Eco-Friendly Piper cubeba official extract corrosion inhibition of c-steel in 1M sulphamic acid

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Research Article

Keywords: Corrosion inhibition, C-steel, H2NSO3H, Piper cubeba official extract

Posted Date: September 8th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3322263/v1

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Abstract

The examination of the inhibitory rates of Piper cubeba official extract (P. cubebaOE) on C-steel in 1.0 M \( \text{H}_2\text{NSO}_3\text{H} \) solution is covered in the research article. Utilizing chemical and electrochemical methods in addition to theoretical calculations such as DFT, Fukui function, the study produced results that indicated up to 96.0% inhibition at 300 ppm at 25°C. P. cubebaOE is an inhibitor of mixed kind. Through increasing concentration, Nquist diagrams showed that the charge transfer resistance elevated and the capacitance of the double layer decreased. It was also discovered that the inhibition process follows the Langmuir isotherm, demonstrating the generation of a monolayer on the surface of the C-steel.

1. Introduction

Metal corrosion is now a serious concern to a variety of sectors as well as the environment as a whole. As a result, efforts must be undertaken to lower corrosion risks across many businesses. Inhibitors are added in small amounts to the corrosive media to protect metals against corrosion-induced dissolution, which has a significant practical benefit[1, 2]. Thus, it reduces and in some cases prevents the interaction of aggressive ions on the surface of the metal or performs both processes[3, 4]. rusting of numerous metals as well as alloys[5, 6]. The high toxicity of these compounds has led to a limitation in their inhibitors and the search for more environmentally friendly alternatives that contain functional groups containing atoms of oxygen, nitrogen, or sulfur which have been approved as corrosion inhibitors[6, 7]. The interest in green alternatives has increased in the last decade as a result of increased environmental awareness and the adoption of many strict regulations to preserve the environment. Natural alternatives have been used as antimicrobial[8–10], antifungal[11], anticancer[12], and antibacterial activities[13]. Several efforts are being made to develop compounds suitable for use as anti-corrosion agents in various forms of entertainment. The foundation of this research is the use of plant extracts that are safe for the environment to prevent metal and alloy corrosion. The application of plant extracts as barriers to corrosion, as the following research indicates this role. Calicotome extract[14], Hibiscus rosa-sinensis Linn [15]Beet root extract in well water[16], spirulina solution which confirms with electrochemical techniques[17], spirulina[18]. Finding a naturally occurring, inexpensive, and ecologically friendly chemical that might be utilized to prevent corrosion of c-steel is the goal of the current research. Utilizing natural resources will enable the achievement of both economic and environmental objectives. In several research, plant extracts have been mentioned as prospective agents to lessen corrosion in different industrial solutions[19, 20]. As reported previously, the ethanolic extract of (P.cubebaOE) contains major levels of Yatein, Cbenin, cubebinone, cubebinolide, Hinokinin and cubebinin, single aldehyde, \( \alpha \), \( \beta \)-unsaturated ketone. From Piper cubeba, several phenolic acids and flavonoids have been found and extracted. In addition to rutin (8 ppm) and catechin (5 ppm), researchers found that the aqueous extract of piper cubeba fruits also contained gallic acid (8 ppm), caffeic acid (13 ppm), syringic acid (3 ppm), and ferulic acid (11 ppm[21]. The aqueous extract from the same study contained 2.11 mg/g of total phenols [22]. In some literature, oxygen atoms, and aromatic rings are considered the centers of adsorption in the four ingredients[22, 23]. As a result, (P.cubebaOE) may be studied as an environmentally
friendly corrosion inhibitor. Our work examined the inhibitory effect of this extract on c-steel in 1.0 M H$_2$NSO$_3$H acid using weight loss (WL), (PP), (EIS), (FTIR) and (AFM) Analysis.

