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Anti-Corrosive Properties of *Salvadora oleoides* and *Pennisetum typhoideum* Extracts Against Mild Steel in Acidic Environment

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Abstract: Corrosion causes the collapse of metallic structures such as bridges, buildings, and overpasses, as well as explosions in chemical industries. For the development of green corrosion inhibitors with using plants parts extract (leaf, root and stem) of Salvadora oleoidesandPennisetum typhoideumplants represent a significant advancement in sustainable materials science and environmental protection.The effectiveness of corrosion inhibition was investigated using potentiodynamic polarisation, thermometric approaches as well as surface analysis by SEM photograph.

The low entropy and negative enthalpy values of the system, which show less randomness and more adsorption of the plant elements, clearly show that the corrosion process is exothermic.The values of free energy (ΔG_{ads}) of adsorption for all the systems studied lie between -14.21561and -36.94375kJ mol^{-1} signifying spontaneous adsorption of the additives on the metal surface primarily due to physisorption.The SEM images of steel after immersion in 0.1 N HCl for 24 hours with 500 ppm concentration of plants parts extracts. The SEM images of untreated metal surface indicate the smooth metal surface, whereas SEM images of without inhibitor in acid solution exhibited manifest immense roughness with pits and cracks in structure which indicate that steel surface has been adversely affected. Finally conclude that, the present investigation has been effectively shown that plant extract is a corrosion inhibitor for steel in the presence of hydrochloric acid.
Keywords: Corrosion, Salvadora oleoides,Pennisetum typhoideum,potentiodynamic polarisation, physisorption.

I. INTRODUCTION

The International Union of Pure and Applied Chemistry (IUPAC) has defined corrosion as an environment-dependent, irreversible interfacial material interaction that leads to the consumption or dissolution of materials. The formation of an oxide layer on the surface of a metal or alloy is another method to conceptualise corrosion as a redox process[1]. Therefore, moisture and oxygen are required for it to occur.A comprehensive study conducted by the National Association of Corrosion Engineers (NACE) across various nations revealed that the annual worldwide economic impact of corrosion is approximately 5 % of the global Gross Domestic Product (GDP). Corrosion also causes the collapse of metallic structures such as bridges, buildings, and overpasses, as well as explosions in chemical industries. In India, corrosion is estimated to cause losses of Rs. 2 lakh crore (Rs. 2 trillion) annually.

The development and application of green corrosion inhibitors represent a significant advancement in sustainable materials science and environmental protection. These environmentally acceptable substitutes for conventional corrosion inhibitors have shown to be very effective at minimizing the negative effects on the environment while reducing metal degradation. The continuous advancement and extensive use of green corrosion inhibitors will be essential in supporting environmentally friendly production methods[2].

Green corrosion inhibitors, particularly those derived from plants, are gaining significant interest due to their safety and environmental benefits. They are safer to handle, gentler on the environment, and offer a distinct advantage over traditional inhibitors. With their inherent chemical diversity, plant extracts create a synergistic effect that produces a more complete and effective corrosion inhibition mechanism.

The present research article deals with the corrosion inhibition action of ***Salvadora oleoides***and*Pennisetum typhoideum*plants parts extract (leaf, root and stem) on the corrosion of steel sheet in an acidic medium. The effectiveness of corrosion inhibition was investigated using potentiodynamic polarisation, and thermometric approaches as well as surface analysis by SEM photograph.The effectiveness of different plant extracts in prevention of corrosion is slightly dependent on the inhibitors ability to attach on the metal surface.

II. METHODOLOGY

The report offers a thorough explanation of the research study's methodology. Since inhibitors work to create molecular barriers against water damage, their application is one of the best methods for preventing corrosion. Green inhibitors work by preventing either the cathodic or anodic reactions, or both, and comprise heteroatoms such as N, O, S, and P. Key takeaways from the Methods section include[3]:

Steel was selected as the test metal, and acidic solutions (0.1 N HCl) were used since they are typical industrial settings that cause corrosion problems. Two plants provided the plant extracts that were utilised as corrosion inhibitors:*Salvadora oleoides*and *Pennisetum typhoideum*.

The leaves and other part were dried, powdered, and extracted using ethanol. Pure plant extracts were then obtained by treating the extracts with activated charcoal.Plant extract inhibitor solutions were made in distilled water at several doses (50, 100, 200, and 500 ppm).

