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The Effect of Using Conocarpus Extract as Green Inhibitor on Steel Corrosion in Hydrochloric Acid Environment in Oil Well Acidizing

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Abstract

The effect of using Conocarpus extract as a green inhibitor on the corrosion behavior of mild steel in a 1M HCL environment was investigated by electrochemical impedance spectroscopy (EIS), potentiodynamic polarization (PDP), scanning electron microscopy (SEM), and Fourier-transform infrared spectroscopy (FTIR). The impedance test showed that the polarization resistance increased from 29 for the blank solution to 299 for the solution containing 2500 ppm of Conocarpus extract. The results of the polarization test showed that at room temperature, the corrosion current density for the blank solution decreased from 3.5E-4 to 2.6E-5for the solution containing 2500 ppm of Conocarpus extract, and the potential was shifted to negative values. The polarization test was performed at three temperatures of 25, 55, and 85. The results showed that the efficiency of 1925 ppm has decreased from 93% at room temperature to 86% at 85 ° C. Obviously, the high-temperature efficiency has not reduced significantly, which means the effectiveness of Conocarpus extract at high temperatures. FTIR test also proved that the corrosion inhibitory effect of Conocarpus extract is due to the presence of heteroatoms such as N, S, and O. The adsorption isotherm results showed that the adsorption of the extract as a single layer on the surface is consistent with the Langmuir isotherm.

Keywords: Green Inhibitor, Polarization, Electrochemical Impedance, Fourier transform Infrared Spectroscopy, Langmuir.

1. Introduction

Acidizing is a crucial step in oil and gas drilling. Acidizing means injecting acid into a well or formation capable of producing oil and gas, intending to increase productivity. Acidizing is also used in old wells for the removal of scale deposits. The formation of these deposits is a common problem in oil wells. The area near the bottom of the well is the most critical area exposed to deposition, due to the high pressure and temperature. These deposits cause plugging of the porosity of the formation containing oil and, or gas and

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decrease the production of the wells Scale formation on the production equipment is also a significant operational problem. It causes corrosion, flow restriction, and production decline.[Institute, A. P.I.]
There are three general types of acidizing: 1) acid Washing, 2) matrix acidizing, and 3) fracture acidizing. In the first type, the purpose is only to clean the well. Usually, HCL is used to clean sediments (such as calcium carbonate), rust, etc.

But in the other two types, the goal is to restore or increase the efficiency of the oil or gas well, which uses the dissolution of materials that limit the flow from the formation or the dissolution of the rock formation itself to increase flow or create a new flow path.[Kootiyani et al., 2015]

The use of corrosive acids in acidizing causes corrosion, Therefore, anti-corrosion additives are used to reduce the corrosion of metal pipes and wellhead equipment.[Moazeni, 2009]

Corrosion is the destruction of metal by contact with a corrosive aqueous medium (air, moisture, soil) that occurs through chemical or electrochemical reactions.[Thompson et al., 2007] Corrosion is an environmental threat with economic, protective, and safety effects in various industries such as construction, chemical, automotive, metallurgy, and medicine.[Sharma et al., 2011]

For this reason, it is necessary to implement techniques and methods to prevent and protect against corrosion, which include: protective coatings, cathodic/anodic protection, corrosion inhibitors, insertion of corrosion considerations in design, and material selection. According to the research results on the use of anti-corrosion materials, it can be alleged that the use of inhibitors is the easiest and most effective way to prevent corrosion.[Basargin et al., 2004] One of the methods of corrosion prevention that is used in different parts of the industry due to its low cost, high compatibility, and cost-effectiveness is inhibitors. Corrosion inhibitors are divided into two categories according to origin: organic and inorganic.[Hossain et al., 2021]

