RASĀYAN *J. Chem.*
Vol. 17 | No. 1 |236-243| January - March | 2024
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

INHIBITORY EFFECTS OF CUSCUTA REFLEXA (AMERBEL) ON THE CORROSION OF IRON IN 1M HYDROCHLORIC ACID: A GREEN APPROACH

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ABSTRACT

The corrosion inhibition properties of Cuscuta reflexa (Amerbel) leaf extract as a green inhibitor for iron corrosion in hydrochloric acid were investigated using gravimetric and surface techniques. Results show that the extract's inhibition efficiency varied with concentration and temperature. The Langmuir adsorption isotherm model was followed, and the adsorption was physical and spontaneous. The studies suggest that Cuscuta reflexa extract exhibits great potential as a mild steel corrosion inhibitor in HCl environments.

Keywords: Corrosion Inhibition, Iron, Cuscuta reflexa, Acidic Conditions, Mild Steel, Gravimetric, Surface Techniques.

RASĀYAN *J. Chem.*, Vol. 17, No.1, 2024

INTRODUCTION

Steel is a popular, affordable, and strong alloy used in construction and everyday objects, but it is prone to corrosion in aggressive environments.[1,4]One practical way to protect it is using low-cost, environmentally safe plant extracts as corrosion inhibitors.[2]Cuscuta reflexa, a parasitic plant studied for its various medicinal properties, has been investigated for its potential as a corrosion inhibitor. Green inhibitors are an excellent solution for preventing corrosion in various industries while also being environmentally friendly and safe for human health.[43]These inhibitors have gained popularity due to their effectiveness and biodegradability, making them a sustainable alternative to traditional inhibitors. They are being extensively researched to develop more efficient and cost-effective formulas to replace the current corrosion inhibitors.[44] As the use of green inhibitors continues to rise, it is clear that they hold great promise for protecting equipment and machinery while promoting sustainability.[45]This study focuses on usingCuscuta reflexa extract as an environmentally friendly inhibitor for protecting mild steel against corrosion in dilute hydrochloric acid solution.[3] The inhibition efficiency of the extract was measured using the weight loss method, SEM, and AFM techniques in a 1M HCl solution.[6,8]The findings of the experiments indicate that the extract has great potential as a corrosion inhibitor for mild steel in HCl environments.[46]

Botanical Classification of Cuscuta reflexa

Kingdom:	Plantae
Sub kingdom:	Tracheobionta
Superdivison:	Spermatophta
Division:	Angiosperms
Class:	Eudicots
Subclass:	Asteroids
Order:	Solanales
Family:	Cuscutaceae

http://doi.org/10.31788/RJC.2024.1718751

Alternate: Convolvulaceae
Genus: Cuscuta
Species: Reflexa

EXPERIMENTAL

Alloy Used

Commercially available mild steel (C 0.15% by weight) was used for all experiments. The mild steel sheet was mechanically press-cut into 2.5×2.5×0.1 cm coupons. The steel coupons were immersed in 5% HCl to remove rust and sequentially polished using SiC emery papers of grade 220, 400, 600, and 1000, washed thoroughly with distilled water, and degreased with acetone.

Chemicals used

1M HCl was prepared using analytical grade concentrated 37% HCl (Merck products) respectively and double distilled water.[5]

Preparation of Inhibitor

The extraction of Cuscuta reflexa (CR) was performed using the reflux method. Fresh thin stems of Cuscuta were collected from Gorakhpur city of (U.P.), India. The parts of the plant were left to dry in the shade in an air atmosphere for about 6 days. The extract was prepared separately in 1M HCl .10 g of dried powder of stems was digested in 200 mL 1M HCl and kept overnight. The next day it was filtered and the filtrate volume was made up to 200 mL using 1M HCl. The extracts so far prepared were taken as stock solutions from which 1, 2, 3,4, and 5 % test solutions were prepared.[7,10]

Weight Loss Method

The weight loss studies were carried out at 30ºC by immersing steel coupons of known weight and surface area in 100 ml each of blank 1M HCl and test solutions containing various concentrations of extracts for 48 hours.[9]

The dissolution of iron takes place and the reaction can be written as:

$$Fe + 2HCl \rightarrow FeCl_2 + H_2\uparrow$$
$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2\uparrow$$

After 48 hours of reaction, the specimens were taken out, washed with water, dried, and weighed. Corrosion rates (in terms of $g.cm^{-2}h^{-1}$) were calculated using the following expression.[11,14]

$$Corrosion\ Rate\ (CR) = \frac{Wi - Wf}{Surface\ Area\ \times Time}$$

Where, Wi = initial weight of coupon,
W_f = weight of coupons after treatment
$W_i - W_f$ = weight loss (g)

