibitors for mostly employed industrially important steel materials. Curcumin and its derivatives satisfy this primary criterion along with the added advantages like economical, easy to obtain, and hazardous free quality. The present article reviews the application of curcumin and its derivatives in the corrosion inhibition of industrially important materials in different corrosive environments.

Keywords: Curcumin and Curcumin derivatives, Corrosion Inhibitor, Corrosion rate, Inhibitor efficiency

INTRODUCTION

Corrosion is the degradation of materials by chemical interaction with their surroundings. Corrosion causes economic loss, structural damage, leakage, environmental impurity, and so forth. Corrosion inhibitors are used to protect metals that are the portion of an entire system. The corrosion inhibitors are used in fuel pipelines, machinery, filtering apparatus, water heaters, storage containers, and other related applications. A lot of research is being done to reduce the corrosion rate. The earliest metal-protection agents were chromate inhibitors. Because of their hazardous nature, they are being replaced by alternative inorganic inhibitors such as sodium molybdate and sodium tungstate [1]. Green inhibitors are favoured due to their inherent characteristics such as eco-friendliness, accessibility, economic effectiveness, biodegradability, and non-toxicity [2]. Numerous organic substances that contain N, S, and O effectively reduce corrosion on metal surfaces [3]. Since many synthetic inhibitors were both expensive and harmful by nature, efforts were focused on creating inexpensive, environmentally safe inhibitors. As an advancement, a few non-organic materials like nanoparticles are also employed for corrosion protection applications in the case of industrially important metals and alloys and studied their performance using advanced techniques such as voltammetry [4-7].

The ginger family includes the chemical component curcumin, which is produced from the Curcuma longa (turmeric) plant [8]. The substance was discovered to be a blend of resin and turmeric oil. It is also well-known for its antibacterial, anti-inflammatory, and antioxidant effects. Although curcumin has anticancer effects, its limited clinical use is a result of its poor chemical stability and bioavailability. It is also used in dietary supplements, food, drug [9-10] cosmetics, and industries to make products that contain curcumin.

The diarylheptanoid exists in organic solvents in the enolic form and water in the keto form [11]. Curcuma longa

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can be grown in tropical and subtropical climates. India is where turmeric is most frequently made [12]. The curcumin molecule has a functional group hydroxyl (-OH) and carbonyl (C=O) at its centre and end, respectively. The presence of these functional groups and their characteristics make the molecules interesting to study. Along with these electroactive groups, it possesses benzene rings which are planar in nature facilitating the molecule to adsorb on the substrate material. This helps the molecules to exhibit more corrosion inhibition and related performances. The structure of the curcumin molecule and its derivative's representation is depicted in Figs. 1 and 2. The corrective action taken to reduce corrosion is influenced by the type of alloy, the climate it is exposed to, the site of demand, and other considerations. Using the right inhibitors is one of the most popular ways to stop metal corrosion in different electrolyte media where the metal and electrolyte are both components of a closed system. Because of their environmental friendliness, simplicity of availability, and economic efficiency, plant materials were utilized as corrosion inhibitors. Curcumin is a fantastic corrosion inhibitor for shielding metals in a variety of environmental settings, according to numerous research. Curcumin will be positioned as a variable inhibitor for metal protection in the future due to its affordability and accessibility [13]. Also, the derivatives of the curcumin are considered to be performing better because of more number of electroactive groups. In this direction, this review consolidates the performance of curcumin and its derivative molecules as corrosion inhibitors studied under different conditions including aggressive environments, temperatures, substrates, *etc*.

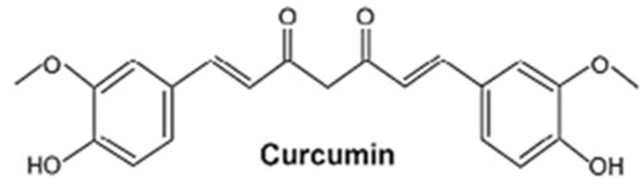
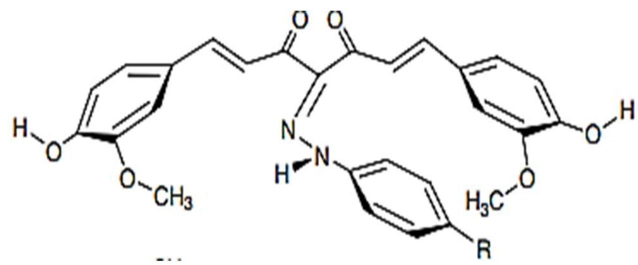


Fig. 1. Curcumin molecule [3].



