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Research Article

INHIBITION OF MILD STEEL CORROSION IN 1N HCL AND 1N H_2SO_4 BY LEAVES EXTRACT OF *GOSSYPIUM HERBACEUM*

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ABSTRACT

Inhibitory effect of ethanol extract of *Gossypium herbaceum* leaves on the corrosion of mild steel in 1N HCl and 1N H_2SO_4 has been investigated by burden Loss Method, FTIR, SEM, Potentiodynamic and Polarization measurements. The experiment by Weight Loss Method has shown that the ethanol extract of *Gossypium herbaceum* inhibits mild steel corrosion and the inhibition efficiency of the extract increases with increase in concentration and temperature. FTIR spectra were used to examine the protective layer formed on the metal surface. The Electrochemical Impedance Spectroscopy result have revealed that variation in the impedance parameters, charge transfer resistance and double layer capacitance, with the deviation in extract concentration are due to the adsorption of active molecules resulting in the construction of a protective layer on the mild steel surface. The SEM method has provided the confirmatory evidence of the safeguard of mild steel by the green inhibitor. The consequences of the study have shown that the leaf extract of *Gossypium herbaceum* exhibits fine corrosion inhibition efficiency for mild steel in both acid media.

Keywords: *Gossypium herbaceum*, Green inhibitors, Impedance, Polarization, SEM.

1. INTRODUCTION

Mild steels are used as a constructional material in our day today activities throughout the world because of its inexpensive cost and acceptable high mechanical properties. The natural products as corrosion inhibitors for different metals in different media have been reported by several authors [1-4]. Different kinds of plant extracts have been successfully used for the corrosion treatment of mild steel in HCl and H_2SO_4, and it's also been proven to be quite effective [5-6]. The present research has been carried out on the problem of mild steel protection in two frequently encountered environments in the industries. In last few decades, the research has been more focused on the formation of naturally occurring, environmentally beneficial corrosion inhibitors. Unfortunately, uses of some organic and inorganic chemical inhibitors are limited as their synthesis compounds are very expansive and for their qualities of poor biodegradability, toxic and hazardous for human beings and the environment as well [7, 8].

Plants in the *Gossypium herbaceum* family (Malvaceae) are well known for the chemical diversity of their alkaloids, phenolics, flavonoids, amino acids, carbohydrates, saponins, terpenoids, cardiac glycoside, anthraquinones and steroids constituents [9].

Gossypium herbaceum plant is very effective in indigenous system of medicine. It's a 2-8 foot tall, shrubby, hairy plant with strong woody stems and twigs, and sparsely hairy, seldom glabrous leaves. Moreover, the plant leaves are five to seven lobed, lightly thin at the part of base and the bracteoles are roughly triangular, generally wider than long, with 6-8 serrated teeth on the border. This plant flowers are little large with purple center and yellow around the flowers, the base of calyx flower is black with ovate capsules and glandular dots, pointed 4.5. The appearance of eye-rays on the corolla is a distinguishing feature of *Gossypium herbaceum*. After the fuzz removal, the seeds are dark brown or almost black coloured, pointed ovoid, and the length ranges from 5.0 to 20 mm.

Herbal medicines are gaining popularity due to their efficacy, low cost, and clinical expertise with minimal adverse effects. Orally given ethanol extracts of

Gossypium herbaceum have also been reported to lower blood glucose levels considerably. It is therefore convenient to assess the inhibitory effect of aqueous extract flower, bark, and leaf of plant on the key enzymes (α-amylase and α-glycosidase) linked to type 2 diabetes in order to provide some possible and effective mechanism of action by which they use their anti-diabetic properties [10, 11].

The aim of this study was to evaluate the inhibition effect of the ethanol extract of *Gossypium herbaceum* leaves on the corrosion of mild steel in 1N HCl and 1N H_2SO_4. In this research, the anti-corrosion potential of *Gossypium herbaceum* leaf extracts has been evaluated using Weight Loss, Tafel Polarization, Electrochemical Impedance Spectroscopy, Scanning Electron Microscopy (SEM) and FTIR spectroscopy techniques. The effect of immersion time, temperature and acid concentration on inhibition efficiency of the extract has been investigated using Weight Loss measurements. The investigation has record great potential of the *Gossypium herbaceum* leaf extract for corrosion inhibition of MS in an acidic environment.

2. EXPERIMENTAL

2.1. Preparation of the specimens

The study has been carried out by mild steel specimen of composition, C: 0.13, Si: 0.18, P: 0.39, S: 0.04, Cu: 0.025 and rest Fe. The samples have been cut into sizes with 2.5 cm × 2.5 cm × 0.4 cm and polished mechanically with different grades of emery paper to obtain very smooth surface. Afterwards, the each and every sample was degreased using acetone wash, dried at ambient temperature. Further, the samples were kept at moisture-free desiccators. For the complete study, analar grade HCl, H_2SO_4 and double distilled water have been used.