The surface coverage (θ) as a result of adsorption of inhibitor and inhibition efficiency (η%) were calculated from corrosion rates using the following expression:

$$(\theta) = \frac{CR\ (Blank) - CR\ (Inhibitor)}{CR(Blank)}$$

$$\eta = \frac{CR\ (Blank) - CR\ (Inhibitor)}{CR\ (Blank)} * 100$$

Table-1 shows the relationship between mass loss and contact period. The presence of Cuscata extract enhances inhibition efficiency due to the hetero atoms like nitrogen and oxygen in the extract, as reported in previous studies.[13,19,15] Increasing the concentration of extract results in a decrease in weight loss and an increase in metal dissolution prevention. The observed values clearly indicate the presence of plant extract.[12,16,17] reduces the corrosion rate with an exposure time of 48 hours. This can be attributed to the fact that the solution resistivity increases when the metal is exposed to an inhibitor for a longer immersion time, forming a protective layer over the metal surface against corrosion. The maximum inhibition efficiency of 95.90% is attained at higher concentrations.[18,20] Based on the weight loss method, the results demonstrate that adding Cuscata extract to the corrosion medium reduces the corrosion rate and increases inhibition efficiency.The relationship between mass loss and contact period is shown in Table-1. Inhibition efficiency is enhanced by the presence of Cuscata extract due to heteroatoms like nitrogen and oxygen in the extract.[13,19,15]A higher concentration of extract gives a decreasein weight loss and a rise in metal dissolution prevention. The observed values exhibit that in the presence of plant extract.[12,16,17]The corrosion rate decreases with an exposure time of48 hrs. because the solution resistivity increases when a metal is exposed to an inhibitor with great immersion time by forming a protective layer over the metal surface against corrosion. The maximum of 95.90% of inhibition efficiency is attained at higher concentrations.[18,20]The measuring result of corrosion rate and inhibition efficiency by using the weight loss method shows that adding Cuscata extract into to corrosion medium causes the corrosion rate to become lesser and conversely an increase in inhibition efficiency as seen in Table-1.

Table-1: Values of Corrosion Rate, Surface Coverage, Inhibition Efficiency, Rate Constant, And Half-LifeTime at Various Concentration

S.No.	Inhibitor Weight of steel sample g/cm^2	The initial weight of the steel sample g/cm^2	The final weight of the steel sample g/cm^2	Weight loss g/cm^2	Corrosion rate ($gcm^{-2}h^{-1}$)	Surface coverage(θ)	Percent Inhibition Efficiency %η	Rate constant	Half-time ($t_{1/2}$)
1.	0	2.420	2.100	0.32	0.3320	-	-	0.1419	4.884
2.	1	2.290	2.120	0.17	0.0176	0.9470	94.70	0.0771	8.984
3.	2	2.310	2.140	0.17	0.0176	0.9470	94.70	0.0764	9.064
4.	3	2.960	2.790	0.17	0.0161	0.9515	95.15	0.0591	11.72
5.	4	2.520	2.370	0.15	0.0149	0.9551	95.51	0.0613	11.29
6.	5	2.660	2.510	0.15	0.0136	0.9590	95.90	0.0580	11.95

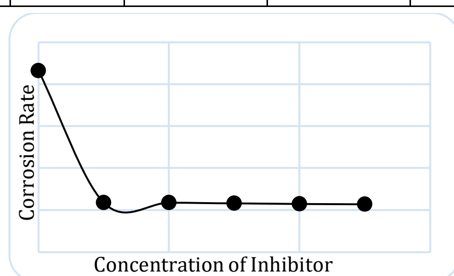

Fig.-1: Variation of Corrosion Rate with Concentration of Plant Extract in 1M HCl Solution

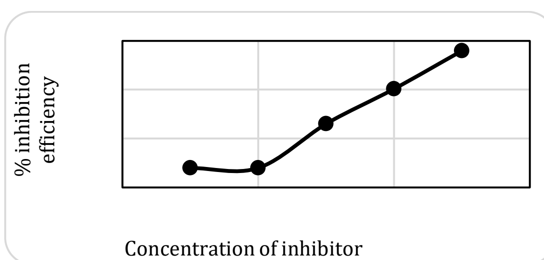

Fig.-2: Variation of Percent Inhibition Efficiency with Concentration of Plant Extract in 1M HCl Solution

This indicates that at 60ºC, the corrosion inhibition efficiency reaches 95.50%. This suggests that as the temperature increases, there is a gradual improvement in inhibition efficiency, indicating a potential chemical adsorption mechanism at play.[21,24,27] Adsorption studies play a key role in the investigation of the mechanism of corrosion reaction because the inhibitor molecules may retard the corrosion by adsorption at the metal-solution interface.[29,30] The Langmuir and Temkin isotherms28,26 are two commonly used models in such investigation.

