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RESEARCH ARTICLE

Corrosion Inhibition by *Musa paradisia ca* Peel Extract for SS 304 in 1 M Hydrochloric Acid Solution

Jeeni Patel[1], Dhara D Patel[1]*

1 Department of Chemistry, Sankalchand Patel University, Visnagar, Gujarat, India

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* **Corresponding author**.

dr.dhara29@gmail.com

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Abstract

Objectives: To study the corrosion inhibition of *Musa paradisiaca* peel (MPP) extract for stainless steel (SS) 304. **Method:** The corrosion rate of stainless steel was studied by weight loss measurements in a 1 M hydrochloric acid solution at different concentrations of MPP inhibitor and at various temperatures, e.g., 298 K, 303 K, and 308 K. Scanning electron microscopy (SEM) was used to study the morphology of the films created on the stainless steel surface in various immersion media at various immersion times. Both potentiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS) examined inhibition efficiency. Langmuir adsorption isotherm studied inhibitor surface adsorption SS 304. **Findings:** The corrosion rate and inhibition efficiency depend on the concentration of the inhibitor and the temperature. When there is an increase in the concentration of the inhibitor, inhibition efficiency increases, e.g., at 50 mg/l concentration, 77% inhibition efficiency, and at 200 mg/l concentration, 87% inhibition efficiency at 298 K. When temperature increases, inhibition efficiency decreases, e.g., at 200 mg/l concentration, 87% at 298 K, 85% at 303 K, and 83% at 308 K. **Novelty:** This article provides an eco-friendly corrosion inhibitor for stainless steel 304. *Musa paradisiaca* peel extract inhibitor was previously used for iron, mild steel, and carbon steel but was not used for stainless steel 304 in 1 M HCl.

Keywords: Corrosion; Stailess stell; Inhibitor; Acid

1 Introduction

Steel is globally used in various applications in industries like oil well acidification, acid cleaning and processing, acid pickling and descaling, etc.[1]. In all anticorrosive methods, organic corrosion inhibitors containing polar groups of synthesized molecule structures can behave as working centers, and heteroatoms such as nitrogen, oxygen, and sulfur that play a major role in the absorption of the inhibitor on steel surfaces are used as effective corrosion inhibitors, but they are hazardous for the environment and animals[2]. Corrosion inhibitors are materials that form a layer of metal in a corrosive medium to slow metal corrosion. Alternatively, green corrosion inhibitors are considered eco-friendly, low-cost, and effective corrosion inhibitors[3,4]. The inhibitive properties of leaf extracts of *Acalypha torta*, bamboo, *Colocasia esculenta, Ficus tikoua, Geissospermum* sp., *Ginkgo* sp., *Glycyrrhiza glabra, Emblica officinalis*, and olive have been used as green corrosion inhibitors for mild steel and carbon steel in acidic solutions[5,6]. There are reports on the use of *M. paradisiaca* peel extract as an inhibitor of corrosion for iron, mild steel, and carbon steel in a different medium of solution[7]. Previous studies of this plant by various experiments found the presence of bioactive compounds such as catechin, gallocatechin, dopamine, and ascorbate. *M. paradisiaca* peels are attractive for corrosion inhibition studies because of their easy availability, free cost, and green value. *M. paradisiaca* peel extract was evaluated for stainless steel 304 in 1 M hydrochloric acid medium by applying the following methods: SEM-scanning electron microscopy, PDP-potentiodynamic polarization, and EIS-electrochemical impedance spectroscopy. The adsorption behavior between the corrosion inhibitor and the metal surface was studied by the Langmuir adsorption isotherm.

2 Methodology

2.1 Material Detail

The SS 304 electrode was prepared from the chemical composition of Fe, rest; Ni, 8.12; Cr, 18.06; Mn, 1.74; Si, 0.35; C, 0.065; S, 0.012; Mo, 0.149; Cu, 0.233; and P, 0.028 (wt%). The preparation of a 1 M hydrochloric acid solution by 37$^{\%}$ hydrochloric acid with purified water at ambient temperature.

2.2 Preparation of MPP extract solution:

Musa paradisiaca peel tissue was collected in distilled water, boiled for 15 minutes, and homogenized using a pestle mortar in acetone and water. *M. paradisiaca* peel was homogenized for 2 days at 298 K. Hence, the solution was filtered, centrifuged, and concentrated in an evaporator for 24 hours. Then the *M. paradisiaca* peel powder was obtained, and 10 ml of purified water and 1 g of *M. paradisiaca* peel powder were made in solution and used for the study of corrosion on metal[8].