2.2. Extraction of *Gossypium herbaceum leaf* extract

Three kilograms of *Gossypium herbaceum* leaves were procured in and around Madurai and washed carefully with distilled water to eliminate any form of dirt from the leaves. The dried leaves were ground with an industrial scale grinder. Fine powder was entirely soaked in ethanol solution for 6 hours. After 6 hours, the mixture was stirred properly in order to have homogenous solution and then filtered. The filtrate was subjected to evaporation to remove the ethanol in the filtrate to have the inhibitor in its pure form. The inhibitor test solution was prepared by using respective stock solution with different concentration range from 450 to 600 ppm.

2.3. Electrochemical measurements

H and CHI electro-chemical workstation (Model CHI 604 D) was used to record the Nyquist impedance and Polarization curves. The electrodes were placed in three compartments of a cell. A test solution was used to immerse the functioning polished mild steel electrode with an exposed surface of 0.5 cm^2. The counter and reference electrodes in the study were platinum and saturated calomel electrodes (SCE), respectively. The electrode was freely permitted to corrode before electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization (Tafel) experiments and also open circuit potential was measured. Potentio-dynamic polarization curves were measured from -300 to +300 m Vsce at a scan rate of 1N Vs-1. Electrochemical impedance spectroscopy measurements were carried out at frequency range from 0.1 Hz to 100 K Hz. All the electrochemical tests were carried out at 308 K in a stationary condition with 100 ml of electrolyte (1 N H_2SO_4 and 1 N HCl). Every experiment was carried out three times to ensure that the results were reproducible.

2.4. Surface analysis studies

2.4.1. Fourier Transform Infra-Red spectroscopy (FTIR)

FTIR spectra for *Gossypium herbaceum* leaf extract and the dried product formed between finely powdered mild steel specimen and the concentrated solutions of the extract was recorded in Shimadzu-FTIR-8400S spectrophotometer.

2.4.2. Scanning Electron Microscopy Studies

Scanning Electron Microscopy (JEOL, JSM 6390) was used to evaluate the nature of the surface layer produced on the assured samples.

3. RESULT AND DISCUSSIONS

3.1. Weight Loss Measurement

Table 1 shows the weight loss data acquired on mild steel in 1N HCl and 1N H_2SO_4 in the absence and presence of GHLE at various concentrations. From the Fig.1, it is clearly shown the addition of GHLE significantly decreases corrosion rate in both the acidic media. Simultaneously, a decrease of corrosion rate and increase in inhibition efficiency confirms that GHLE adsorbs on steel surface and then inhibits the corrosion process. The inhibition efficiency of GHL extract increases with inhibitor concentration to reach higher value 91.1% in 1N HCl and 78.52% in 1N H_2SO_4 when the concentration of GHLE is only 300 ppm. This behaviour indicates that GHLE acts as an efficient inhibitor for the corrosion on mild steel in both acidic media (1N HCl and1N H_2SO_4).

The corrosion study was performed at different temperatures viz., 308, 313, 323 and 333 K and the maximum inhibition efficiency was found at 308 K. Inhibition efficiency decreases with increasing temperature and corrosion rate increases with increasing temperature and indicating that GHLE as a good corrosion inhibitor in both the acidic media.

Table 1: Inhibition efficiency and corrosion rate of mild steel specimens submerged in 1N HCl and 1N H_2SO_4 at different temperatures with and without GHLE

Test solution	Temperature (K)	Concentration (ppm)	Corrosion Rate (mpy)	Surface coverage(Θ)	Inhibition Efficiency (%)
1N HCl	308	0	0.306		
		150	0.042	0.8529	85.29
		200	0.033	0.8920	89.20
		250	0.029	0.9051	90.51
		300	0.027	0.9110	91.10
	313	0	0.379		
		150	0.163	0.5699	56.99
		200	0.146	0.6147	61.47
		250	0.131	0.6543	65.43
		300	0.105	0.7213	72.13
	323	0	0.874		
		150	0.579	0.3373	33.73
		200	0.523	0.4016	40.16
		250	0.430	0.5080	50.80
		300	0.236	0.6012	60.12
	333	0	1.508		
		150	1.121	0.2560	25.60
		200	1.036	0.3129	31.29
		250	0.912	0.3952	39.52
		300	0.698	0.5371	53.71
1N H_2SO_4	308	0	0.489		
		150	0.151	0.6892	68.92
		200	0.121	0.7525	75.25
		250	0.117	0.7607	76.07
		300	0.105	0.7852	78.52
	313	0	0.782		
		150	0.491	0.3718	37.18
		200	0.337	0.5690	56.90
		250	0.317	0.5946	59.46
		300	0.272	0.6521	65.21
	323	0	1.272		
		150	1.039	0.1831	18.31
		200	0.791	0.3781	37.81
		250	0.689	0.4579	45.79
		300	0.517	0.5932	59.32
	333	0	1.946		
		150	1.722	0.1151	11.51
		200	1.459	0.2502	25.02
		250	1.131	0.4188	41.88
		300	0.878	0.5488	54.88