Inorganic inhibitors have devastating effects on both human health and the environment due to their non-biodegradability and cumulative impact on the environment. Therefore, their use is limited, and instead, natural organic inhibitors are obtained, obtained from plants, fruits, fruit skins, etc. These materials are cheap, harmless, affordable, and environmentally friendly. They are also called eco-friendly inhibitors or green inhibitors.[Popoola, 2019]

A. Etre investigated the effect of using a Khillah plant extract as a corrosion inhibitor for s x 316 steel in the HCL medium. The results showed that the presence of the extract significantly reduces the corrosion rate of steel in acid solution. The efficiency of 98.2% was obtained at a concentration of 300 ppm.[A.Y. El-Etre,2006]

A. Ostovari et al. studied Corrosion inhibition of mild steel in 1 M HCl solution by the henna extract. The maximum inhibition efficiency of 92.06% was obtained at 1.2 g/l of henna extract.[A. Ostovari et al.,2009]

T. Ibrahim et al. investigated Corrosion Inhibition of Mild Steel using Fig Leaves Extract in Hydrochloric Acid Solution. The inhibition efficiency of as high as 87% was achieved for Figleaves extract above 200 ppm.[T.H. Ibrahim et al.,2011]

A. Fidrusli et al. used Ginger extract as a green corrosion inhibitor of mild steel in hydrochloric acid solution. The experiment shows that the maximum inhibition efficiency of the 150 g/l concentration of inhibitor is 91%.[A. Fidrusli et al.,2017]

K. Haruna et al. investigated the performance of gelatin as a green corrosion inhibitor for carbon steel in an HCL medium. The synergistic effect of potassium iodide on gelatin performance was also investigated. The efficiency of 2.5 ppm gelatin was 70%, while with the addition of 0.05 potassium iodide, the efficiency increased to 84%.[K. Haruna et al.,2018]

A. Fouda et al. Investigated the Conocarpus Erectus extract as an environmentally friendly corrosion inhibitor for aluminum in a 1 M HCl solution by chemical and electrochemical methods. The results showed that a concentration of 300 ppm had an efficiency of 99.3%. The efficiency of Conocarpus extract increased with increasing temperature due to chemical adsorption.[Abd El-Aziz S. Fouda et al.,2021]

As mentioned earlier green inhibitors, have no dangerous effects on the environment and human health and are inexpensive, and affordable.

According to research, Conocarpus has anti-cancer, antimicrobial, anti-diabetic, antioxidant, and purifying of environmental toxins effects. It also contains flavonoids, tannins, carbohydrates, saponins, steroids, and alkaloids.[M. Bashir et al.,2015] These organic compounds contain heteroatoms such as O and N and can form coordination bonds with the empty orbitals of the iron atoms, resulting in a stable adsorption layer on the surface. Conocarpus has many resources on earth, grows in the provinces of Khuzestan, Bushehr, and Hormozgan, as well as in Saudi Arabia, West India, Mexico, West Africa, some US states, and Brazil. Therefore, it is available and inexpensive, and eco-friendly.[M. Javidan et al.,2022]

In this study, the effect of using Conocarpus extract as an affordable novel green inhibitor in the HCL medium used for acidizing, on the corrosion performance of mild steel was investigated. EIS, PDP, and FTIR methods have been used to evaluate the extract's effectiveness. The surface of the metal is also examined by scanning electron microscope (SEM).

2. Experimental methods

2.1. Extraction

Conocarpus leaves were picked, washed, dried and powdered then used for extraction. In this study, the Soxhlet method was used for extraction, and 96% ethanol was used as a solvent. After extraction, the extract was placed under the hood to evaporate and the extract thickens.

2.2. Sample preparation

In this study, the working electrode used in electrochemical tests was obtained by cutting a thin Mild Steel rod. The area of the piece was 0.9 x 1cm, was covered with polyester resin, and after 6 hours, it was washed with distilled water; and dried; finally, the surface of 0.9 cm was not covered for exposure to the solution remained. Then the surface was sanded with sandpaper from number 120 to 1000, and then it was used as a working electrode. Also, a graphite electrode was used as the counter electrode; a Saturated Calomel electrode was used as the reference electrode. The sample used for SEM was also obtained by cutting a mild steel coupon. The chemical compounds of mild steel used in this research are given in Table 1.