Where R: $-OCH_3$, $-CH_3$, -H, -Cl, $-NO_2$, different Metallic Complex, *etc*.

Fig. 2. Curcumin derivatives [32].

APPLICATION OF CURCUMIN MOLECULE AS A CORROSION INHIBITOR IN DIFFERENT ENVIRONMENTS

Fresh Water Environment

According to the literature, curcumin prevents carbon steel from corroding in well water [14]. Curcumin was utilised along with additional inorganic $NaMoO_4$, and Zn^{2+} inhibitors. In order to create a protective coating consisting of $NaMoO_4$-Fe^{+2}, Zn $(OH)_2$ & Fe^{2+}-curcumin complex, the following ingredients were added to steel specimens: 0.0025% $NaMoO_4$, 0.025% Zn^{2+}, and 0.025% curcumin. According to M. A. Quraishi *et al.* [15], Curcumin extract in aqueous form was utilized to keep mild steel specimens cold. It followed Temkin's adsorption isotherm and slowed down the corrosion with 65% inhibition efficiency. Yaro A S *et al*. studied the performance of curcumin as a corrosion inhibitor in different concentrations of simulated refinery wastewater at different temperatures [16]. It was found to obey Langmuir adsorption isotherm with the exhibition of 84% efficiency.

Marine Environment

Many enterprises ran cooling water plants that used saline solution (NaCl) or seawater to improve cooling efficiency. Metal corrosion was extremely high in saline solution as compared to regular water. Metals experience localized corrosion due to the presence of chlorine in saline groundwater. Biofouling was another issue that developed when using seawater in the tower coolers. The effectiveness of inhibitors was also examined in a seawater/saline medium, taking into account the NaCl/saline solution-operated circulating water system and businesses that use seawater for a variety of purposes, including heat exchangers, filters, and other devices. On the mild steel specimen, a continuous film developed. The aforementioned components improved the mild steel samples' ability. M. Edraki *et al*. reported on the inhibitory effect of turmeric root for preserving low-carbon steel in 3.5% sodium chloride [17]. Literature also cites the suppression of carbon steel corrosion in sodium chloride solution at 1%. Corrosion current decreases and corrosion positive potential values in mild steel film increase in inhibition efficiency decreasing the corrosion rate in mild steel samples [18]. K.A. Saleh *et al.* [19] investigated anticorrosive properties of little quantity of nono-curcumin in a solution containing 3.5% sodium chloride which elaborates on the kinetics and thermodynamics characteristics of the corrosion process.

To preserve specimens in seawater, Rajendran. S *et al.* reported on the inhibiting effects of an aqueous extract of Curcuma longa plant substance to preserve specimens in seawater. The weight-loss study employed an aqueous extract of the plant substance in Curcumin as a corrosion inhibitor to restrain the corrosion of specimens in salt water in both the presence and absence of Zn^{2+} [20]. The inhibitory efficacy of curcumin alone and in combination with zinc ions was described in the article. The inhibition was caused by curcumin adsorption on metal surfaces. This synergy helped to obtain the inhibition efficiency of up to 93% wherein the combination behaves as a mixed-type inhibitor [20]. According to published research [21], pure curcumin in seawater has been shown to protect carbon steel from corrosion. This study examined the corrosion rate, apparent activation energy (E_a*), and other corrosion-related factors. The authors report the performance of the curcumin molecule at different concentrations at wide range of temperatures and 2.7×10^{-5} M was the best to exhibit the highest inhibition. The results were supported by the adsorption studies which infer chemisorption obeying Langmuir isotherm [19,21,22].

When low-carbon steel was immersed in an aqueous solution containing 60 ppm chloride, S. Rajendran *et al*. [23], demonstrated how an aqueous extract from Curcuma longa L, rhizome inhibited corrosion. The synergy between zinc ion and curcumin results in the formation of protective layer which contains Fe^{2+}-curcumin complex and zinc hydroxide [23]. Also, it was demonstrated that a water-based extract of Hexane and methanol extract for Curcuma longa employed corrosion inhibitors for steel carbon submerged in a chloride solution using electrochemical techniques.