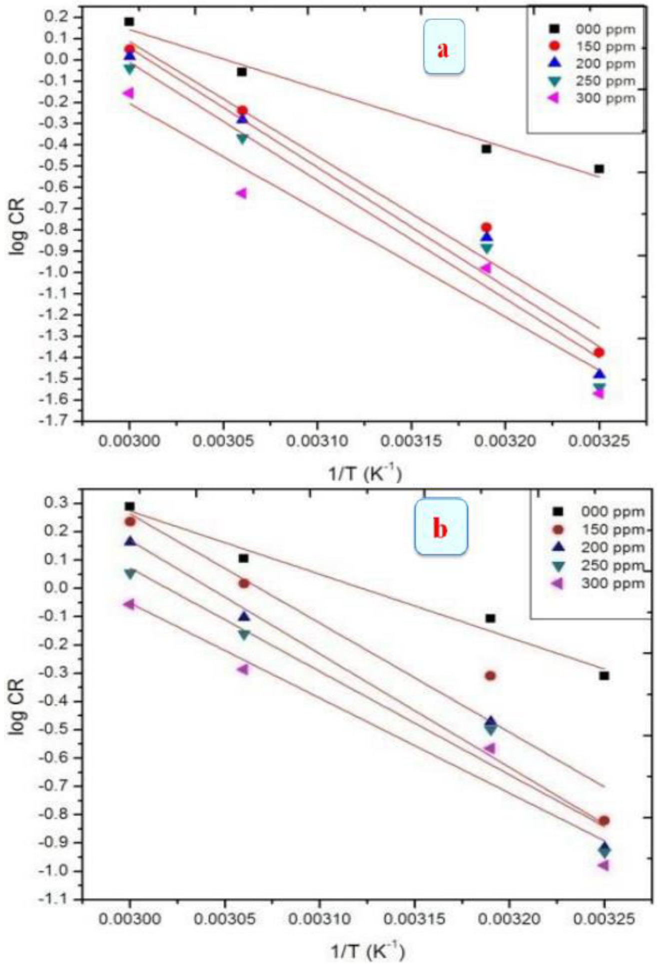


Fig. 1: Arrhenius curve of log CR vs 1/T in 1N HCl and 1N H_2SO_4 at different concentrations of GHLE

3.2. Thermodynamic studies

Thermodynamic factors of enthalpy of activation (ΔH), entropy of activation (ΔS) and apparent activation energy E_a were measured using the following Arrhenius equation for corrosion of mild steel in 1N HCl and 1N H_2SO_4 solutions in the absence and presence of GHLE at temperature range from 308 to 333 K.

$$CR = A \exp(-E_a/RT) \quad (1)$$

It is possible to derive the logarithm of both sides of the given equation.

$$\log CR = \log A - E_a/2.303\,RT \quad (2)$$

The transition state equation was used to calculate the change in enthalpy [ΔH] and entropy [ΔS] for the production of the activated complex.

$$\log CR/T = \{(\log R/hN + (\Delta S)/2.303\,R)\} - \Delta H/2.303\,RT \quad (3)$$

Herein, CR and A are the corrosion rate and pre-exponential factor, h and N are the Planck's constant and Avogadro's number, E_a is the apparent activation energy, gas constant is denoted as R (R= 8.314 J mol^{-1} K^{-1}) and T is the temperature in K.

As shown in Fig. 1, the graph plot of log CR vs 1/T of 1N H_2SO_4 and 1N HCl produced a straight line with a slope (-Ea/2.303 R) and intercept (log A).

In both media; 1N HCl and 1N H_2SO_4, the values of E_a obtained in solutions containing GHLE extracts may be regarded as physical adsorption [20]. The ΔH and ΔS were determined using the slope (-ΔH/2.303R) and intercept (log R/hN + (ΔS)/2.303 R) of the plot of log CR/T vs 1/T as shown in Fig. 2. Moreover, the calculated values of ΔH and ΔS were presented in Table 2.

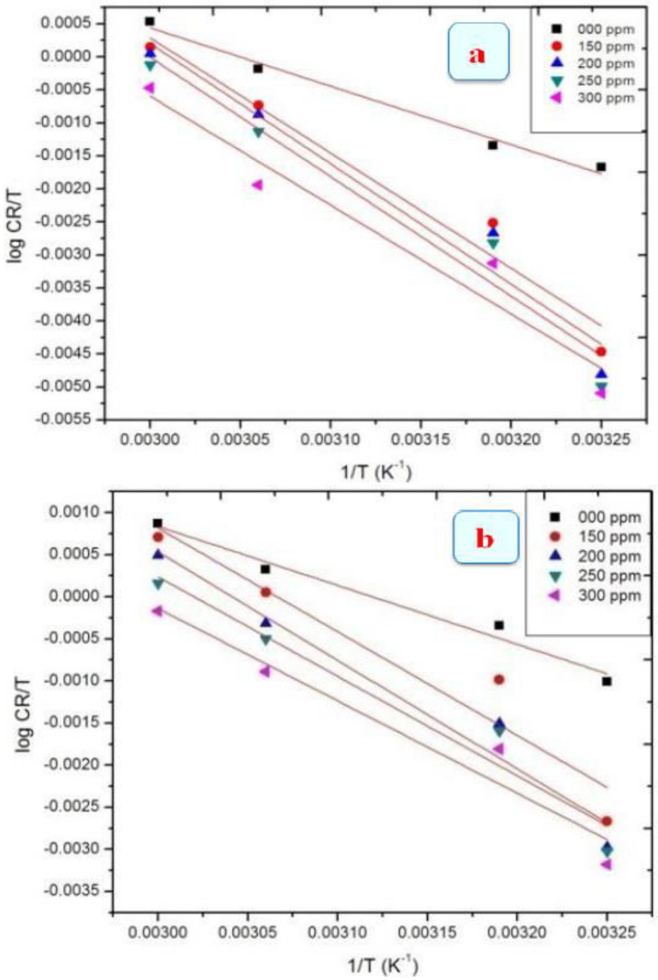


Fig. 2: Transition state plots of log CR/T vs 1/T at various concentrations of GHLE in a) 1N HCl and b) 1N H_2SO_4