2.3 Weight loss measurements

The calculation of the weight loss experiments for the stainless steel 304 immersed in 1 M HCl with the presence and absence of *M. paradisiaca* peel extracts at different temperatures. After absorption, the stainless steel samples were removed from the acidic medium, cleaned with water and acetone, dried, and weighed. The difference in the weight of the stainless steel specimens before and after immersion was recorded by an electronic weight balance. To confirm precision in measurements, four sets of the samples were used to accumulate information on various concentrations, e.g., 50 mg/l, 100 mg/l, 150 mg/l, and 200 mg/l at 298 K, 303 K, and 308 K temperatures[9].

3 Result and Discussion

3.1 Surface analysis by SEM

SEM analysis is regularly carried out with the immersion of the specimen in a corrosive solution in the absence and presence of inhibitors to examine the surface morphology of metal[10–12]. Figure 1 indicates the morphology of the SS surface plunged in 1 M HCl at room temperature in the absence and presence of the inhibitor at various concentrations. To allow other perceptions into the sample formed by the adsorption of the inhibitor molecule on the SS surface. As Figure 1 shows, before immersion, stainless steel had a flat plane (Figure 1**A**). However, it damaged, corroded, and became a rougher and deeper crack in the corrosive solution without an inhibitor caused by the metal dissolution in an acidic solution (Figure 1**B**). In contrast, in the presence of the inhibitor, when the inhibitor concentration increases, the SS plane is improved in appearance, as observed in images of SEM (Figure 1 **(C, D, E, F**)). We observe the protective film formation of inhibitors around the SS, which protects the SS against the acidic medium.

3.2 Potentiodynamic Polarization (PDP)

Figure 2 shows PDP plots for SS in 1 M hydrochloric acid medium with different concentrations of MPP inhibitors. Electrochemical kinetic variables values, such as the potential of corrosion (E_{corr}), current density of corrosion (I_{corr}), Tafel slopes of anodic and cathodic (βa and βc), and percentage of inhibition efficiency (η%)[13–15], which were concluded from polarization curves at different temperatures like 298 K, 303 K, and 308 K, are listed in the table. Figure 2 illustrates the polarization diagram of cathodic and anodic SS 304 in a 1 M hydrochloric acid solution in the absence and presence of concentrations of MPP inhibitors. The MPP inhibitor addition shifted anodic and cathodic lines, so the MPP inhibitor can

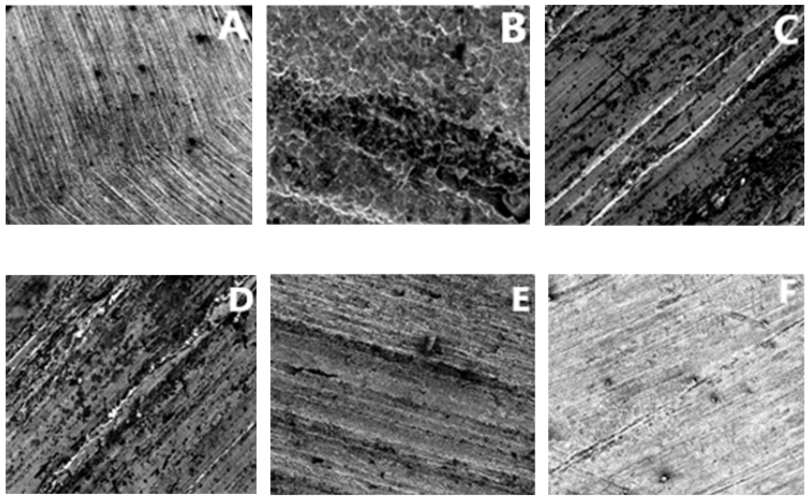

Fig 1. SEM images of SS 304 immersed (A) without HCl, (B) in 1M HCl, (C) 50 mg/l in 1 m HCl, (D) 100 mg/l in 1 M HCl, (E) 150 mg/l in 1 M HCl, (F) 200 mg/l in 1 M HCl

be considered a mixed-type inhibitor at each temperature. Table 1 shows that when the current density of corrosion (I_{corr}) decreases, the MPP inhibitor concentration increases. We observed anodic (βa) and cathodic (βc) tafel slope changes when we added MPP inhibitors and the anodic and cathodic kinetic processes were studied by the MPP inhibitors in the acidic solution.