Acidic Environment

The metal samples are cleaned with pickling solutions. The main ingredients of the pickling solution are acid and an inhibitor. Hydrochloric acid is the most common acid used in pickling solutions. Curcumin was used as an inhibitor by, Chetouani *et al*. [22] to investigate the corrosion of specimens in a 1.0 M HCl solution. The effectiveness of the inhibitor was evaluated using numerous techniques, including the weight-loss method and electrochemical ones. The effectiveness of inhibition rises with increasing inhibitor concentration. Additionally, it has been proved that electrical structure and inhibitory effectiveness are related to each other [22,24]. The inhibitor follows Langmuir adsorption isotherm in its mechanism to adsorb to the mild steel specimen and exhibited 87% of inhibition efficiency at 1 mM HCl concentration. The density functional theory remarks adsorption of curcumin molecules is through active centres oxygen and π electrons of the ring [25]. Turmeric root extract was tested as a corrosion inhibitor for iron 0.5 HCl using EIS, SEM, and EDX analysis. The inhibition efficiency was found to be sensitive to immersion time and temperature. It is directly proportional to the immersion time and inversely proportional to that the temperature of the environment. The Nyquist plots obtained from electrochemical impedance spectroscopy exhibit the increasing trend in charge transfer resistance (R_{ct}) and the decreasing trend in double layer capacitance (C_{dl}) with the increase in immersion time. The concentration of inhibitor increases with increased maximum efficiency of 90% at 8 g/100 ml [26].

It has been demonstrated that Curcuma extract prevents the carbon steel from corroding in 0.5 M sulfuric acid. E A F Frias *et al.* [27], demonstrate the cathodic class of the indicator for 1018 carbon steel and that their effectiveness increased with the inhibitor concentration. The mass loss was reduced by one and the I_{corr} was reduced by two folds of magnitude by Curcuma longa L. According to polarisation tests depicted in Fig. 3 Curcuma longa L. behaves primarily as cathodic kind of inhibitor, and its effectiveness rises with the amount added to the medium, which attains up to 90% [27]. M. Abdulla *et al*., found that curcumin extract when employed as the inhibitor molecule showed 83% of efficiency against carbon steel at 500 ppm [28]. Curcumin

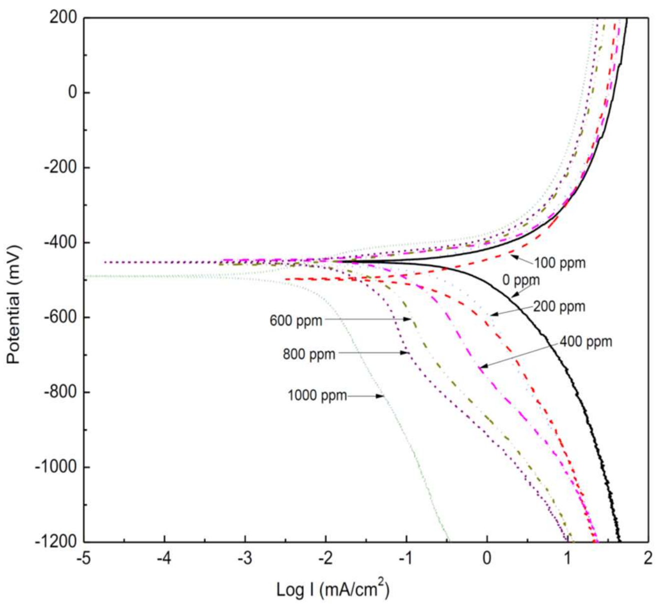


Fig. 3. Effect of Curcuma longa L. concentration on the polarization curves for 1018 carbon steel in 0.5 M H_2SO_4 [27].

extracts inhibit corrosion of C-steel in 0.5 M H_2SO_4 solution inhibition efficiency increases with increasing the concentration of the natural extract. The mixed type of inhibitor shows good adsorption on the carbon steel surface which improves inhibitory efficiency as extract concentration rises. As curcumin extract follows Temkin adsorption isotherms the efficiency depends on the molecular size extract and also inhibits the pitting corrosion of C-carbon steel by shifting the pitting potential to more noble values [28].