From these data, it was found that the thermodynamic parameters such as ΔH and ΔS of dissolution reaction of mild steel in 1N H_2SO_4 and 1N HCl in the presence of GHLE were higher than the uninhibited solution. The negative values of ΔH clearly confirmed the exothermic nature of the steel dissolution process [12]. The ΔS values were negative in both the absence and presence of tested inhibitor. Moreover, the activated complex in the rate-determining phase was a dissociation step rather than an association step, confirming that the decrease in disordering takes place when reactants converted to activated complex [13].

Table 2: Corrosion kinetic factors for mild steel in 1N HCl and 1N H_2SO_4 in the absence and presence of various concentrations of GHLE

Test solution	Concentration (ppm)	E_a (kJ/mol)	-ΔH (kJ/mol)	-ΔS (J/mol/K)
1N HCl	0	53.13	169.48	197.54
	150	103.24	334.32	197.52
	200	107.61	349.12	197.51
	250	106.46	346.56	197.51
	300	96.17	315.94	197.52
1N H_2SO_4	0	42.78	133.99	197.15
	150	73.93	235.98	196.84
	200	76.80	246.65	196.82
	250	69.96	226.33	196.89
	300	64.34	210.17	196.94

3.3. Adsorption isotherm

Generally, adsorption isotherm provides essential information on the adsorption of inhibitor on metal surface. The θ values of different concentrations of inhibitor were tested by fitting to various isotherms including Frumkin, Langmuir, Temkin and Freundlich isotherms. In the present study, the results fitted best the Temkin adsorption isotherm in both acid media. In Temkin adsorption isotherm, the plot of surface coverage (θ) obtained from weight loss method versus log C at different concentrations of the inhibitors showed a straight line (Fig. 3). Temkin adsorption isotherm is given as follows,

$$\theta = \log K + \log C \qquad (4)$$

Where, K is equilibrium constant of adsorption process and C is the concentration of GHLE. The adherence of this adsorption process to Temkin adsorption isotherm is suggestive of molecular interaction within the adsorption layer species and the negative values of '*a*' are the indication of repulsive interaction in the adsorbed layer [14, 15].

The free energy values of adsorption (ΔG_{ads}) of GHLE on mild steel surface were calculated using Eq. (5).

$$\Delta G_{ads} = -RT \ln (55.5\, K_{ads}) \qquad (5)$$

Here, R and T are the gas constant and absolute temperature; the concentration of water in the solution is 55.5. The K_{ads} values were found to decrease with increasing temperatures. As a result of the weak connection between the metal surface and the adsorbed molecules, the inhibitor molecules are readily removed. According to this data, the production efficiency was decreased with increasing temperature.

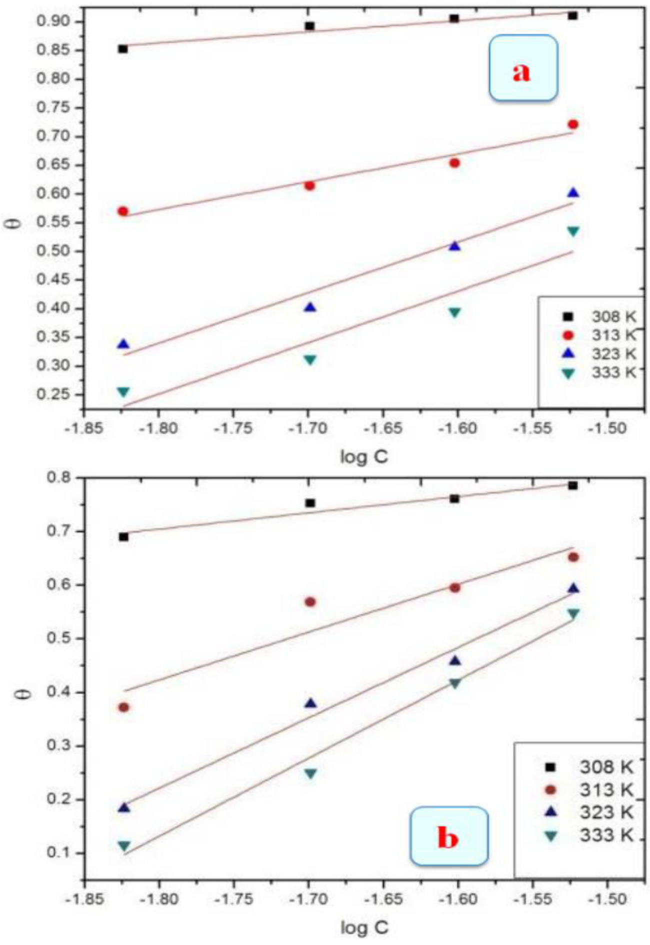


Fig. 3: Temkin adsorption isotherm for mild steel in a)1N HCl and b) 1N H_2SO_4 containing different concentrations of GHLE at different temperatures

The negative value of ΔG_{ads} (Table 3) in this study clearly revealed the spontaneous GHLE adsorption on mild steel surfaces and poor interactions between metal surface and inhibitor molecules [16, 17].