Langmuir Adsorption Isotherm

Figure-4 confirms that the inhibition is due to the adsorption of the active organic compounds onto the metal surface.[23,25] This is because a straight line is obtained when concentration is plotted against (C/θ) the regression co-efficient (R^2) of the fitted data is close to unity (R^2=1), indicating that the adsorption of the inhibitor molecules obeys the Langmuir adsorption isotherm.[22]

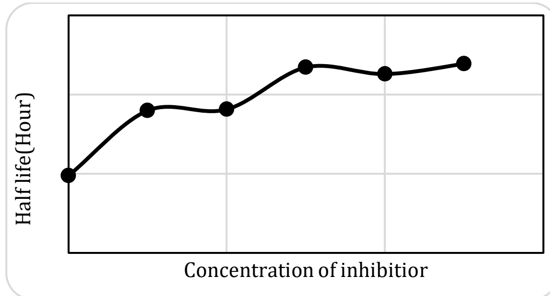

Fig.-3: Half-Life of Corrosion of Mild Steel in 1M HCl Solution With and Without Inhibitors

Table-2: Langmuir Adsorption Parameters of Plant Extract on Mild Steel in 1M HCl

C	(C/θ)
0	0
1	0.01858
2	0.01858
3	0.01692
4	0.01560
5	0.01418

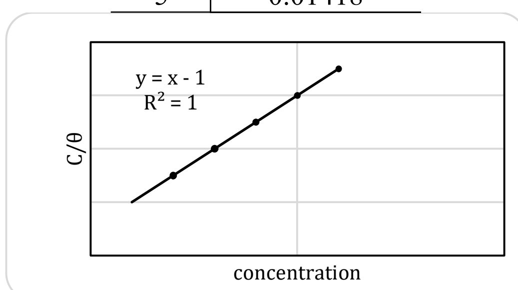

Fig.-4: Langmuir Adsorption Isotherm of Inhibitor on Mild Steel in 1M HCl

Temkin Adsorption Isotherm

A plot of θ Vs log C as shown in Fig.-5 does not give a linear plot, indicating that the application of the Temkin adsorption mechanism is not suited for Cuscata extract in a perfect manner.[31,34] The values of the adsorption parameters deduced from the Temkin plot are presented in Table-7.5. The average regression coefficient value (R^2=0.9543) observed from the plot is not close to unity.[37,40] Hence Cuscata inhibitor does not obey the Temkin adsorption isotherm.[41,42]

Table-3: Temkin Adsorption Parameters of Plant Extract on Mild Steel in 1M HCl

Log C	(θ)
-	0
0	0.9470
0.3010	0.9470
0.4771	0.9515
0.6620	0.9551
0.6989	0.9590

Adsorption isotherm plots produce reliable information on the interaction between the hetero atoms in CR and mild steel surface. θ values obtained from the mass reduction technique have been used to illustrate the best isotherm that explains the adsorption process.[32,33] To suggest the adsorption isotherm, which explains the adsorption of CR extract on the mild steel surface, several adsorption isotherm plots such as Langmuir, and Temkin have been verified.[35] Among these only Langmuir isotherm shows a best fit according to the higher linear regression value, which is almost to unity.[38,39] This suggests monolayer adsorption of inhibitor molecules on the metal surface.

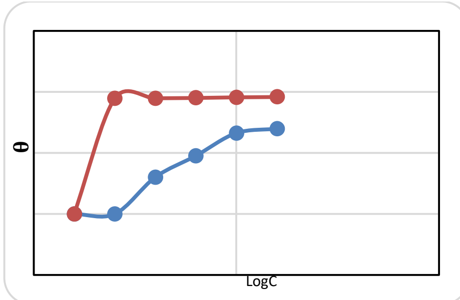

Fig.-5: Temkin Adsorption Isotherm of Inhibitor on Mild Steel in 1M HCl

Scanning Electron Microscopic Analysis

SEM analysis was carried out to inspect variations on the metal's surface in the polished, presence and absence of the inhibitor. SEM analysis was done on the mild steel specimen immersed in 1M HCl with and without inhibitors for 24 hours.[36]