In a study, curcumin-stabilized silver nanoparticles (Cur-AgNp) were produced using a straightforward chemical procedure and stabilized with curcumin made using a simple chemical process. AgNp was employed as Bio derived corrosion inhibitor for low-carbon steel in a 1 M H_2SO_4 medium for this time around. At 800 mg l^{-1}, the inhibition efficiency was 92.87%. Inhibitory behaviour and Cur-adsorption of Cur-AgNp on the steel surface are made easier by the presence of the inhibitor. According to a combined manner of physical/chemical adsorption of the Langmuir Kinetic-thermodynamic isotherm, the inhibitor adhered to the steel surface and began to function [29].

Other Metals

Curcumin extract was used as a corrosion inhibitor to shield aluminium in a solution that replicated the concrete pore environment [30]. The studies found that natural seawater has been evaluated in the absence and presence of a curcumin extract zinc ion. It is observed that Aluminium is more corrosive. The addition of curcumin to a simulated concrete pore solution (SCPS) both increases the aluminium corrosion rate and the Curcumin-Zn^{2+} system, decreases the corrosion resistance of Al in SCPS [30,2]. A. S. Layla reported the reduction of aluminium leaching through the use of an aqueous extract of curcumin as a corrosion inhibitor. On aluminium surfaces, curcumin with Al^{3+} coordination as a complex was adsorbed on the surface of metal [31]. The aforementioned report discovered curcumin significantly decreased the amount of aluminium that leached into food from aluminium cookware by 60 to 80%, as well [31]. The brass corroded less quickly in nitric acid solution when exposed to derivatives of curcumin [32]. Turmeric is used in drilling mud to reduce the high rate of corrosion of drilling equipment, according to a study that was published in the literature. The corrosion inhibition studies of steel specimens were performed under different corrosive environments and the corrosion rate was found to be diminished in presence of turmeric [33].

A summary of the literature on curcumin molecules is given in Table 1.

Application of Curcumin Derivatives as a Corrosion Inhibitor

The curcumin-based derivatives with structural modification are quite interesting to study owing to their high inhibition efficiency. This is because the change in the electronic structure within the molecule which allows the molecule to adsorb more strongly onto the surface of the substrate with the increase in the inhibition efficiency. Here we discuss a few literature reports which describe curcumin derivatives and their performance as corrosion inhibitors. The key results are summarised in Table 2.

Environment-friendly corrosion and scale inhibitor, curcumin-citric acid-aspartic acid polymer (PCCA) were designed utilising a green synthesis technique that was solvent- and catalyst-free. For the first time, curcumin served as a fluorescent monomer during the building of the inhibitor.

Table 1. Inhibiting Performance of Curcumin

Specimen	Concentration curcumin	Inhibitor combination	Medium	Maximum inhibition efficiency	Ref.
Mild steel	10 ml	Fe^{2+}-Cur	Sea water	98%	[37]
Mild steel	400 ppm	Nill	Sea water	65%	[15]
Iron	10^{-3} M	Nill	1.0 M HCl	94%	[20]
Mild Steel	1.2%	Nill	Petroleum refinery wastewater	84%	[16]
Iron	50 mg l^{-1}	Fe^{2+}-Curcumin	0.1 M NaCl	71.4%	[23]
Iron	50 mg l^{-1}	Nill	0.1 M NaCl	74.1%	[25]
Carbon steel	60 ppm	Zn^{2+} (4 ml)	3% Chloride solution	89%	[23]
Carbon steel	50 ppm	Nill	1% Sodium chloride	89.88%	[18]
Steel carbon	2.7×10^{-5} M	Nill	3.5% Sodium chloride	86.21%	[19]
Mild steel	10^{-3} M	Nill	1 M HCl	93%	[22]
Steel bars		Calcium palmitate & calcium nitrite	3.5% NaCl	90% 92%	[41]
Mild steel	800 ppm	Nill	NaCl	72.02%	[17]
Carbon steel	10 ml	Zn^{2+} (50 ppm)	Sea water	93%	[20]
Steel carbon	2.7×10^{-5} (10 ml)	Zn^{2+} (25 ppm)	Sea water	77.5%	[38]
Mild steel	10 g l^{-1}	Nill	1 M HCl	92%	[24]
Carbon steel	600 ppm	Nill	1 M HCl	98%	[40]
Iron	8 g/100 ml	Nill	0.5 M Hydrochloric acid	90%	[26]
Aluminium	10 g/100 ml	Al^{3+} Cur-complex	NaCl	80%	[31]
Carbon steel	800 mg l^{-1}	Cur-AgNp	1M H_2SO_4	92.87%	[29]
Aluminum steel	10 g/100 ml	Zn^{2+}-Cur	Sea water	80%	[2]
11 1018 steel Carbon	1000 ppm	Nill	0.5M H_2SO_4	90%	[27]