It should be noted that before performing all the tests, the piece was immersed in the solution for 20 minutes with the open circuit potential to achieve a steady-state.

2.3. Solution preparation

The solution was prepared using 37% pure HCl acid with distilled water. In all experiments, 1 M HCL solution was used.

2.4. Methods

2.4. a. Potentiodynamic polarization (PDP)

PDP test was performed using a 3-electrode cell (Mild Steel piece as working electrode, graphite rod as counter electrode, Calomel electrode as reference electrode) and Potentiostat–Galvanostat model Auto lab controlled by a PC equipped with the GPES Software). The potential scan range was -800 mVSCE to -200 mVSCE with respect to the open circuit potential. Then, from the obtained diagrams, corrosion current density, corrosion potential, anode and cathode branch slope, and polarization resistance were obtained, and corrosion rate and efficiency were calculated.

2.4. b. Electrochemical impedance spectroscopy (EIS)

The EIS test was performed with an auto lab device (Potentiostat PGSTAT302N) and frequency response analysis software (FRA). The impedance diagram was obtained by the device in the frequency range of 100 kHz to 10 mHz, and the wavelength range of 5mV. Laboratory data were fitted with Randle's equivalent circuit and ZView software, and then the impedance and extract efficiency parameters were obtained.

2.4. c. Scanning electron microscope

To provide helpful information about surface morphology and corrosion products, the corrosion analysis of the mild steel sample surface in HCl acid solution with and without inhibitor was investigated by the SEM method. SEM test was performed with TESCAN Mira3 apparatus.

2.4. d. Fourier transform infrared spectroscopy (FTIR)

FTIR analysis was used to confirm the results of polarization and impedance methods and determine the functional groups of Conocarpus extract. The FTIR test was performed using a spectrum RXI device.

3. Result and discussion

3.1. Potentiodynamic polarization

Figure 1 shows the polarization diagram in the presence and absence of different concentrations of the Conocarpus extract at different temperatures. The corrosion parameters obtained from the polarization diagram, including potential corrosion E_{corr}, corrosion current density i_{corr}, the anodic and cathodic slope of Tafel βa and βc, polarization resistance Rp are given in Table2. Equations1 and 2 were used to calculate the efficiency (E%) and surface coverage (θ).[Popoola, 2019]

$$E\% = \frac{i^0corr - i^1corr}{i^0corr} \times 100 \quad (1)$$

$$\theta = \frac{i^0corr - i^1corr}{i^0corr} \quad (2)$$

The polarization resistance is calculated from the Tafel diagram using the Stern-Gray formula:

$$R_P = \frac{\beta_a * \beta_c}{2.303(\beta_a + \beta_c) i_{corr}} \quad (3)$$

It can be seen from Figure 1 that the cathodic and anodic currents density has decreased in the presence of Conocarpus extract, resulting in a reduced corrosion rate. It can be seen from Figure 1 that this effect has increased with increasing concentration. These results indicate that adding plant extract reduces anodic dissolution and prevents hydrogen reduction. Also, with the addition of extract, the corrosion potential changes to more negative values (along with a decrease in the corrosion current density), indicating the adsorption of extract molecules on the metal surface and the formation of a protective layer. According to Table 2, the maximum potential change is less than 85 mV, so the inhibitor is of the mixed type, and the inhibitor function occurs by blocking sites on the surface. Based on the charts, the addition of the extract has changed the diagram in the cathodic direction of the TOFEL diagram, and the potential has also changed to more negative values; therefore, the performance of Conocarpus extract is of mixed type with cathodic predominance.[Popoola, 2019; Moradi, 2017]