Physisorption is often defined as values of ΔG_{ads} up to -20kJ/mol, which is compatible with electrostatic interaction between the metal surface and charged molecules. If the ΔG_{ads} value is around -40 kJ/mol or higher, charge transfer or sharing takes place on the metal surface from inhibitor molecules through coordinate bond [18]. The ΔG_{ads} values are below -10 kJ /mol in both acid media in the present study. Therefore, the physisorption played a significant role on the adsorption mechanism of GHLE on mild steel in 1N H_2SO_4 and 1N HCl solution at investigated temperature range [19, 20].

Table 3: The adsorption parameters of Temkin isotherm on the surface of mild steel in 1N HCl and 1N H_2SO_4,

Test solution	Temperature (K)	$-\Delta G_{ads}$ (kJ/mol)	K_{ads}	R^2 Value
1N HCl	308	9.79	0.825	0.919
	313	9.49	0.693	0.956
	323	9.01	0.518	0.965
	333	9.39	0.536	0.908
1N H_2SO_4	308	9.71	0.800	0.922
	313	8.61	0.493	0.901
	323	8.23	0.387	0.986
	333	8.31	0.363	0.987

GHLE used as inhibitor

3.4. Electrochemical studies

3.4.1. Potentiodynamic polarization studies

Fig.4 shows the polarization curves of mild steel in 1N H_2SO_4 and 1N HCl in the presence and absence of GHL extract. From the Fig. 4, it is observed that in the presence of inhibitor, the E_{corr} values were shifted towards positive direction and the shift was found dependent on the concentration of the inhibitor and the curves are displaying a preferential suppression of the anodic reaction.

Table 4 shows the various parameters of potentio-dynamic polarization studies such as E_{Corr}, $I_{Corr,}$ cathodic (β_c), anodic (β_a) and linear potential resistance values (R_p). I_{Corr} decreases with increasing the concentration of GHLE from 5355 to 424 μA cm^{-2} in 1N HCl and from 10050 to 3078 μA cm^{-2} in 1N H_2SO_4. These values are used for calculate the inhibition efficiency on mild steel in various concentration of GHLE.

The inhibition efficiency was calculated by the following equation [12]

$$IE\ \% = (I^{\circ}_{corr} - I_{corr}/I^{\circ}_{corr}) \times 100 \qquad (6)$$

where I°_{corr} and I_{corr} are the corrosion current density values without and with inhibitor respectively, linear potential resistance (R_p) increases with increasing concentration of the GHLE [21]. R_p value increases from 7 to 46 Ohm m^{-2} in 1N HCl and from 4 to 12 Ohm m^{-2} in 1N H_2SO_4. Table 4 showed the values of β_c were changed less than β_a values both in 1N HCl and 1N H_2SO_4.

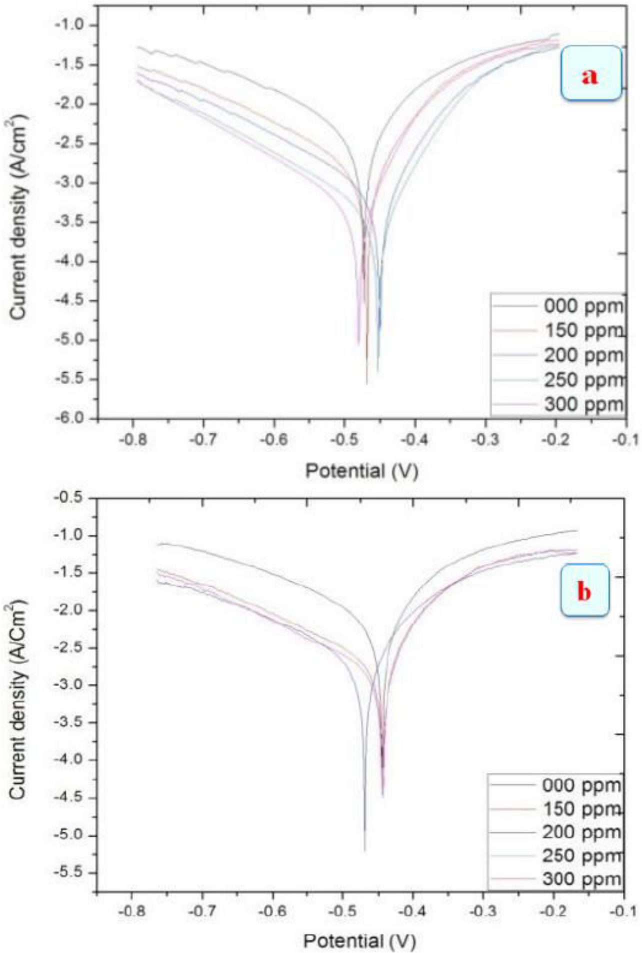


Fig. 4: Tafel plots of mild steel immersed in a) 1N HCl and b) 1N H_2SO_4 with and without GHLE

This suggested that the anodic reaction was controlled predominantly than the cathodic one at all concentrations in both acid media. This suggests that only anodic reaction was controlled and GHLE is the anodic type inhibitor [22].