PCCA demonstrated a high scale inhibitor performance of 99.7% for $CaSO_4$, and 98.8% for $CaCO_3$, respectively, and good environment flexibility. Corrosion performance is evaluated using electrochemical impedance spectroscopy (EIS) and polarisation curves show that PCCA had a high corrosion inhibition capacity with a performance of 84.1%. This was due to the limited entrance of O_2 and Cl to the steel surface. A study developed the eco-friendly and effective polymer (PCCA), which was easily fluorescently tagged using naturally available, inexpensive curcumin. They inhibit the growth of scale and corrosion. This study is the first to show how useful curcumin is as a fluorescent monomer, providing a novel method for making fluorescently-tagged inhibitors. Polarisation and impedance studies revealed that the curcumin-citric acid-aspartic acid polymer, with an efficacy of 84.1%, was a successful corrosion inhibitor [34]. Al-Amery *et al.* [35] employed chloro-curcumin as a hydrochloric acid corrosion inhibitor for carbon steel and prove its suitability. Chloro-curcumin showed increased inhibition with increased concentration and lower temperature. At 30 °C, inhibition efficiency was found to be nearly 78% for 0.5 mM HCl concentration [35].

The corrosion inhibitor for the specimen in sulfuric acid Curcuma longa, an Sn-metallic complex produced from, bis[1,7-bis(4hydroxy-3-Methoxylphenyl)-1,6-heptadiene-3,5-dionato-κO,κO′] bis(butyl), as tested [36]. Steel's

Table 2. Inhibiting Performance of Curcumin Derivatives Reported in the Literature

Sl. No.	Curcumin derivatives	Concentration/ medium	Type of substrate	Inhibitor combination	Type of inhibitor	Corrosion efficiency	Ref.
01	Curcumin-Citric Acid-Aspartic Acid Polymer (PCCA)	$CaSO_4$ $CaCO_3$	Carbon steel	CD-Zn^{2+}		99.7% and 98.8%	[34]
02	Chlorocurcumin or (1E,4Z,6E)-5-chloro-1,7-bis (4-hydroxy-3-methoxyphenyl) hepta-1,4,6-trien-3-one	0.5 M HCl	Carbon steel	Cl-Curcumin	Mixed type	78%	[35]
03	Commercial aluminium (95% pure)	Sodium nitrite and the traditional calcium nitrite	carbon steel	SCPS+ Curcumin> SCPS > SCPS+ Curcumin +Zn^{2+} > Sea water	Anodic inhibitors	95%	[30]
04	Curcuma longa (or) bis[1,7-bis(4hydroxy-3-Methoxylphenyl)-1,6-heptadiene-3,5-dionato-κO,κO′] bis(butyl),	0.5 M H_2SO_4 (1000ppm)	Carbon steel	Sn-metallic complex	Mixed type	89.1%	[36]
05	Curcuma longa- L OR 1,7-Bis-(4-hydroxy-3methooxyl-phenyl)-hepta-1, 6-diene-4-arylazo-3,5-dione [I-V]	2 M HNO_3 Acidic (0.0001 g\100 ml)	α -Brass	-CH_3, -H,-Cl, OCH_3, NO_2 Curcumin derivative complex	Mixed type	33.9%	[32]
06	All extract (curcuma longa)	1 M HCl (600 ppm)	Carbon steel	Different complexes	Mixed type	98%	[40]
07	Aqueous extract of turmeric powder	Sea water (10 ml)	Mild steel	Fe^{2+}-Curcumin	Cathodic type	98%	[37]

corrosion rate was reduced as a result of the metal complex corrosion inhibitor adsorption, which was discovered to follow the isotherm of Frumkin adsorption. The kinetics of a corrosion process is influenced by the metallic complex and an increase in inhibitor concentration led to higher inhibition efficiency. According to thermodynamic measurements, the inhibitor is continuously adsorbed. Negative values for ΔG_{ads} imply that the metallic complex spontaneously adsorbs to the surface of the steel. Gravimetric methods, Tafel extrapolation plots, and Impedance methods have all been used to assess Curcuma extract as a corrosion inhibitor for the specimen in a 0.5 M Sulfuric acid solution. Both inhibitors' effectiveness at inhibiting is a result of the heteroatoms included in these substances. Figure 4a depicts the Tafel extrapolations for the Sn-metallic complex which convey the fall in corrosion current density with increase in the concentration. Similarly, Fig. 4b presents Nyquist plots for the Sn-complex which relates the incremental resistance with that of an increase in the concentration attributing to the improved inhibition performance of the complex [36].