The maximum efficiency of 93% was obtained for the concentration of 1925 ppm of Conocarpus extract. The inhibitory efficiency for concentrations above 1925 ppm remains almost constant due to the metal surface being covered with inhibitory molecules. M. H. Mahross investigated Rice Straw Extract as an Environmental Waste Corrosion Inhibitor on Mild Steel in an Acidic Media and obtained a maximum efficiency of 59.8 % for maximum concentration.[M. H.Mahross,2016]

T. H. Ibrahim analyzed fig leaf extract for mild steel in HCL medium and obtained 87% efficiency for 400 ppm concentration.[T. H. Ibrahim et al.,2011]

3.2. Electrochemical impedance:

Figure 2 shows the Nyquist diagram for different concentrations of Conocarpus extract in an HCL medium. Based on Figure 2 it is obvious that the graph consists of a capacitance semicircle (meaning that there is a time constant) which indicates that the corrosion process is controlled by the charge transfer. Also, the similarity of the general shape of Nyquist diagrams for different extract concentrations suggests that the corrosion mechanism does not change due to the addition of extract.[Ostovari et al., 2009]

With the addition of extract, the diameter of the semicircle increased compared to the blank solution. It can be seen that the increase in the diameter of the graph(R_p) has increased with increasing concentration. This is due to the adsorption of inhibitory molecules on the metal surface and forming a resistant film layer, which increases with increasing concentration.[Ibrahim et al., 2011]

The experimental data were well fitted, and the equivalent circuit components were calculated. The efficiency and surface coverage were also obtained from Equations 4, 5:

$$\%\eta_E = \frac{R_p^1 - R_p^0}{R_p^1} \times 100 \tag{4}$$

$$\theta = \frac{R_p^1 - R_p^0}{R_p^1} \tag{5}$$

$R_p{}^0$, $R_p{}^1$ = polarization resistance values in the presence and absence of extract.

Table 3 represents the impedance parameters for corrosion of mild steel in 1 M HCL solution with and without different concentrations of Conocarpus. It can be seen from the table that with the addition of extract, R_p increased and C_{dl} decreased. The maximum R_p value was 299 for a 2500 ppm concentration of Conocarpus extracts. The increase in resistance is the adsorption of inhibitory molecules on the metal surface and forming a corrosion-resistant layer. The decrease in C_{dl} can be due to 3 reasons: 1) reduction of local dielectric constant and, or increase in the thickness of the double layer. 2) Inhibition of the metal surface has occurred due to the adsorption of inhibitors and the replacement of water molecules with inhibitor molecules. 3) Increased surface coverage has increased inhibitory performance.[Popoola, 2019]

An increase in n values was observed with increasing the concentration of Conocarpus extract. n is a criterion for surface homogeneity; it means that the metal surface has become more homogeneous by increasing the concentration and absorbing it on the surface and preventing corrosion.[Moradi, 2017]

Increased efficiency is observed with increasing concentration. The maximum efficiency was 90% for a concentration of 2500 ppm.

N.A. Odewunmi investigated watermelon rind extract for mild steel in HCL and H2SO4 by electrochemical methods. Maximum efficiency of 83% was achieved in HCL medium and 77% in H2SO4 medium for a concentration of 2 g / L.[N.A. Odewunmi et al.,2015]

3.3. Effect of temperature

The increased temperature speeds up the reactions. Corrosion reaction is also one of the reactions that occur faster with increasing temperature.[mitreh,2018]

A polarization test was performed at 25, 55, and 85 ° C to determine the corrosion changes with increasing temperature. Figure 2 shows the polarization diagram of mild steel in a 1 M HCl medium with and without 3 concentrations of Conocarpus extract at different temperatures. Polarization parameters at different temperatures are also given in Table 2. Based on Figure 2, with increasing temperature, corrosion current density and corrosion rate increase, polarization resistance and efficiency decrease. The corrosion current density increases with increasing solution temperature, while the corrosion current density decreases with the addition of extracts to the acidic solution at the tested temperatures.