2. Experimental Section

2.1. Preparation of (P. CUBEBA)OExtract

To prepare the plant extract, dried leaves of the P. CUBEBA plant were used and soaked in an ethanol solution. After 48 hours, using filter papers, the unwanted objects were removed and then heated to get rid of the ethanol. Deionized water was used to prepare the different concentrations used in the research. The molecular structures of the major constituents in PcubebaOE which are caffeic acid, ferulic acid, gallic acid, syringic acid, (-)- catechin and rutin are shown in Fig. 1.

2.2. Materials preparation

Table 1 lists the chemical details contents of the pieces of C-steel that were used. where the coupons were formed with different dimensions of (2 × 2 × 0.1 cm) and dimensions (1 × 1 × 0.1 cm) for the electrochemical measurement’s studies. All of the specimens were scrubbed with deionized water and then alcohol to remove dirt and greases. Deionized water was used in all preparations. The samples were polished with sandpaper of various sizes. A solution of 1.0 M sulphamic acid was used as a corrosive medium for all measurements. The P. cubeba extract was diluted in 1.0 M H$_2$NSO$_3$H corrosion medium to prepare (50, 100, 150,200, 250, and 300 ppm) test solution, respectively.

<table>
<thead>
<tr>
<th>Element</th>
<th>Fe</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight %</td>
<td>Balance</td>
<td>0.200</td>
<td>0.600</td>
<td>0.024</td>
<td>0.098</td>
<td>0.026</td>
<td>0.245</td>
</tr>
</tbody>
</table>

2.3 Mass loss

C-steel specimens with a thickness of 2.0 * 2.0 * 0.2 cm were used for mass degradation measurements, and they were polished to varying degrees with sanded before being scrubbed with double distilled water, followed by alcohol for eliminating debris, and then adequately dried and counted. The weight is followed by the use of traditional methods for measuring WL at temperatures of (25–450C), this data was computed using the formula below. [24–27]:

$$\%IE = x100 = 1 - \frac{W}{W^*}x100$$

1

The diminution in mass of metal absent from and along with the evaluated extract is shown by W and W*, consequently.
2.4 Electrochemical laboratory tests

Electrochemical laboratory tests were performed using a traditional platinum, calomel, and C-steel three-electrode cell at an average temperature of 25°C. In this model, the calomel conductor served as an indicator, the platinum-based electrode functioned as a sort of counter, and the C-steel electrode operated as the actual working electrode. The C-steel wire was submerged at a closed loop to attain a semi-stable condition. In the present situation, impedance was recorded at multiple points, with attribute hz from $10^{-2}$ to $10^{-5}$ Hz, in addition to the presence of intermittent current signals of 5 mv, employing the Gamry Instrumentation category G 750TM -Potentiostat/ Galvanostat/ ZRA device. In order to verify the reliability of what was found, the technique was executed out three times and all output were gathered.

2.5 Theoretical calculations

The Gaussian 09 program (Gaussian, Inc., CT, USA) was used to perform quantum chemical calculations utilizing generalized density functional theory (DFT) and the Becke three parameters Lee, Yang, and Parr (B3LYP). The electrical attributes and geometries of many organic compounds can be computed perfectly using 6-311G++ (d,p)

2.6 Surface characterization

Using the Scanning Electron Microscope (SEM - Quattro S) approach, the C-steel interface was completely screening with respect to its inhibitor- and inhibitor-free variations. In the purpose of this research, two C-steel pieces were left submerged for 48 hours in sulphamic acid alone (Blank) alongside one in sulphamic acid with 300 ppm of P.cubebaOE blends.[24, 25]

2.7 AFM Technique

The AFM approach works well because it can measure the roughness of a variety of surfaces[28, 29]. Through the use of AFM, it was possible to gain a clear understanding of the changes in surface shape that occur at a distance of several hundred nanometers as a result of the development of consumption and the placement of minding successive layers on the metallic substrate when inhibiting agents have been added. The Pico SPM2100 is the AFM device model. An AFM device working in contact mode in air was used to create images in three and two dimensions at the nano unit of the College of Engineers at Mansoura Univ. 5 m × 5 m AFM imagery portions were generated at an average of 2.4 lines per second.