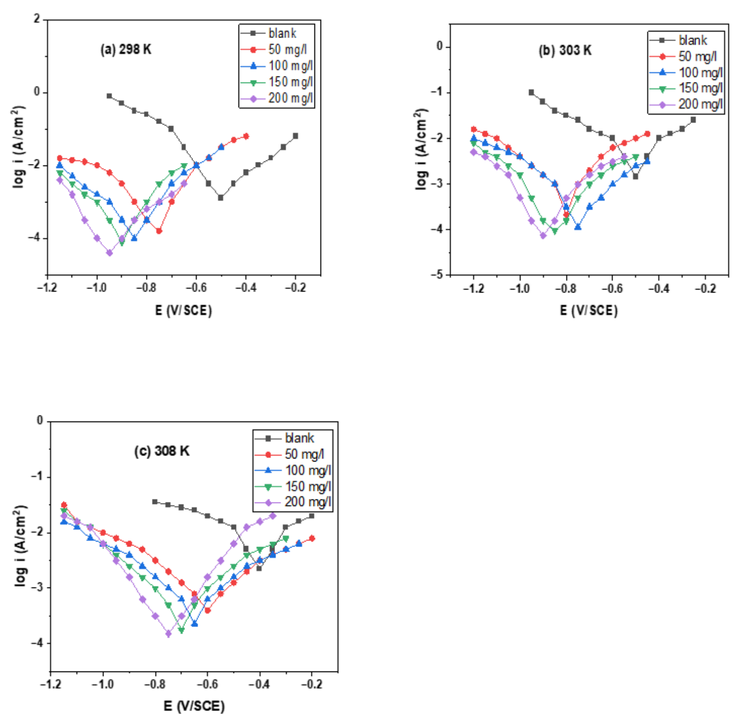

Fig 2. Polarisation diagram of SS 304 in 1 M hydrochloric acid medium with the different concentrations of MPP inhibitor at different temperatures: (a) 298 K (b) 303 K (c) 308 K

Table 1. Potentiodynamic polarisation diagram of electrochemical variables for SS 304 in 1 M hydrochloric acid medium with and without various concentrations of MPP inhibitor at various temperatures

T (K)	C (mg/l)	E_{corr} (mV/ SCE)	I_{corr} (μA cm−2)	β_a	$-\beta_c$	η%
	Blank	-532	1281	44	552	-
	50	-754	168	67	310	77
298	100	-854	92	61	253	83
	150	-910	74	69	206	84
	200	-943	38	43	208	87
	Blank	-476	1443	42	524	-
	50	-809	216	125	185	75
303	100	-765	114	82	221	82
	150	-843	95	80	172	83
	200	-865	76	78	173	85
	Blank	-421	2249	47	1355	-
	50	-610	398	172	183	72
308	100	-621	228	109	188	80
	150	-698	178	112	191	82
	200	-721	148	98	181	83

3.3 EIS measurements

EIS is a genuine and implied method for screening corrosion inhibitors. It provides details regarding plane properties and electrode kinetic processes, and this method is significantly effective for inquiring into corrosion inhibition processes. In the electrochemical study of polarization, we have to understand further techniques, such as impedance spectroscopy. The EIS study is more precise for the corrosion inhibition of steel compared to the other methods because it gives many electrochemical parameters more precisely[16–18]. Figure 3 shows the Nyquist diagram of SS 304 in a 1 M HCl solution containing various concentrations of MPP inhibitor at 298 K, 303 K, and 308 K, respectively. The spectra of impedance indicate one single depressed semicircle. The diameter of the semicircle increases with the concentration of the MPP inhibitor. The diameter of the semicircle decreases with an increase in temperature. These results communicate the formation of a film of inhibitor-adsorption on the stainless steel surface and the increased anti-corrosive standard. Table 2 shows electrochemical parameters for impedance, for example, the resistance of solution (R_s), resistance of charge transfer (R_{ct}), the capacitance of the double layer (C_{dl}), deviation parameter (n), and inhibition efficiency (η%).

Table 2. Impedance of electrochemical variables for SS 304 in 1 M hydrochloric acid medium with various concentrations of MPP inhibitor at different temperatures

T (K)	C (mg/l)	R_s (Ω cm^2)	R_{ct} (Ω cm^2)	n	C_{dl} (μF cm^{-2})	η%
	Blank	3.5	0.68	1.00	38.6	-
	50	1.8	4.68	1.00	27.5	86
298	100	1.7	13.15	0.97	16.6	95
	150	1.7	19.09	1.00	12.1	96
	200	1.6	27.06	0.97	10.4	98
	Blank	1.8	0.41	1.00	124.7	-
	50	1.6	2.23	1.00	65.0	84
303	100	1.8	6.56	1.00	30.1	94
	150	1.8	11.01	1.00	17.2	96
	200	1.7	15.05	1.00	15.8	97
	Blank	1.6	0.36	1.00	208.7	-
	50	1.7	1.76	1.00	47.5	80
308	100	1.6	4.10	1.00	26.6	91
	150	1.9	8.87	1.00	22.2	96
	200	1.7	12.19	0.96	15.6	97