Table 4: Potentiodynamic polarization parameters for the corrosion of mild steel in 1N HCl and 1N H_2SO_4 containing different concentrations of GHLE

Test Solution	Concentration (ppm)	E_{Corr} (mV)	I_{Corr} (μA cm^{-2})	β_c (mV/decade)	β_a (mV/decade)	R_p (Ohm m^{-2})	I.E %
1N HCl	0	-0.473	5355	190.3	161.6	07	
	150	-0.468	1656	191.9	109.7	18	69.07
	200	-0.450	848	194.2	94.0	33	84.16
	250	-0.458	542	179.53	83.2	46	89.87
	300	-0.452	424	183.95	78.4	56	92.08
1N H_2SO_4	0	-0.445	10050	208.7	160.8	04	
	150	-0.443	3491	222.7	135.7	11	65.26
	200	-0.469	3088	221.2	138.5	12	69.27
	250	-0.444	3078	242.3	133.3	12	69.37
	300	-0.444	3078	242.3	133.3	12	69.37

3.4.2. Electrochemical impedance spectroscopy

The corrosion behavior of mild steel, in acidic solution (1N HCl and 1N H_2SO_4) in the presence of GHLE was investigated by the EIS method at 308 K after immersion for 2 hours and are shown in Fig. 5.

The locus of the Nyquist plots was regarded as one part of a semicircle. The equivalent circuit models employed for this system are as previously reported [23]. Nyquist plots of mild steel in inhibited and uninhibited acidic solutions (1N HCl and 1N H_2SO_4) containing various concentrations of GHLE. The impedance diagrams obtained are not perfect semicircles and the diameter of the semicircle increases with increasing concentration in both acidic media. The charge transfer resistance, R_{ct} value increases from 5.503 to 68.737 Ω cm^{-2} in 1N HCl and from 3.356 to 13.153 Ω cm^{-2} in 1N H_2SO_4. R_{ct} values are used to calculate the inhibition efficiency. Inhibition efficiency was calculated by the following formula

$$IE\ \% = (R_{ct(inh)} — R_{ct}/R_{ct(inh)}) \times 100 \quad (6)$$

where, R_{ct} and $R_{ct(inh)}$ are uninhibited and inhibited charge transfer resistance respectively.

The impedance parameters derived from these investigations are given in Table 5. It is found that as GHLE concentration increases, the R_{ct} values also increases, but the C_{dl} values tend to decrease in both the acidic media. The decrease in the C_{dl} values is due to the adsorption of inhibitor on the metal surface [24]. This suggests the film formation of GHLE on mild steel simultaneously which acts as protective layer and similar behavior is observed in both the acidic media. The inhibition efficiency in 1N H_2SO_4 is comparatively lower than that in 1 N HCl solution. The results were in good agreement with weight loss measurement and electro-chemical impedance spectra.

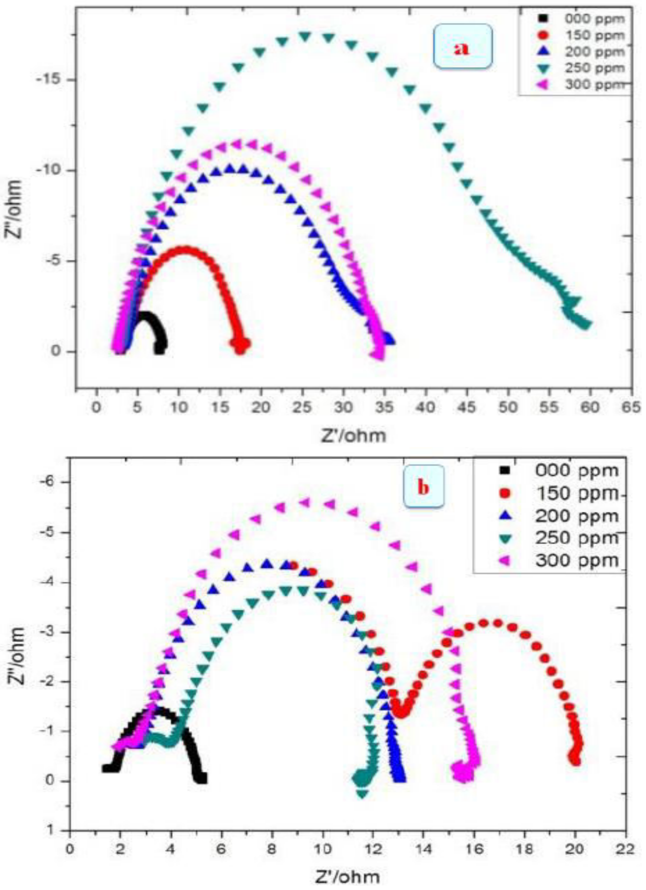


Fig. 5: Nyquist plots for mild steel immersed in a) 1N HCl and b) 1N H_2SO_4 different concentrations of GHLE at 308 K