2.8 FT-IR technology Spectra

The spectral data from of the P.cubebaOE extract (crude) has been employed with IR affinity (Perkin-Elmer). They were completed in the university's school of pharmacy's core labs at Mansoura Univ.

3. Results and Discussion

3.1. Mass Loss Method
Equation (1) was used to obtain the inhibition ratios at temperatures between (25 and 45°C). According to the findings, values for the (P.cubebaOE) extract's CR and% IE were determined. Table 2 and Fig. 2 display the findings. The findings demonstrated that adding more (P.cubebaOE) extract raises the inhibition ratios, which were observed to decrease with rising temperature. This is because the plant extract occurs to desorb from the metal's surface. It was determined that the optimal concentration for the inhibition process was 300 ppm, which yielded the maximum inhibition rate of 96%. These findings allow us to draw the conclusion that this the high efficiency of this plant extract in the process of inhibiting corrosion C-steel in 1.0 M H₂NSO₃H solution.

<table>
<thead>
<tr>
<th>[conc.], ppm</th>
<th>θ</th>
<th>%IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.856</td>
<td>85.6</td>
</tr>
<tr>
<td>100</td>
<td>0.877</td>
<td>87.7</td>
</tr>
<tr>
<td>150</td>
<td>0.897</td>
<td>89.7</td>
</tr>
<tr>
<td>200</td>
<td>0.920</td>
<td>92.0</td>
</tr>
<tr>
<td>250</td>
<td>0.938</td>
<td>93.8</td>
</tr>
<tr>
<td>300</td>
<td>0.960</td>
<td>96.0</td>
</tr>
</tbody>
</table>

3.2 Adsorption Isotherm

The corrosion process is considered by thermal isotherms to be primarily dependent on the amount of surface coverage, making it another component of IE, where \( \%IE = \frac{IE}{100} \). The Langmuir adsorption isotherm has been proven to be the best curve to characterize the inhibitory performance after numerous attempts to adopt a relationship between the degree of coverage and the greatest concentration of the inhibitor at a specific temperature. For the plant extract (Fig. 3), The concept that the metallic surface has a certain amount of adsorption cores and that each center has a particular kind of adsorbent can be summed up in the equation [31] below:

\[
\frac{C}{\%IE} = \frac{1}{K_{ads}} + C
\]

The net energy \( G_{ads} \) signifies were derived using the formula after the adsorption factor \( K_{ads} \) quantity had been established.
The level of concentration of water on the metal surface is 55.5 in mol/L. The distributions of Gads as a reflection of temperature are shown in Table 4 at an average temperature around 298 & 318 K. As a direct consequence of the findings, we derived an association between Goads and T (Fig. 3), which means that Goads is strongly influenced on temp. This formula [32] can be used to compute the entropy (S_ads) and enthalpy of Adsorption capacities (H_ads):

\[
\Delta G_{\text{ads}}^0 = \Delta H_{\text{ads}}^0 - T \Delta S_{\text{ads}}^0
\]

The negative G_ads values increased with the increase of %IE values, which confirm the stability of the adsorbent layer physical adsorption, can indicate the extract’s spontaneous sorption on the outer layer that covers C-steel. We discover that as G_ads increases, the values of the inhibition ratios rise as well, and as H_ads has a sign that is negative, we infer that the adsorption of the extract on the surface of the C-steel is an exothermic operation., meaning that %IE decreases as temperature rises. On the other hand, the rise in solvent entropy when disorder develops at the metal/solution interface is what is responsible for the positive value of S^o_ads. This is a result of P.cubebaOE molecules dislodging H_2O molecules from the metal surface in the test medium.