Figure-6(a) illustrates the uncorroded surface of mild steel coupons without damage, Figure-6(b) Depicts the surface of uninhibited mild steel revealing deep pits that indicate corrosion have taken place. Figure-6(c) shows of Inhibited mild steel coupons which indicating the protected base

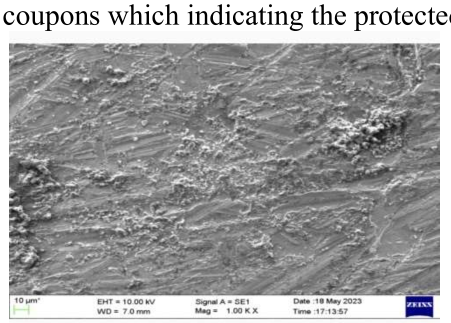

Fig.-6(a): SEM Micrograph of Polished Mild Steel Surface

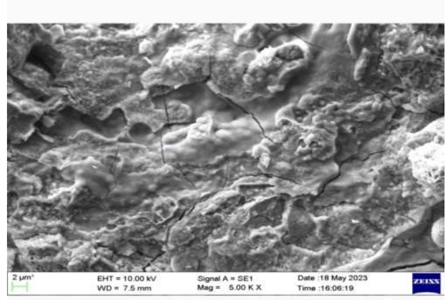

Fig.-6(b): SEM Micrograph of Mild Steel in 1M HCl in the Absence of Inhibitor

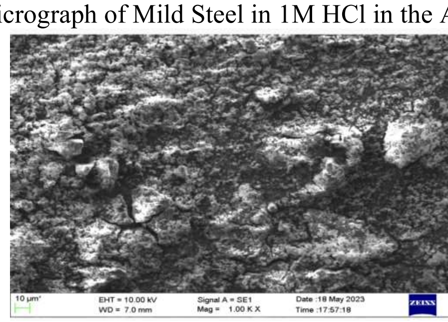

Fig.-6(c): SEM Micrograph of Mild Steel in 1M HCl in the Presence of Plant Extract

Atomic Force Microscopy (AFM) Analysis

Atomic Force Microscopic analysis is a dynamic tool used to analyze surface morphology at both micro and macro levels, as well as to examine the formation of thin film formation on the metal surface. Figure-7 portrays the 3D AFM topography of the surface of the metal in the absence (Fig.-7a) and in the presence (Fig.-7b) of the inhibitor. The average roughness of MS exposed to the inhibitor 1M HCl is 431.7 nm and that exposed to inhibited acid is 234.6 nm. The reduction of average roughness indicates that the adsorbed wrapping zonal film of inhibitor molecules protects the metal from the direct attack of corrosive acid and, hence, prevents corrosion.

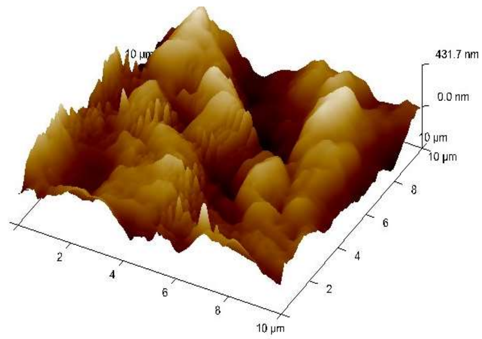

Fig.-7(a): AFM Image of Mild Steel in 1M HCl Without Inhibitor

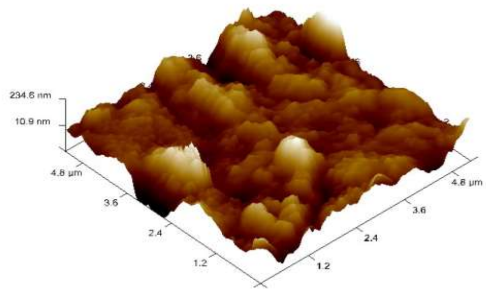

Fig.-7(b): AFM Image of Mild Steel in the Presence of CRL in 1 M HCl

CONCLUSION

1. Cuscuta reflexa (Amerbel) leave extracts were found to be good non-toxic and safe inhibitors for mild steel corrosion in 1M HCl.
2. The non-electrochemical measurements showed that inhibition efficiency increased with an increase in plant extracts concentrations.
3. The inhibition efficiency was found to increase with the increase in extract concentration in the acidic solutions.
4. The adsorption of Cuscuta reflexa (Amerbel) extracts on the mild steel surface in hydrochloric acid obeys the Langmuir adsorption isotherm model and the adsorption is physical.

ACKNOWLEDGMENTS

Authors would like to thank Central Instrumentation Facility ,Manipal for providing the necessary resources and support to complete the research work.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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