The reason for this behavior can be explained as follows: the inhibitor was adsorbed on the surface, and the repulsion of the adsorbed inhibitor molecules occurred as a result of increasing temperature, which caused the surface of the metal to be more exposed to an acidic environment, so expanding the Dissolution rate of metal has increased current density and reduced efficiency for 55°C.[Kadhum et al., 2014]

Increasing the temperature to 85°C slightly increased the efficiency of all three concentrations of Conocarpus extract compared to 55°C. This result indicates that Conocarpus extract can prevent corrosion at all tested temperatures, and its performance has not decreased with increasing temperature. Based on the table5, it is obvious that the adsorption of the extract on the surface was a combination of physical and chemical adsorption; it can be said that the adsorption occurred physically at room temperature and 55 ° C. At 85 ° C, physical and chemical adsorption coincided. It can be said that this is the reason for the increase in efficiency at 85 ° C compared to 55 ° C . (more absorption, higher efficiency)

To obtain activation energy E_a, the Log CR is plotted against the 1/T(Figure 3). According to Equation 6, the slope and intercept of the diagram show the value of $-E_a/2.303$ and log λ.

$$\log CR = \frac{-E_a}{2.303\ RT} + \log \lambda \qquad (6)$$

It can be seen that the addition of extract increases the activation energy of steel, which indicates the strong adsorption of Conocarpus extract molecules on the metal surface. [Goudarzi, 2011]

The presence of these materials produces an energy barrier against the corrosion reaction. Increasing the activation energy with increasing concentration indicates increased energy barriers to the corrosion reaction. Physical absorption also occurs in the early stages of the process. [Popoola, 2019; Herrage et al., 2010; Khadom et al.,2010].

The log CR / T versus 1 / T is plotted according to the Arrhenius equation(Equation 7). The slope and intercept of the diagram give $-\frac{\Delta H_a}{2.303R}$, and $\log\frac{R}{NH} + \frac{\Delta S_a}{2.303\ R}$.[Popoola, 2019]

$$\frac{\log CR}{T} = \log\frac{R}{NH} + \frac{\Delta S_a}{2.303\ R} - \frac{\Delta H_a}{2.303RT} \qquad (7)$$

Where CR= corrosion rate (mm/year), N = Avogadro number, H = Planck constant, R= gas constant, T=absolute temperature, E_a= activation energy, A = Arrhenius factor number.

A plot of log (log CR / T) against 1/T is provided in Figure 4. Table 4 also represents the calculated activation parameters. It is observed that the activation enthalpy is increased by adding the extract, indicating the presence of an energy barrier to the corrosion reaction due to the adsorption of the extract on the surface. Positive enthalpy values indicate the endothermic nature of the mild steel dissolution process.[Popoola, 2019; Singh et al., 2012; Zaafarany et al., 2010]

Negative ΔSa indicates the amount of reduction in irregularity that occurs in the movement of reactants to active states.[Popoola, 2019, tang et al., 2006]

3.4. Adsorption isotherm and thermodynamics of corrosion

Corrosion inhibition is due to the adsorption of inhibitory molecules on the metal-solution interface. This process is accompanied by a change in the potential difference between the metal and the solution due to the non-uniform distribution of electrical charges at the interface. The adsorption process is a surface-related process in which the adsorbents are transferred to the adsorbent.[Wang et al., 2020]

The adsorption of the inhibitor on the surface of the metal-solution interface is written as follows:

n H2O ads + Inhibitor(sol) → Inhibitor (ads) + n H2O (sol)

In the inhibitor adsorption process, the inhibitor replaces the water molecules initially adsorbed on the metal surface. Inhibitory adsorption occurs because the energy of the interaction between the metal and the inhibitor is more favorable than the energy between the metal and the water molecule.[Sastri, 2012]

Different models of adsorption isotherms are Langmuir isotherm, Temkin isotherm, Frumkin isotherm, Freundlich isotherm, Virial Parson isotherm, etc.