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>K_ads x 10^{-3}</th>
<th>-ΔG^0_{ads}</th>
<th>ΔH^0_{ads}</th>
<th>ΔS^0_{ads}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M^{-1}</td>
<td>kJ mol^{-1}</td>
<td>kJ mol^{-1}</td>
<td>J mol^{-1}</td>
</tr>
<tr>
<td>25</td>
<td>2.02</td>
<td>15.32</td>
<td>118.60</td>
<td>44.2</td>
</tr>
<tr>
<td>30</td>
<td>1.96</td>
<td>15.60</td>
<td>48.90</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>1.93</td>
<td>21.00</td>
<td>65.05</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.98</td>
<td>21.14</td>
<td>68.62</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>0.940</td>
<td>21.50</td>
<td>68.79</td>
<td></td>
</tr>
</tbody>
</table>

### 3.3 Potentiodynamic Polarization (PDP) tests

The usual curves that characterize the polarization of C-steel in a 1M H_2NSO_3H medium are shown in Fig. 4. The voltage and current have both increased in value until they have reached their highest peak without being inhibited, as seen by the curve of polarization[30, 33]. With the inhibitor, there was noticeably less cathodic and anodic current density as well. Additionally, the E_corr value is altered by the
presence of \((P.cubebaOE)\). An inhibitor can be classified as cathodic or anodic if the \(E_{corr}\) movement has a value higher than 85 mV; otherwise, if the displacement is lower than 85 mV, it can be classified as mixed. The present investigation's experimental inhibitor showed an optimal \(E_{corr}\) shift value of 85 mV, indicating that it is a mixed-type inhibitor. Increased \((P.cubebaOE)\) concentration prevents anodic corrosion of C-steel electrodes, as seen in Fig. 3. Additionally, \((P.cubebaOE)\) suppresses the cathodic response less than the anodic reaction when it is present. As demonstrated in Table 6, \((P.cubebaOE)\) elevates the values of \(\beta_a\) for \((P.cubebaOE)\) above those obtained using a blank in the event that there is no of \((P.cubebaOE)\). As a result, the oxidation mechanism is suppressed by the \((P.cubebaOE)\), thus regulating the anodic processes on the metal's outermost layer. [34]

Table 4 illustrates the corrosive potential \((E_{corr})\), corrosive density of current \((i_{corr})\), the Tafel slopes \((a, c)\), degree of surface coverage \((\theta)\), and the inhibition effectiveness \((%IE)\) of C-steel for \(P.cubebaOE\) in 1M \(H_2NSO_3H\) at 25°C.

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>[conc.] ppm</th>
<th>(-E_{corr}) Mv vs SCE</th>
<th>(i_{corr}) (x10^{-4}) μA cm(^{-2})</th>
<th>(\beta_a), mV dec(^{-1})</th>
<th>(\beta_c), mV dec(^{-1})</th>
<th>(\theta)</th>
<th>%IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>0</td>
<td>867</td>
<td>301.0</td>
<td>366</td>
<td>390.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>(P.cubebaOE)</td>
<td>50</td>
<td>847</td>
<td>173.0</td>
<td>319</td>
<td>281</td>
<td>0.425</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>852</td>
<td>149.0</td>
<td>277</td>
<td>250</td>
<td>0.504</td>
<td>50.4</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>742</td>
<td>69.7</td>
<td>340</td>
<td>130</td>
<td>0.768</td>
<td>76.8</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>938</td>
<td>47.8</td>
<td>82</td>
<td>93</td>
<td>0.841</td>
<td>84.1</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>854</td>
<td>39.7</td>
<td>157</td>
<td>59</td>
<td>0.868</td>
<td>86.8</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>552</td>
<td>25.8</td>
<td>64</td>
<td>57</td>
<td>0.914</td>
<td>91.4</td>
</tr>
</tbody>
</table>