Thermodynamic metrics such as the enthalpy of adsorption (ΔH°ads), entropy of adsorption (ΔS°ads), and free energy of adsorption (ΔG°ads) were assessed from the temperature investigations to shed light on the spontaneity and characteristics of the adsorption process.According to Gibbs – Helmholtz equation,

$\Delta G^0_{ads} = \Delta H^0_{ads} - T\Delta S^0_{ads}$

Where, ΔG^0_{ads} = Change in free energy of adsorption;

ΔH^0_{ads} = Change in enthalpy of adsorption

ΔS^0_{ads} = Change in entropy of adsorption

The free energy of adsorption (ΔG^0_{ads}) was demonstrated as an indicator of temperature. The intercepts on the free energy axis indicate the corresponding (ΔH^0_{ads}) change in enthalpy, and the slopes of these lines equal ΔS^0_{ads}.

The corrosion current density (icorr) values were obtained by Tafel extrapolation after the open circuit potential was established and the specimen potential was scanned through a range for anodic, cathodic, and combined anodic and cathodic polarisation.The percentage inhibition efficiency (η%) by Tafel method was calculated by using the equation[4].

$$\text{Inhibition Efficiency } (\eta\%) = \frac{i^0_{corr} - i_{corr}}{i^0_{corr}}$$

Where i^0_{corr} and i_{corr} are the values of corrosion current density when inhibitors are present and absent, respectively.

SEM surface morphology experiments were performed to examine how the steel coupons surface composition changed following exposure to the inhibited and uninhibited acid solutions[5].

III. RESULTS AND DISCUSSION

By employing thermodynamic and kinetic characteristics obtained from standard thermodynamic theories, it was shown that the corrosion inhibition process was spontaneous, with a negative free energy value and a drop in entropy with increasing extract concentration[6].

The corrosion inhibition performance of *Salvadora oleoides*and *Pennisetum typhoideum* plant extracts was tested against the corrosion of steel in 0.1 N HCl solutions at 298 K.The low entropy and negative enthalpy values of the system, which show less randomness and more adsorption of the plant elements, clearly show that the corrosion process is exothermic. To determine the nature of the adsorption process, thermodynamic parameters including enthalpy (ΔH), entropy (ΔS), and Gibbs free energy of adsorption (ΔGads) were computed.

Table:Kinetic-Termodynamic parameters for steel corrosion in 0.1 NHCl without and with *Salvadora oleoides* plant parts extracts at immersion time 6 hours.

	ΔH^0_{ads} (kJ/Mol)	T	**ΔS^0_{ads} (kJ/Mol)**	TΔS	**ΔG^0_{ads} (kJ/Mol)**
Leaves Extract	18.191032	298	0.10874712	32.4066418	-14.21561
Root Extract	-17.367946	298	0.01058372	3.15394916	-20.5219
Stem Extract	-22.464816	298	0.04858702	14.4789308	-36.94375

Table:Kinetic-Termodynamic parameters for steel corrosion in 0.1 NHCl without and with ***Pennisetum typhoideum***plant parts extracts at immersion time 6 hours.

	ΔH^0_{ads} (kJ/Mol)	T	ΔS^0_{ads} (kJ/Mol)	TΔS	ΔG^0_{ads} (kJ/Mol)
Leaves Extract	27.142122	298	0.14391534	42.8867713	-15.74465
Root Extract	-20.288868	298	0.0448956	13.3788888	-33.66776
Stem Extract	-18.473708	298	0.02003674	5.97094852	-24.44466

On the basis of resulted presented in Table indicate that the values of free energy (ΔG_{ads}) of adsorption for all the systems studied lie between -14.21561and -36.94375kJ mol^{-1} signifying spontaneous adsorption of the additives on the metal surface primarily due to physisorption and also a minimal involves of chemisorption[7-8].

The adsorption of inhibitor molecules on the steel surface is a spontaneous process, as evidenced by the negative values of ΔGads, which also point to a dominating physisorption mechanism[9]. This physisorption process is further supported by the low values of ΔS and the positive values of ΔH.

Various potentiodynamic polarization parameter like the value corrosion current densities (Icorr) and corrosion potential (Ecorr) are acquired for extrapolations of Tafel area of anodic and cathodic branches, cathodic (βc) and anodic (βa) Tafel constant.Electrochemical parameters such as corrosion potential (Ecorr), anodic and cathodic Tafel slopes (βa and βc), corrosion current density (Icorr) and percentage inhibition efficiency are shown in the Table.