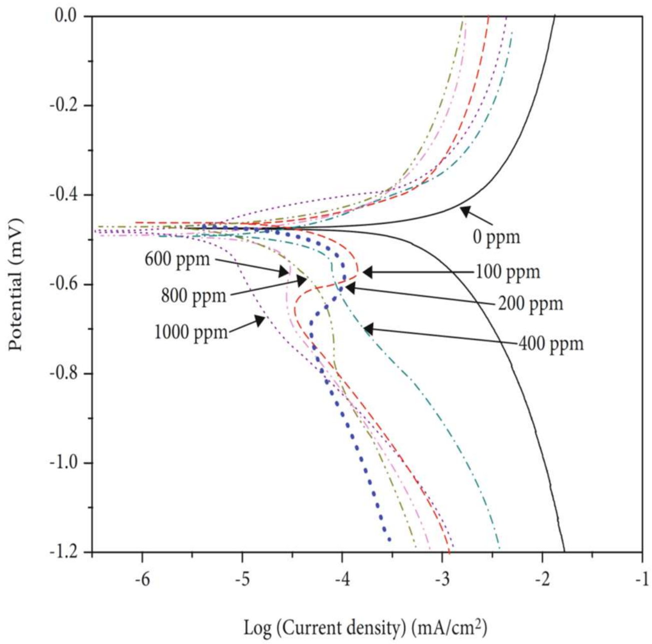


Fig. 4a. Polarization curves for 1018 carbon steel immersed in 0.5 M H_2SO_4 with different concentration of Sn-metallic complex [36].

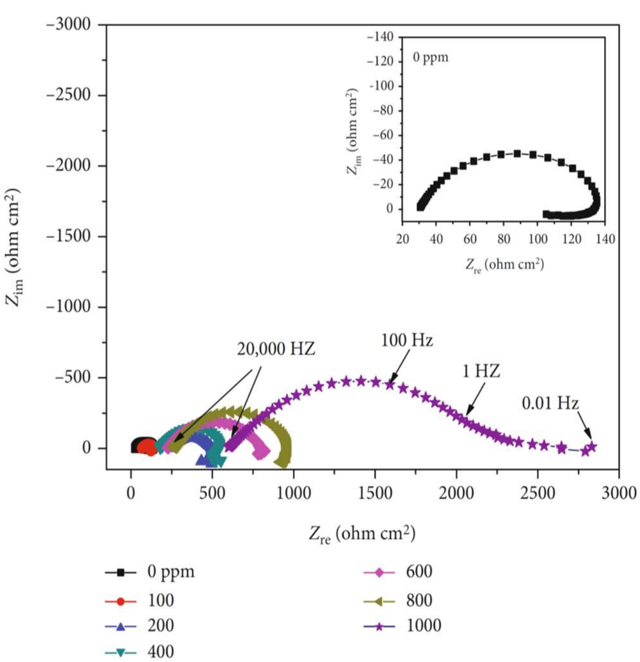


Fig. 4b. Effect of the Sn-metallic complex concentration on the Nyquist plots for 1018 carbon steel immersed in 0.5 M H_2SO_4 [36].