### 3.4 Electrochemical Impedance Spectroscopy (EIS) tests

We additionally utilized the EIS approach to assess the rusting behavior of C-steel in 1M sulphamic acid solution, as well as zero concentration and addition a variety of \(P.cubebaOE\) doses[35]. The hard exterior of the C-steel electrode generated unfinished circular shapes with a time variable to appear on Nyquist plots. The capacitive ring's dimensions substantially increases when the inhibitor gets added to the 1M concentrations of \(H_2NSO_3H\), and this growth strengthens as the inhibitor's level rises. The observations point to a shielding layer has formed and those inhibitory molecules are bound to the surface of C-steel. This layer substantially reduces the surface area that is actively oxidizing of C-steel, promotes its durability against corrosion, and diminishes rust start in due to the presence of a 1M \(H_2NSO_3H\) solution[36]. While the Rct value goes up as the inhibitor dosage rises, the impedance values shown in Table 5 demonstrates that the inhibitory action turns into more intense in acidic conditions. As a consequence of this, as C-steel disintegrates a barrier develops at the metal solution interface. This
barrier implies that just a single charge transfer process utilized place, and that the connected molecule
had no impact on this mechanism. As the inhibitor conc. rises the capacitance value of the double layer
drops. The densities of the shielding layer and the electrical double layer varies. Both the weight loss and
polarization procedures achieve comparable consequences in terms of IE adoption.

(CPE₃), specifically CPEᵣ and CPE₅, have been used in place of all capacitance elements in Fig. 4. Rₛ
stands for the solution resistance, and CPEᵣ for the capacitance of a passive film. Rᵣ is equivalent to the
ionic resistance in passive films. CPE₅ stands for the capacitive action of the two-layer corroded region,
while R₅ symbolizes for the amount of charge transmit barrier. Furthermore demonstrated in Fig. 6 (a and
b[37], Nyquist and Bode diagrams for C-steel rusting in 1M H₂NSO₃H solution are highlighted according
to phase angle and frequency. Find the circuit’s double-layer capacitance, C₅, using the following
equation.

\[
C dl = Y0 (\omega max)^n - 1
\]

where \( f_{\text{max}} \) is the resonance frequency at which the simulated portion of the impedance is full, \( Y0 \) is the
absolute value of the CPE, \( \text{max} = 2f_{\text{max}} \), and factor \( n \) a varies from 0.50 to 1.0[38]. The general curves’
similarity (with or without an inhibitor) demonstrates that the corrosion mechanism remains unchanged.
As additional proof, it was demonstrated that Bode plots prevented by a phase angle increase had a
higher degree of phase angle. With a rise in phase angle values, shielded surfaces’ morphology got better.
Nyquist curve diameters and phase angle values in Bode plots increase when P. cubebaOE is concentrated
(Fig. 6b).

Table 5
P. cubebaOE doses with and without respect to the kinetics of C-steel
electrochemistry in H₂NSO₃H.

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>inh ,ppm</th>
<th>( R_{ct} ), Ω cm²</th>
<th>C₅ x 10⁻⁴, µF cm⁻²</th>
<th>( \Theta )</th>
<th>% IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>0</td>
<td>110.5</td>
<td>9.77</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>P. cubebaOE</td>
<td>50</td>
<td>339.7</td>
<td>8.03</td>
<td>0.674</td>
<td>67.4</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>498.5</td>
<td>3.91</td>
<td>0.778</td>
<td>77.8</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>544.5</td>
<td>3.62</td>
<td>0.797</td>
<td>79.7</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>1219</td>
<td>0.231</td>
<td>0.909</td>
<td>90.9</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>1397</td>
<td>0.129</td>
<td>0.921</td>
<td>92.1</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>1492</td>
<td>0.112</td>
<td>0.926</td>
<td>92.6</td>
</tr>
</tbody>
</table>