To obtain the proper adsorption isotherm, we must plot the corresponding graph according to the equation of each isotherm, using the θ values (surface coverage) and the inhibitory concentration obtained from the experiments. Then the isotherm with a correlation coefficient (R2) close to or equal to 1 can be selected as the appropriate isotherm.[Popoola, 2019]

Isotherm computation provides valuable information about the interaction of inhibitory molecules with the surface. Adsorption strength can be obtained from the adsorption isotherm, the equilibrium relationship between the inhibitory concentration on the surface and within the bulk of the solution. There are different isotherms for determining the inhibitory efficiency mentioned earlier. Whatever the adsorption isotherm, the electron density of the functional groups, polarity, and electronegativity are essential factors that determine the inhibitor efficiency.[Revie, 2011]

According to Figure5, the plot θ/1-θ versus C_{inh} leads to a straight line with a correlation coefficient of R^2=1, indicating that the adsorption of Conocarpus extract matches Langmuir adsorption isotherm in an acidic solution. The Langmuir isotherm equation is as follows:[Popoola, 2019]

$$\frac{\theta}{1-\theta} = K_{ads} * C_{inhibitor} \quad (8)$$

Where $C_{in\square}$ represents the inhibitor concentration, and K_{ads} is the adsorptive equilibrium constant, θ also shows the degree of the surface coverage of inhibitor molecules.

Based on the Langmuir isotherm: 1) Inhibitor adsorption is a monolayer. 2) The distribution of adsorption sites is homogeneous. 3) The absorption energy is constant. 4) Interaction between adsorbed molecules is negligible.[Wang et al., 2020]

The intercept of the adsorption isotherm diagram gives the adsorption constant (K_{ads}), used to calculate the ΔG_{ads}. To obtain ΔG_{ads}, the value of K_{ads} obtained from the isotherm diagram is placed in Equation 9.[Popoola, 2019]

$$\Delta G_{ads} = -RT\ Ln(\frac{55}{5} * k_{ads}) \tag{9}$$

Where 55.5 is the molar concentration of water in the solution (mol/L), R = universal gas constant (equal to 8.314 j/k.mol), t = temperature (K).

$$\Delta G_{ads} = \Delta H_{ads} - T\Delta S_{ads} \tag{10}$$

Also, the values of ΔH_{ads} and ΔS_{ads} are obtained according to the equation (10) by plotting ΔG_{ads} against temperature. The slope and the intercept of the chart show the values of -ΔS_{ads}, and ΔH_{ads}.[Popoola, 2019] (Represented in Figure 6)

The calculated adsorption parameters are shown in Table 5.

A negative ΔG_{ads} value indicates that the adsorption process is spontaneous, and a stable, protective layer is formed.[Fontana, M.1987; Singh et al., A.,2012] ΔG_{ads} less than -20 kJ / mol represent the electrostatic force between the charged molecules of the Conocarpus extract and the charged metal, which is called the physical adsorption process. The calculated ΔG_{ads} values range from -25 to -41 Kj/mol, which means the adsorption process is a mixture of physical and chemical for Conocarpus extract molecules in 25 and 55 ̊C; in 85 ̊C, adsorption occurred chemically. chemical adsorption can be the reason for the increase in efficiency of 85 ° C compared to 55 ° C.[Popoola, 2019; Musa et al., 2011]

Based on the results, it can be seen that positive enthalpy and entropy values were obtained. The positive value of ΔH_{ads} indicates that the adsorption process of the Conocarpus extract was endothermic.[Popoola, 20195, Olasehinde et al., 2012]

The positive value of ΔS_{ads} also demonstrates that the adsorption process on the metal surface is increased by increasing entropy.[Popoola, 2019, Lazarova et al., 2002]

3.5. Scanning electron microscope (SEM)

SEM analysis was used to evaluate the corrosion of Mild Steel surface in solution with and without Conocarpus extract. Figures 7 a-b show the results of SEM immersion of Mild Steel in 1M HCL solution with and without Conocarpus extract for 72 hours. It is clear from the image that the piece's surface is heterogeneous and open holes are visible (marked with an arrow). Also, the deposits from corrosion have accumulated on the surface, and are severely damaged. Figure 7b shows that by adding Conocarpus extract, the sample's surface is more homogeneous, uniform, and with fewer open holes.