To prevent the low-carbon steel from corroding in seawater, turmeric powder has been used as an aqueous extract as a corrosion inhibitor. Fluorescence spectra show that the Fe^{2+}-Curcumin combination generated on the metal surface's anodic sites is what makes up the protective coating. Ten millilitres of turmeric extract had a 98% maximum corrosion inhibition effectiveness [37]. For carbon steel submerged in seawater, the preparation of 10 ml CD and 50 ppm Zn^{2+} offers 93% inhibitory performance. Polarization research demonstrates the mixed inhibitory role of the CD-Zn^{2+} system. The protective coating is made up of Zn $(OH)_2$ and Fe^{2+}-curcumin combination, according to FTIR spectra [38,20]. The corrosion resistance of 95% pure aluminium in saltwater, simulated concrete pore solution (SCPS) made in a seawater + curcumin system, and SCPS + Zn^{2+} curcumin +system have all been evaluated using electrochemical impedance spectroscopy (EIS). The resistance of aluminium to corrosion is seen to decline in the following order: SCPS > SCPS + Zn^{2+} + Curcumin > Curcumin Seawater + SCPS. The metal becomes less hard in the absence of inhibitors. These discoveries could be applied to cooling water systems that employ salt water as a coolant [30].

MECHANISM OF INHIBITION

All the investigations showed that curcumin molecules adsorb on the metal surface and slow down the corrosion. Different environments, such as neutral, acidic, and saline conditions, result in the adsorption of curcumin onto metal surfaces. In addition to water [16,31], HCl medium [22,24, 26,35] saltwater [21], sodium chloride [19], and H_2SO_4 [36], Langmuir adsorption isotherms have also been documented in these media. Classical Langmuir was described as the adsorption of curcumin on the alloy of copper in HNO_3 solution [32].

Studies on polarisation have shown that the inhibitor acted as a different-type inhibitor and altered the anodic and cathodic polarisation curves [19,24,35,26]. Cathodic inhibitors inhibit the cathodic reactions on the metal surface. They inhibit the hydrogen evolution in acidic solutions and the reduction of oxygen in neutral or alkaline solutions. In contrast, anodic inhibitors act by reducing anodic reactions and support the natural passivation of metal by film formation effectively in the pH range of 6-10. The molecules usually organic, which get adsorbed on the metal surface provide a barrier to dissolution at the anode and a barrier to hydrogen evolution or oxygen reduction at the cathodic sites are termed as mixed-type inhibitors. The effectiveness of organic inhibitors is related to the extent to which they adsorb and cover the metal surface. Adsorption depends on the structure of the inhibitor, the surface charge of the metal, and the type of electrolyte. Mixed inhibitors protect the metal in three possible ways: physical adsorption, chemisorption, and film formation.

Inhibitor molecule adsorbs onto the surface of the substrate material to be protected and thus forms a protective layer. This film or coating becomes the physical barrier and stops further interaction with the corrosion medium. A combination of Fe^{2+} and curcumin makes up the film and using the FTIR spectrum, the purported protective layer's makeup was investigated [14,20,39].

Figure 5 depicts the optimized molecular structure of curcumin complex involving, the highest occupied and lowest empty molecular orbitals of the Sn-metallic complex (Sn-X), as well as the optimal structure of the atom in its inactive state. The atoms and their corresponding colors are as follows: H-white, C-grey, O-red, N-blue, and Sn-dark-blue squares. The electrical density distribution of the HOMO on the metal surface is crucial because it shows that the inhibitor is mostly an electron donor (reducing agent) [36]. The Sn-metallic complex exhibits a dispersion of its highest occupied and lowest unoccupied molecular orbitals.

According to the electronic density seen in Highest occupied molecular orbital, which correlates to the electrophilic attack, the molecule's optimal structure has multiple active protonation centres. The Fukui functions were used to identify the molecule's protonation location (Fig. 6). Electronic properties of the protonated molecule were revealed through the studies, which include ΔE (difference in energy b/w HOMO & LUMO), frontier orbital energy, dipole moment μ, *etc*. The adsorbing of the metallic complex corrosion inhibitor, which was shown to follow the isotherm of Frumkin adsorption, resulted in a reduction in the corrosion rate in the steel specimen [36].

Curcumin derivatives show good inhibitive action of the Corrosion α-Brass in 2 M HNO_3 and it obeys Frumkin adsorption isotherm. Curcumin derivatives efficiency increases and increases in their concentration but decreases

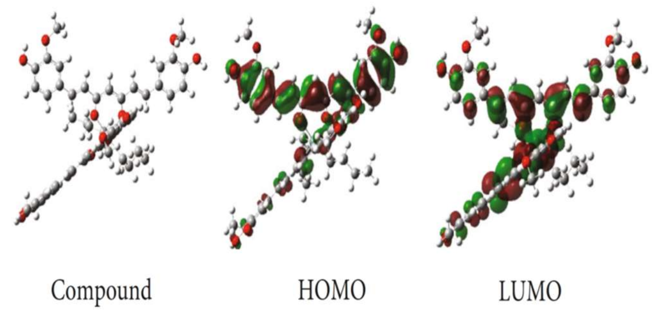


Fig. 5. Optimized molecular structure and HOMO and LUMO orbitals of the Sn-metallic complex, SnX molecule. Color code: C – gray, H – White, O – Red, N – Blue, Sn – dark-blue square [36].