Table 5: Electrochemical impedance parameters for mild steel in 1N HCl and 1N H_2SO_4 in the absence and presence of GHLE

Test solution	Concentration (ppm)	R_s (Ω cm^{-2})	R_{ct} (Ω cm^{-2})	C_{dl} (F/cm^2)	I.E %
1N HCl	0	2.823	5.503	1.4×10^{-2}	
	150	2.913	14.942	1.8×10^{-3}	63.17
	200	1.012	35.399	4.4×10^{-4}	84.45
	250	0.464	36.082	3.8×10^{-4}	84.74
	300	-3.836	68.737	1.3×10^{-4}	91.99
1N H_2SO_4	0	1.737	3.356	3.3×10^{-2}	
	150	2.967	11.048	3.4×10^{-3}	52.38
	200	2.138	11.145	3.2×10^{-3}	69.88
	250	2.290	11.498	3.7×10^{-3}	70.81
	300	1.473	13.153	2.1×10^{-3}	74.48

3.5. FTIR spectral studies

FTIR spectra of the GHLE in the presence and absence of inhibitor were performed to identify the functional groups present in it and to the study the interaction between the metal and the extract. The FTIR spectral frequencies of the extract and the corrosion products are presented in Fig. 6a and b.

The obtained results show that corrosion inhibition takes place through adsorption process. The different bonds of the molecules present in the corrosion products and extracts are shown in Table 6.

The presence of -OH, -CN and -C=C (unsaturated) functional groups were confirmed by the peak at 3442, 1386 and 1701 cm^{-1}, respectively. The extracts included oxygen and nitrogen atoms, which satisfied the general criteria for corrosion inhibitors. Corrosion occurs on mild steel when it is submerged in both acid media, as evidenced by the change in shift frequency of the extract. According to the statement, there was an interaction takes place between the mild steel surface and the extract which resulted in inhibition.

3.6. Morphological studies

SEM images of mild steel surfaces after 2 hours of immersion in 1N HCl in the absence and presence of GHLE are shown in Fig. 7b and c. Fig. 7d and e show SEM images of mild steel surfaces after 2 hours of immersion in 1N H_2SO_4 in the presence or absence of GHLE.

The specimens were taken out after 2 hours and dried. The surface of the inhibited mild steel specimens was better than the uninhibited sample, according to SEM photographs. The corrosion rate was lowered in the presence of inhibitors, according to these findings. The adsorption of inhibitor molecules on the metal surface as a protective layer reduces the rate of corrosion [25].