After all, if the shift of corrosion potential (Ecorr) with addition of inhibitors concentrations is above 85 mV, than the corrosion inhibitor can be categorized as cathodic or anodic nature of corrosion inhibitor and if the shift of corrosion potential (Ecorr) is lower than 85 mV, then it is identified as mixed type behaviour of corrosion inhibitor which can affects combined anodic metal disintegration and cathodic hydrogen evolution reactions[10].

Table: Corrosion Parameters Observed in the Potentiodynamic Polarization Measurements at 500 ppm concentrations of different plant parts extract in 0.1 N HCl for steel

	-Ecorr (mV)	Icorr (µA)	βc (mV)	βa (mV)	Corrosion rate (mmpy)	η%
Steel HCl (Blank)	-690.25	1223.87	300.1	246.8	1.883 49	
Leaves extract	-671.34	968.476	265.8	195.5	1.122 66	9.63782 9
Root extract	-660.73	742.14	190	155.4	0.860 291	18.1790 9
Stem extract	-576.94	62.518	278.6	223.4	0.072 471	43.8260 6

Table: Corrosion Parameters Observed in the Potentiodynamic Polarization Measurements at 500 ppm concentrations of different plant parts extract in 0.1 N HCl for steel

	-Ecorr (mV)	Icorr (µA)	βc (mV)	βa (mV)	Corrosion rate (mmpy)	η%
Steel HCl (Blank	-690.25	1223.87	300.1	246.8	1.883 49	

)						
Leaves extract	-677.39	991.506	254.9	210.6	1.149 36	8.76874 4
Root extract	-442.99	40.709	378.4	167.2	0.047 19	44.6490 7
Stem extract	-476.89	831.52	209.4	154.5	0.963 906	14.8061 5

The SEM images of steel in corroded condition and after immersion in 0.1 N HCl for 24 hours with and without 500 ppm concentration of plants parts extracts. The SEM images of untreated metal surface indicate the smooth metal surface, which indicates the absence of any corrosion product on the metal surface. It can be obviously observed that figure, manifest immense roughness with pits and cracks in structure which indicate that steel surface has been adversely affected in acid solution without inhibitor whereas corrosion has been inhibited in the presence of inhibitor[12-13].