3.5 Molecular modelling

3.5.1 HOMO-LUMO molecule orbital
The LUMO and HOMO density profiles of the studied chemical in the aqueous phase are shown in Fig. 7. It demonstrates that whereas green has a low electron density, red has a high electron density. In situations where there is a high electron density, the metal surface can donate electrons. Electrons are attracted to the metal surface in the green region. Since resonance is primarily brought on by the bonds between the oxygen and nitrogen atoms on the benzene ring, the distribution of these two locations must be carefully considered. In the interim, the carbon atoms are the core of the LUMO. Improved inhibitory efficiency may be indicated by lower ΔE values. The inhibitor molecule's reactivity to the metal atom can be evaluated using the ΔE value. Lower ΔE values may indicate improved inhibition efficiency. The ΔE value can be used to assess the reactivity of the inhibitor molecule to the metal atom. The DFT simulations have shown that – (-) catechin (ΔE = 2.79) is the most stable.

<table>
<thead>
<tr>
<th>Compound</th>
<th>EHOMO E_LUMO</th>
<th>ΔE = E_LUMO - EHOMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutin</td>
<td>-4.514 eV</td>
<td>-3.486 eV</td>
</tr>
<tr>
<td>Caffeic Acid</td>
<td>-5.223 eV</td>
<td>-3.549 eV</td>
</tr>
<tr>
<td>Ferulic Acid</td>
<td>-5.198 eV</td>
<td>-3.490 eV</td>
</tr>
<tr>
<td>Gallic Acid And</td>
<td>-5.575 eV</td>
<td>-3.444 eV</td>
</tr>
<tr>
<td>Syringic Acid</td>
<td>-5.461 eV</td>
<td>-3.290 eV</td>
</tr>
<tr>
<td>Catechin</td>
<td>-5.112 eV</td>
<td>-2.322 eV</td>
</tr>
</tbody>
</table>

### 3.5.2 2D maps of electrostatic potential

The distribution of electrons and, subsequently, where they are concentrated within each molecule can be seen using ESP maps. According to the electron density contour maps, oxygen atoms on the examined molecule inhibitor appear to be favorable interaction locations, which is in line with the different functions of oxygen and the other atoms. The contact regions that provide the bonding contacts between metal surfaces and inhibitor are surrounded by a dark red outline. The distribution of electrons and, subsequently, where they are concentrated within each molecule can be seen using ESP maps.

### 3.6 SEM examination

SEM research has verified the P.cubebaOE layer's adsorption on the surface of C-steel. Figures (9 a- c) depict SEM images of C-steel's surface before and after 48 hours of immersion in 1 M H₂NSO₃H with a dosage of 300 ppm of P.cubebaOE. Without having P.cubebaOE, H₂NSO₃H corrosion has clearly harmed the C-steel surface, but the metallic edge is still discernible (Fig. 9b). The metal surface, in variance with the material under assessment, appears not to rust (Fig. 9c). It was found that the extract created a slight film on the C-steel's outside that restricted corrosion.[39]

### 3.7 Atomic Force Microscope (AFM)
The metal surface of the C-steel without the investigated P.cubebaOE inhibitor has reportedly been repeatedly corroded by the corrosive attacks of the 1M sulphamic acid (Fig. 10b), according to the 3D picture of the C-steel. The 3D images (Fig. 10c) that reveal smoother surfaces than the blank, however, show that the addition of an inhibitor lessens C-steel corrosion in the aggressive solution. Table 6 shows the mean roughness (Sa) and average RMS roughness (Sq) of the films generated on the Cu surface in accordance with the modular program Gwyddion. The RMS roughness and mean roughness of the blank are greater than those of the inhibitor under study and pure metal, as shown by the data in Table 6, demonstrating the effectiveness of the compound in shielding C-steel's surface from corrosive medium. The AFM data add to the body of information supporting the sequence of inhibitory efficacy discovered by weight loss research and electrochemical tests.