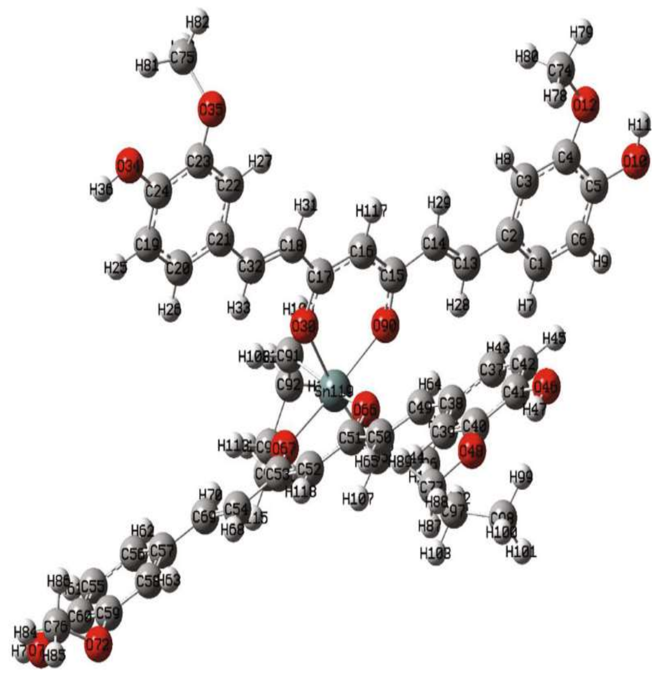


Fig. 6. Sn-metallic complex with Fukui function distribution depicting electrophilic and nucleophilic attack [36].

with rise in temperature for the weight loss and polarization methods. The cathode is more polarized than the anode Tafel inhibitor concentration [32].

Chlorocurcumin inhibits the corrosion of specimen in 1.0 M HCl solution. The inhibition efficiency increases with the concentration of the inhibitor. Potentiodynamic polarization studies implied that chlorocurcumin is a mixed-type inhibitor. The activation energy showed that the entire process is controlled by the polarization resistance and surface reaction and that the adsorption of chlorocurcumin on the metal surface obeyed the Langmuir adsorption isotherm [31]. All the different extracts show good inhibition efficiency above 98% in 1M HCl medium. Results for weight loss, EIS, and LPS are all in good agreement with one another. The combination of inhibitors [40]. The effect of Palmitate alone and in combination with calcium nitrite on the corrosion of steel was investigated. The effect of inhibitor on consistency, soundness, setting times of cement, compressive strength cement, and concrete was also studied. The effective inhibitor of calcium palmitate and calcium nitrite is 92% and 91% inhibition efficiency for 3.5% NaCl Solution [41].

CONCLUSIONS

Many studies have shown that curcumin is an effective corrosion inhibitor for safeguarding metals in various environmental situations. Curcumin's ready availability, environmentally acceptable nature, low cost will position it as a possible inhibitor for metal protection in the future. Based on the literature, this review addresses the inhibitory efficacy of curcumin for safeguarding metals under various environmental situations. Also, Curcumin derivatives effectively prevent specimen corrosion when exposed to aggressive inorganic acids. The data produced using polarisation and weight loss procedures agree well with one another. The rate of steel corrosion was decreased as a result of the metallic complex corrosion inhibitor's adsorption.

Curcumin is naturally available and its low cost will put them in the position of becoming a potential inhibitor for metal protection and demonstrate a strong inhibitory effect against the corrosion of specimens in aggressive acidic. Curcumin molecules can be designed with the required type of electroactive functional groups making them more effective in corrosion protection.

Many recent literatures report corrosion inhibition using molecules obtained from plant extracts which are non-hazardous, eco-friendly, and economically benign. Although such molecules are promising, active research is necessary to evaluate the inhibition mechanism and identify possible degradation in various real-world conditions.

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