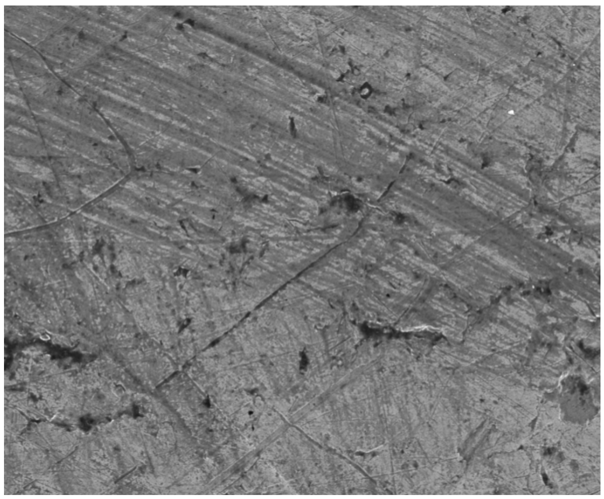

Fig- SEM image of fresh steel coupon

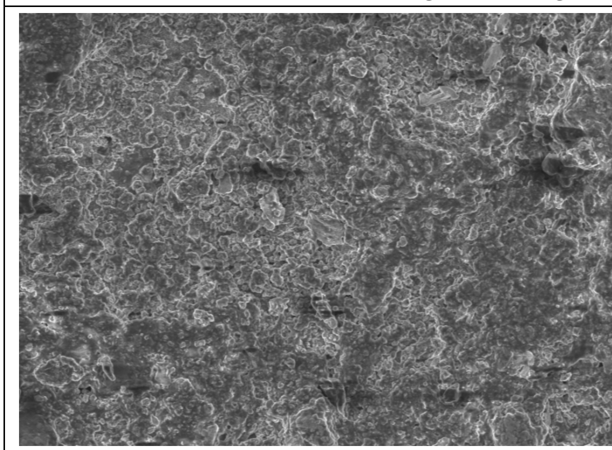

Fig- SEM image of steel coupon usingSalvadora oleoidesleaves extracts

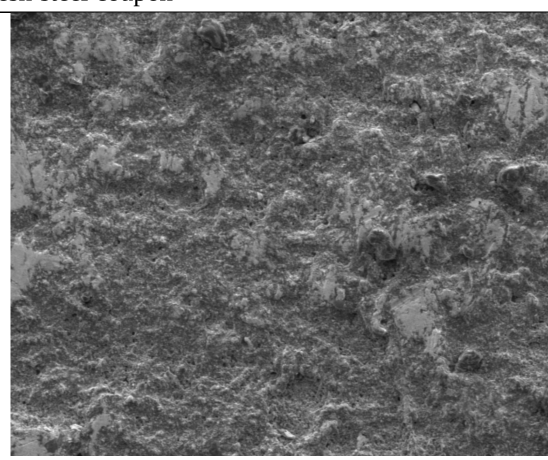

Fig- SEM image ofsteel coupon usingSalvadora oleoidesroot extracts

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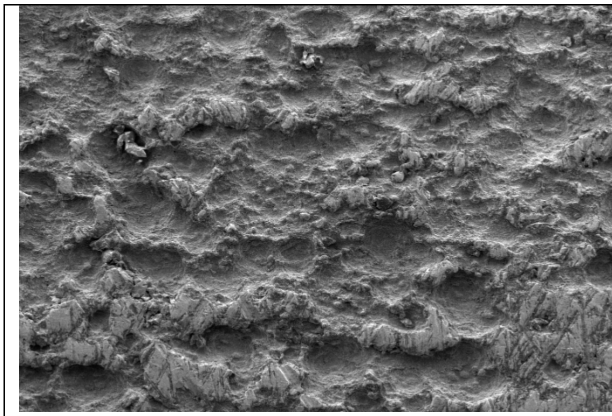	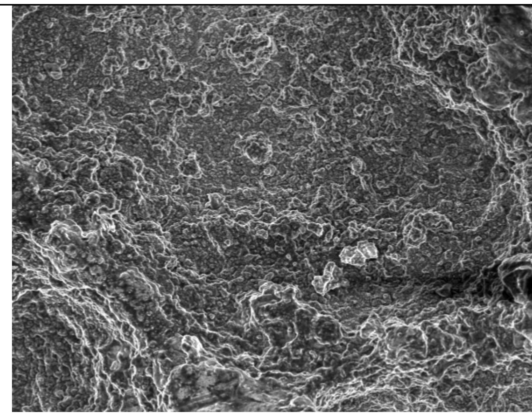
Fig- SEM image ofsteel coupon usingSalvadora oleoidesstemextracts	Fig- SEM image of steel coupon usingPennisetum typhoideumleavesextracts
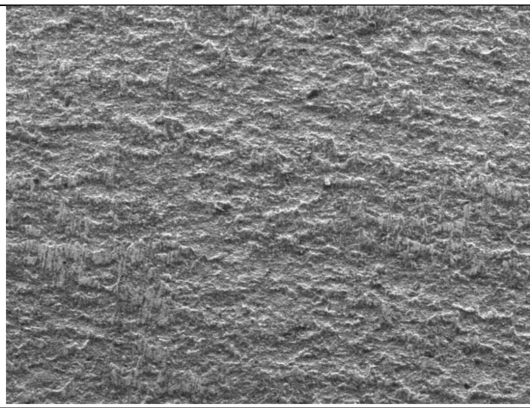	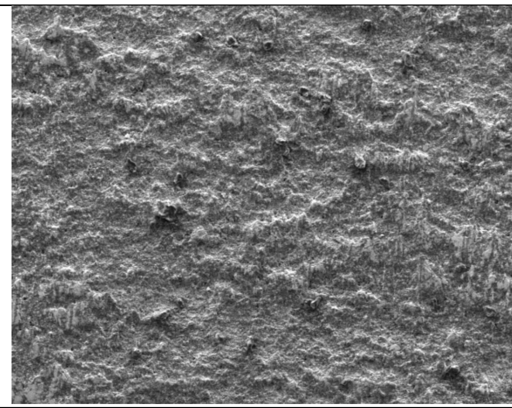
Fig- SEM image of steel coupon usingPennisetum typhoideumrootextracts	Fig- SEM image of steel coupon usingPennisetum typhoideumstemextracts

However, in the context of the weight reduction technique, inhibitory effectiveness is established after immersion durations; hence, it was discovered that the adsorption capacity of the inhibitor chemical on the metal surface increased with longer immersion lengths.In conclusion, the present investigation has effectively shown that plant extract is a corrosion inhibitor for steel in the presence of hydrochloric acid.

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