Figures7b compared to a shows that the corrosion has decreased due to the addition of extracts. This suggests that the extracts protected the surface by adsorption on it, forming a protective layer and preventing corrosion.

3.6. Fourier-transform infrared spectroscopy (FTIR):

Figures 8 show the result of the FTIR spectrum of Conocarpus extract.

Figure8 shows a broad peak at 3395 cm^{-1}, corresponding to the vibrational mode of stretching the N-H or O-H bond. A smaller peak at 2931 cm^{-1} corresponds to the vibrational mode of stretching the C-H, N-H, and O-H bonds. The narrow peak at 1724 cm^{-1} belongs to the stretching mode of the C=O bond. The 1621 cm^{-1} narrow peak is related to the stretching mode of C=C or N-H bonds. The bending mode of the O-H bond and the stretching of the S=O and the N-O belong to the small peak of 1346 cm^{-1}. C-N and C-O stretching modes are observed at the peak of 1288 cm^{-1}. The 1046 cm^{-1}wide peak belongs to the stretching mode of S=O, CO-O-CO bonds. The small peaks of 877 and 775 cm^{-1}also belong to the bending mode of the C-H bond. The 631 cm^{-1}peak also belongs to the stretching mode of C-Br and C-I bonds**.**

The results of the FTIR test demonstrate that Conocarpus extract has heteroatoms such as O, N, and S, so Conocarpus extract has the potential to prevent corrosion. As mentioned earlier, heteroatomic compounds bond with the empty orbitals of iron atoms, forming an adsorbed layer on the surface, which can prevent deterioration of the metal surface in an acidic environment.[Guo et al., 2021]

4. Conclusions

1. Conocarpus extract prevented corrosion of Mild Steel in 1 M HCl medium. In the presence of 1925 ppm, the maximum efficiency of 93% was obtained.
2. Conocarpus extract was tested at 3 concentrations, and it was found that the highest efficiency belongs to 1925 ppm. this concentration is optimum, and with an increasing concentration above this amount, corrosion rate and efficiency are almost constant.
3. The performance of the PDP and EIS methods is compatible. In both methods, the efficiency of Conocarpus extract increased with increasing concentration.
4. The polarization method proved that the Conocarpus extract used was of the mixed type, which prevented both the dissolution of the anode and the reduction of hydrogen at the cathode, With cathodic predominance.
5. In the impedance method, the addition of extract increased the polarization resistance R_p and decreased the C_{dl} due to the adsorption of the extracts on the surface and the creation of a protective film layer.
6. The value of n increased with the increasing concentration of Conocarpus extract, which means that the metal surface is more homogeneous.
7. According to the polarization method, the adsorption of Conocarpus extract on the surface of Mild Steel in a 1 M HCl medium is consistent with the Langmuir adsorption isotherm. ΔG values proved that the adsorption of the extract on the surface was spontaneous, and a protective layer was formed. A combination of physical and chemical absorption occurred. From the obtained enthalpy and entropy values, it is concluded that the adsorption is exothermic, and with increasing entropy, the adsorption increase.
8. SEM test demonstrates that by adding the Conocarpus extract, the surface is more uniform, and the intensity of corrosion is reduced due to the absorption of the extracts on the surface.
9. FTIR test showed that the good inhibitory properties of Conocarpus extract are due to the presence of heteroatoms such as O, N, and S and the reaction between heteroatoms and the metal surface.

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