<table>
<thead>
<tr>
<th>Sample</th>
<th>RMS roughness (Sq), nm</th>
<th>Mean roughness (Sa), nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>22.97</td>
<td>17.64</td>
</tr>
<tr>
<td>b</td>
<td>1234.9</td>
<td>993.76</td>
</tr>
<tr>
<td>c</td>
<td>285.83</td>
<td>180.68</td>
</tr>
</tbody>
</table>

3.8 Fourier transforms infrared spectroscopy (FT-IR) studies

Figure 11 confirms that "the -C = O stretching frequency occurs at 1640 cm⁻¹, with the acute one at 1608 cm⁻¹ referring to -C = C stretching, the O-H stretching has changed from 3225 cm⁻¹ to 3365 cm⁻¹, and the -C = C stretching frequency shifts from 1647 cm⁻¹ to 1640 cm⁻¹ in the film generated on the C-steel submerged in sulphamic acid." The alterations in the IR spectra hint that the bonding of P.cubebaOE with C-steel was accomplished through groups of functions that had already existed in it.

Rusty Inhibition Process

Some plant-based extracts have a restrictive acting characteristic that has been speculated to be attributed to the adsorption of the Phyto-chemical components found in the extract of leaves on the metal surface, which maintains the metal's outermost layer and stops the corrosion process from proceeding. How the inhibitor adsorbs is influenced by the chemical composition of the Phyto-components present, the charge on the metal surface, and the nature of the corrosive media. The inhibitor molecules in our work are electrostatically drawn to the metal surface because the C-steel surface bears a positive charge under acidic conditions. Due to the electrostatic interaction (physical adsorption), (SO3-) ion adsorption on the outermost layer of the metallic substance increases the amount of inhibitor molecules that can adsorb on the C-steel surface by generating an additional negative charge close to the corrosive solution. The chemisorption processes, on the other hand, are made possible by the donation of electron lone pairs on heteroatoms like N, O, and the aromatic ring contains electrons in order to attach to the open d-orbital of C-steel ions. The surface becomes more negatively charged when the surface is
saturated with one electron[40]. The electron in C-steel's d-orbital is then moved (retro-donated) to the open -antibonding orbital of the inhibitor molecules in order to remove the extra electron from the surface[41, 42]. Thus, the C-steel's anodized and either cathodic process in the H₂NSO₃H medium are effectively inhibited by the formation of a durable barrier film. All of this leads us to the conclusion that a number of fundamental mechanisms that the high proportion of %IE is a consequence of chemicals adhering to the metal's surface[43, 44]. In Table 9, the percentage of P.cubebaOE in the current investigation is contrasted with values previously reported in the literature in acidic media[45, 46]. The P.cubebaOE clearly produced 96.0% IE at 300 ppm, indicating that it functions effectively as a sulphamic acid corrosion-preventing agent for C-steel[1].

Table 7
A comparison of P.cubebaOE with some other studied (%IE is reported at the maximum) extracts

<table>
<thead>
<tr>
<th>Source of extract</th>
<th>Test medium</th>
<th>Metal/Alloy</th>
<th>% IE</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange peels</td>
<td>HCl and H₂SO₄</td>
<td>Cu</td>
<td>43.0</td>
<td>[42]</td>
</tr>
<tr>
<td>Mangrove tannin</td>
<td>HCl</td>
<td>Cu</td>
<td>82.4</td>
<td>[44]</td>
</tr>
<tr>
<td>Myrtus communis</td>
<td>H₂SO₄</td>
<td>Cu</td>
<td>&gt;85.0</td>
<td>[47]</td>
</tr>
<tr>
<td>Alhagi Mauro rum plant extract</td>
<td>H₂SO₄</td>
<td>Cu</td>
<td>33.0–83.0</td>
<td>[43]</td>
</tr>
<tr>
<td>Egyptian licorice extract</td>
<td>HCl</td>
<td>Cu</td>
<td>55.0–89.0.0</td>
<td>[45]</td>
</tr>
<tr>
<td>Exudate gum from Dacryodes edulis</td>
<td>HCl</td>
<td>Al</td>
<td>42.0</td>
<td>[46]</td>
</tr>
<tr>
<td>Opuntia ficus indica</td>
<td>HCl</td>
<td>C-steel</td>
<td>70.0–91.0</td>
<td>[48]</td>
</tr>
<tr>
<td>Piper cubeba official extract</td>
<td>H₂NSO₃H</td>
<td>C-steel</td>
<td>96.0</td>
<td>Our results</td>
</tr>
</tbody>
</table>