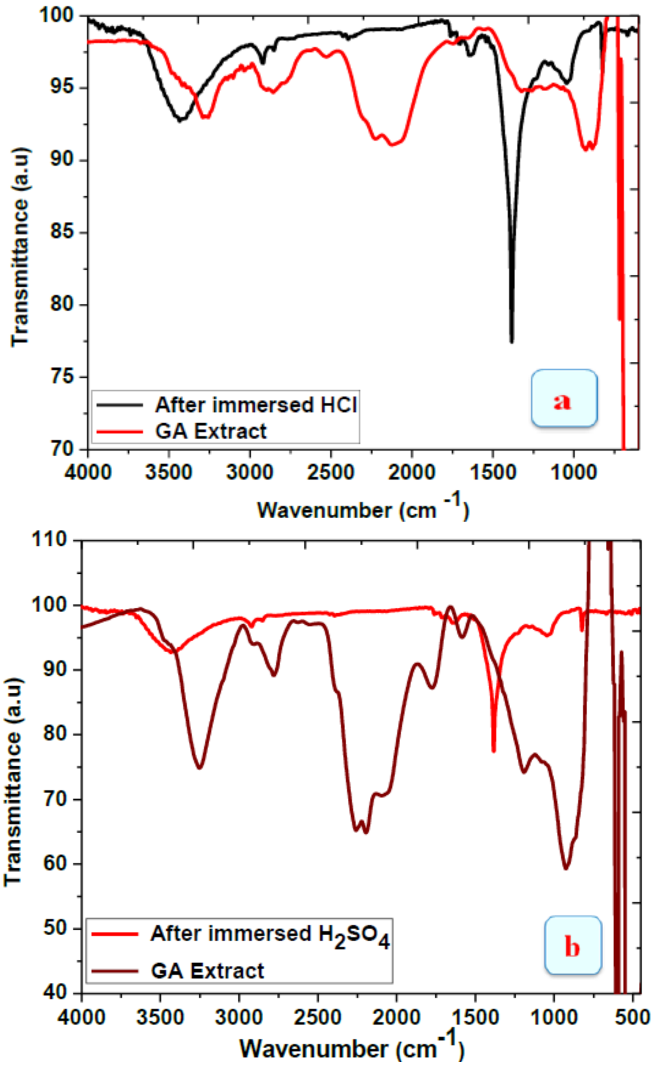
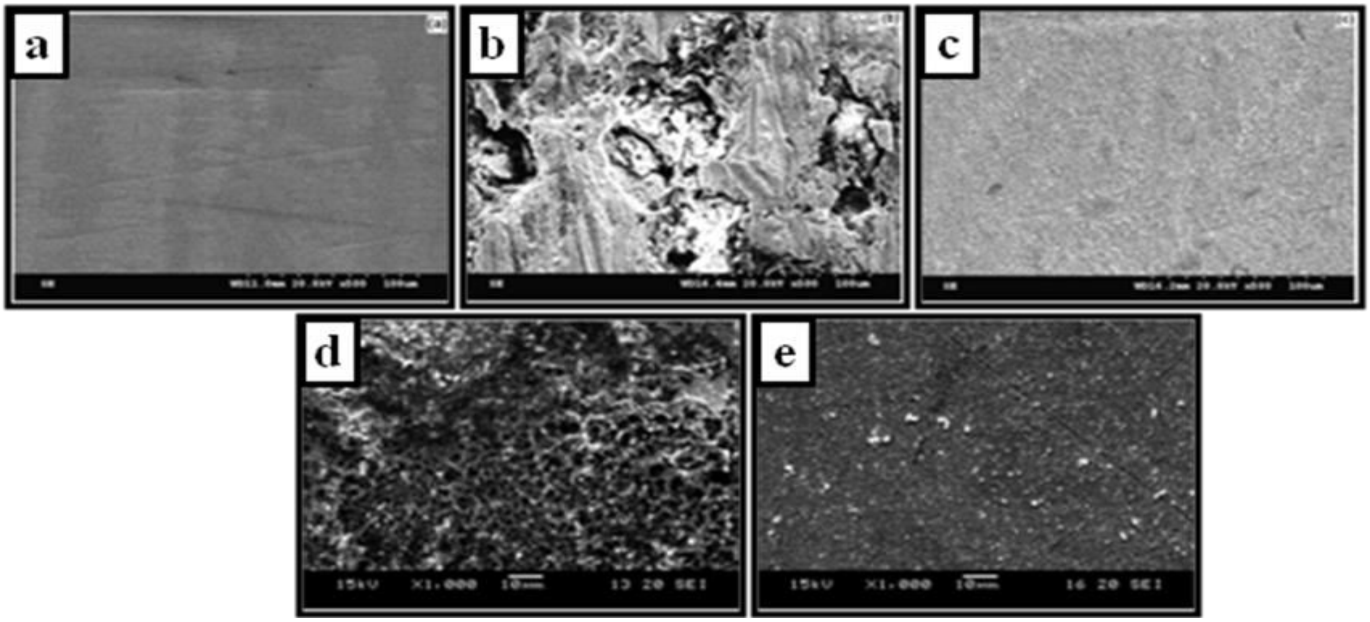


Fig. 6: FTIR Spectra for (a) GHLE and after immersion 1N HCl, (b) GHLE and after immersion 1N H_2SO_4

Table 6: FTIR Spectral data of the 1N HCl and H_2SO_4 leaf extract of *Gossypium herbaceum* and corrosion product

Extract of *Gossypium herbaceum*		Corrosion inhibiter of *Gossypium herbaceum* extract		
Wave number (cm^{-1})	Assignment/vibration mode	Wave number (cm^{-1}) 1N HCl	Wave number (cm^{-1}) 1N H_2SO_4	Assignment/ vibration mode
3252	O-H stretching	3442	3327	O-H stretching
2781	C-H stretching	2928	2844	C-H stretching
1577	C=C stretching	1701	1698	C=C stretching
1196	C-N stretching	1386	1332	C-N stretching



(a) plain mild steel (b) after immersion of 1N HCl in the absence of GHLE (c) after immersion of 1N HCl in the presence of GHLE (d) after immersion of 1N H_2SO_4 in the absence of GHLE (e) after immersion of 1N H_2SO_4 in the presence of GHLE

Fig. 7: SEM images

4. CONCLUSION

The obtained findings in the present study clearly demonstrate that the GHLE effectively inhibits the corrosion of mild steel in 1N H_2SO_4 and 1N HCl. The efficacy of mild steel inhibition improves as the concentration of GHLE in chosen acid medium increases, but decreases as the temperature increases. In both acid media, the GHLE acts as an anodic inhibitor and this statement was confirmed by the potentiodynamic polarization results. According to the EIS results, the increasing concentration of GHLE was enhancing the charge transfer in both media, confirming that the inhibition efficiency was effectively boosted with increasing concentrations. The Temkin adsorption isotherm governs the inhibitor's adsorption at all temperatures studied in 1N H_2SO_4 and 1N HCl, respectively. The effective inhibition of corrosion was occurred by GHLE due to the physisorption on the surface of mild steel. Moreover, the adsorption was spontaneous. The development of a protective coating against acid assault was established by SEM analysis. The results obtained from weight loss, polarization and impedance measurements are in good agreement.

5. ACKNOWLEDGEMENTS

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Conflict of interest

None declared

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