3.4 Adsorption Isotherm

The different isothermal adsorption techniques like Temkin, Frumkin, and Langmuir adsorption, which were compared, included experimental data and explained the adsorption behavior of a steel plane and the nature of the anticorrosive molecule interaction process. The corrosion nature is studied by plant inhibitors based on molecular adsorption, and the inhibition

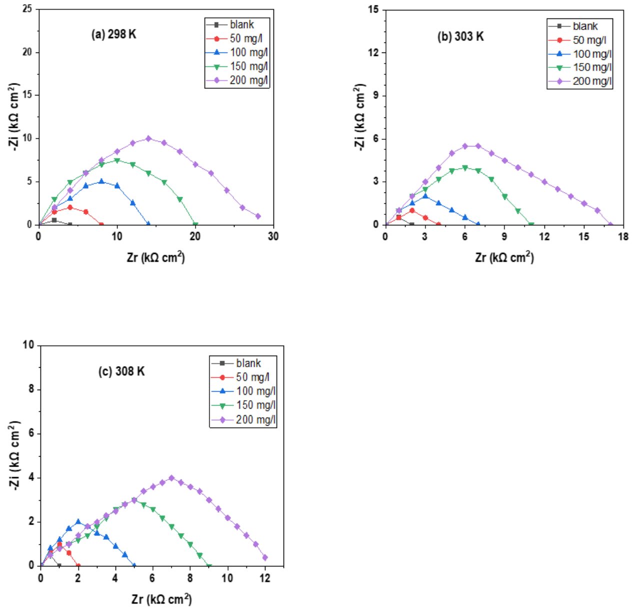

Fig 3. Nyquist diagram for SS 304 in 1 M hydrochloric acid medium with various concentrations of MPP inhibitor at various temperatures: (a) 298 K (b) 303 K (c) 308 K

of these molecules is described[19,20]. The Langmuir adsorption isotherms report was used for the adsorption types of MPP inhibitors on the surface of stainless steel. Figure 4 shows a linear line of C/θ vs. C at 298 K, 303 K, and 308 K individually. From the equation of the Langmuir adsorption isotherm, when the value of K_{ads} is higher, the MPP inhibitor tightly adsorbs on the metal plane, which indicates a good inhibitive ability.

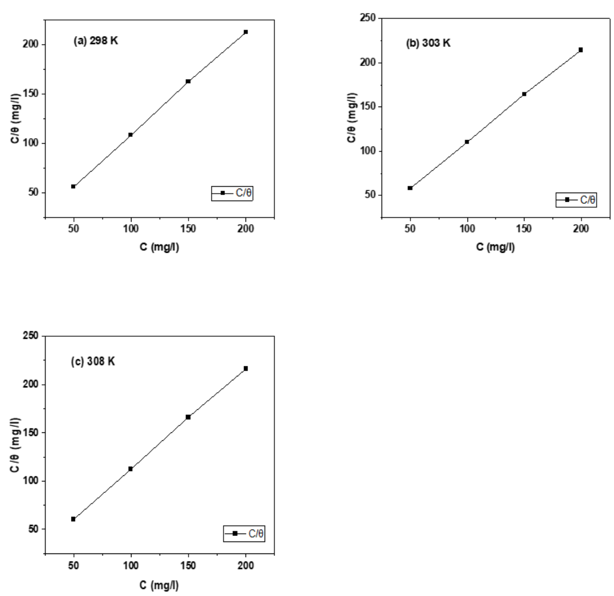

Fig 4. Adsorption isotherm of Langmuir for SS 304 in 1 M hydrochloric acid at various temperatures: (a) 298 K, (b) 303 K, and (c) 308 K

4 Conclusion

- The SEM study confirmed the formation of a protective film around the SS 304, and that's why inhibition increased.
- Polarization data specify that MPP is the mixed-type corrosion inhibitor for SS 304.
- Impedance data shows MPP inhibitors are effective corrosion inhibitors for SS 304.
- Langmuir adsorption isotherm observed chemical adsorption and physical adsorption implicated MPP adsorption on the SS 304 surface.
- The efficiency of inhibition of SS 304 in 1 M HCl increases when the concentration of the MPP inhibitor increases, e.g., when the concentration increases from 50 mg/l to 200 mg/l, inhibition efficiency increases by $10^{\%}$ at 298 K. When temperature increases, inhibition efficiency decreases; e.g., when temperature increases from 298 K to 308 K, inhibition efficiency decreases by 4% at 200 mg/l.

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