Conclusions

It has been demonstrated through experiments that (P.CubebaOE) effectively prevents C-steel corrosion in 1.0 M H₂NSO₃H solution as a mixed-type inhibitor. When this substance was adsorbed on C-steel surfaces, it displayed these isotherms of Langmuir adsorption, which are similar to inhibitory. Due to the fact that Gₐds has a value which is negative, it was assumed that the reaction was spontaneous. It was discovered that temperature and inhibitor concentration regulate the inhibitory process. A protective coating that shields the brass alloy from corrosive fluids was discovered by SEM analysis of the surface of the metal.

Declarations

Author Contributions: Conceptualization, Methodology, project administration and funding acquisition, Merfat S. Al-Sharif; software, validation, and formal analysis, writing, editing and data analysis, supervision, A.M.Salem; All authors have read and agreed to the published version of the manuscript.
**Funding:** The researchers would like to acknowledge the Deanship of Scientific Research, Taif University for funding this work

**Data Availability Statement:** The authors confirm that the data supporting this study are available.

**Acknowledgments:** The researchers would like to acknowledge the Deanship of Scientific Research, Taif University for funding this work.

**Conflicts of Interest:** The authors declare no conflicts of interest.

**References**


Figures

![Gallic acid](image1)

![Caffeic acid](image2)

![Syringic acid](image3)

![Ferulic acid](image4)

![Rutin](image5)

[(-)-Catechin](image6)

Figure 1
Figure 2 shows the impact of submerged intervals on the amount of mass loss of C-steel in 1 M H$_2$NSO$_3$H containing and not containing varied P. cubebaOE doses at 25°C.
Figure 3

provides the Langmuir pattern produced by P.cubebaOE for rusting of C-steel in 1M H$_2$NSO$_3$H solution at 25°C as C/ vs. C, M.
Figure 4

illuminates the potentiodynamic polarization diagrams for C-steel dissolving in 1M H₂NSO₃H in both the existence and not-existence of a variety of P.cubebaOE at 25°C.

Figure 5
Modeling a similar circuit to match a laboratory EIS

Figure 6

(a, b) shows the Nyquist and Bode plots for the corrosion of C-steel in 1M H$_2$NSO$_3$H in both the absence and the existence of multiple amounts of P.cubebaOE at 25°C.
Figure 7

HOMO and LUMO molecular orbitals of major ingredients of P.cubebaOE
Figure 8

ESP pictures of P.cubebaOE
<table>
<thead>
<tr>
<th>a) C-steel alone</th>
<th>b) C-steel + 1M H₂NSO₃H</th>
<th>c) C-steel + 1M H₂NSO₃H + 300 ppm of P. CubebaOE OE</th>
</tr>
</thead>
</table>

**Figure 9**

SEM image of pure C-steel in 1.0 M H₂NSO₃H solution (a), without P. cubebaOE at the optimal concentration (b), and with P. cubebaOE present (c).

<table>
<thead>
<tr>
<th>a) C-steel alone</th>
<th>b) C-steel + 1M H₂NSO₃H</th>
<th>c) C-steel + 1M H₂NSO₃H + 300 ppm of P. cubeba OE</th>
</tr>
</thead>
</table>

**Figure 10**

shows an AFM image of pure C-steel (a) and steel that has been submerged in 1.0 M H₂NSO₃H solutions without P. cubebaOE (b) and with it (c), respectively.
Figure 11

FTIR spectra of P.cubebaOE

Supplementary Files

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