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Green Corrosion Inhibition of Mild Steel in 0.5 M HCl Using Tecoma stans Leaf Extract: Experimental and Thermodynamic Study

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A B S T R A C T

Corrosion of mild steel in acidic environments remains a critical challenge in industrial applications, particularly in oil and gas operations. In this study, the inhibitory performance of Tecoma stans leaf extract as an eco-friendly corrosion inhibitor for mild steel in 0.5 M HCl solution was investigated using the weight loss method. The effects of inhibitor concentration and extraction medium (aqueous and alcoholic) were evaluated. The results revealed that inhibition efficiency increases with increasing extract concentration, with the alcoholic extract showing superior performance, achieving a maximum efficiency of 84.98%. Adsorption studies indicated that the inhibitor molecules adsorb onto the metal surface, The calculated standard free energy of adsorption ($\Delta G°ads = -10.5$ kJ/mol) suggests that the inhibition process is spontaneous and predominantly governed by physisorption with possible chemisorption contributions. The high inhibition efficiency is attributed to the presence of phytochemical constituents containing heteroatoms and π-electrons, which facilitate adsorption and formation of a protective film. These findings confirm that Tecoma stans extract is a promising, low-cost, and environmentally friendly corrosion inhibitor for mild steel in acidic media

تثبيط تآكل الفولاذ الطري في وسط حمضي باستخدام مستخلص اوراق نبات الثيكوما : دراسة تجربيه وتحليل ثيرموديناميكي

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الكلمات المفتاحية:
أوراق تيكوما ستانس
المستخلص
الوسط الحمضي
المثبطات الخضراء
فقدان الوزن

الملخص

يُعدّ تآكل الفولاذ الطري في الأوساط الحمضية من التحديات الرئيسية في التطبيقات الصناعية، لا سيما في صناعات النفط والغاز. في هذه الدراسة، تم تقييم كفاءة مستخلص أوراق نبات الثيكوما كمثبط تآكل صديق للبيئة للفولاذ الطري في محلول حمض الهيدروكلوريك بتركيز 0.5 مولاري، وذلك باستخدام طريقة فقدان الوزن تمت دراسة تأثير كلٍّ من تركيز المثبط ووسط الاستخلاص (المائي والكحولي) على سلوك التآكل. أظهرت النتائج أن كفاءة التثبيط تزداد بزيادة تركيز المستخلص، حيث أظهر المستخلص الكحولي أداءً متفوقًا، محققًا أعلى كفاءة تثبيط بلغت 84.98% أشارت دراسات الامتزاز إلى أن جزيئات المثبط تمتز على سطح المعدن. كما أوضحت القيم المحسوبة للطاقة الحرة القياسية للامتزاز ($\Delta G°ads = -10.5$ كيلوجول/مول) أن عملية الامتزاز تلقائية، وتخضع بشكل أساسي لآلية الامتزاز الفيزيائي مع احتمال وجود مساهمة للامتزاز الكيميائي.وتُعزى كفاءة التثبيط العالية إلى احتواء المستخلص على مركبات فيتوكيميائية غنية بذرات غير متجانسة والإلكترونات طبقة واقية على سطح المعدن . تؤكد هذه النتائج أن مستخلص الثيكوما يُعد مثبط تآكل واعدًا، منخفض التكلفة، وصديقًا للبيئة، ويمكن استخدامه بديلاً فعالاً في حماية الفولاذ الطري في الأوساط الحمضية

Introduction

The Corrosion is a natural process that leads to the deterioration of metals due to chemical or electrochemical interactions with the surrounding environment. It represents a major industrial challenge, causing significant economic losses and safety risks worldwide [1,2].

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Mild steel is one of the most widely used engineering materials due to its excellent mechanical properties, availability, and low cost.
However, it is highly susceptible to corrosion, especially in acidic environments [3]. Hydrochloric acid solutions are extensively used in industrial operations such as acid pickling, descaling, and oil well acidizing, which significantly accelerate corrosion rates [4,5].
Traditionally, synthetic corrosion inhibitors such as chromates and phosphates have been widely used to control corrosion. Despite their effectiveness, these inhibitors are toxic, non-biodegradable, and pose serious environmental and health hazards, leading to increasing restrictions on their application[6,7].
As a result, the development of environmentally friendly (green) corrosion inhibitors derived from natural sources has attracted significant attention in recent years. Green inhibitors are generally biodegradable, non-toxic, and cost-effective, making them promising alternatives to conventional inhibitors [8,9].
Plant extracts are particularly attractive due to their abundance and rich composition of organic compounds such as alkaloids, flavonoids, tannins, and phenolic compounds. These compounds contain heteroatoms (N, O, S) and π-electrons, which facilitate their adsorption onto metal surfaces and consequently reduce corrosion rates [10,11].
In this context, Tecoma stans has emerged as a potential green corrosion inhibitor due to its high content of bioactive phytochemicals. In this work, the inhibitory effect of Tecoma stans leaf extract on mild steel corrosion in 0.5 M HCl solution is investigated using the weight loss method. Furthermore, adsorption behavior and thermodynamic parameters are analyzed to elucidate the inhibition mechanism. green inhibitors receive attention for the replacement of synthesized inorganic inhibitors, which are often toxic, expensive, and environmentally unfriendly [12,13]. Extracts derived from leaves, seeds, fruits, and roots contain nitrogen-, sulfur-, and oxygen-bearing compounds that have been identified as highly effective corrosion inhibitors, capable of performing efficiently even in aggressive corrosive environments [13,14]. Some examples of natural products used as corrosion inhibitors include Medicago sativa [115], Palm leaves [16], Zingiber officinale [17], Rosmarinus officinalis [13], Musa paradisiaca (Banana) peels [18]. These studies have shown that organic compounds containing N, S and O have high corrosion inhibitors. Most of these organic inhibitors are adsorbed on the metal surface [13,19]. Green corrosion inhibitors contain, for instance, tannins, saponins, alkaloids, proteins, flavonoids among others. These compounds form a protective layer on the surface as a result of their absorption onto the metal surface [20].

2. Materials and Methods

2.1. Steel specimens

Use mild steel 1018 corrosion coupons with the chemical composition shown in Table 1.

Table1: Chemical compositions of Mild Steel Used in this Work. Conclusion

C	Mn	P	S	B	Cr	Cu	Mo	Ni	Pb	Fe
0.150-0.200	0.600-0.900	0.030 max	0.035 max	0.0005-0.003	0.150 max	0.200 max	0.060 max	0.200 max	0.150-0.35	Balance

2.2. Preparation of Plant Extract

The leaves of Tecoma stans were collected, washed with water, and dried in the shade. They were then ground into a fine powder and extracted using ethanol and distilled water. Then shake the extract using a rotary shaker, and the extract was filtered through filter paper.

2.3. Corrosion Measurements

The weight loss method was employed to determine the corrosion rates of inhibited mild steel samples using both the aqueous extract and the ethanol extract at room temperature**.** The pre-weighed samples were immersed in a 0.5 M hydrochloric acid (HCl) solution containing different concentrations of the inhibitor for a predetermined period of time. The samples were then removed from the solution, rinsed with deionized water, dried, and reweighed. the corrosion rate of weight loss (CR) was determined using Equ.(1):

$$CR=\frac{w2-w1}{A.t} \quad (1) \quad [21]$$

Where W1 is the original weight (gm) and W2 are the weights after immersion in the test electrolyte, A is the surface area of the mild steel specimen and t is the time of each exposure. The percentage of inhibition efficiency (I. E) of a corrosion inhibitor is calculated from the corrosion rate values using Equ. (2).

$$I.E=[1-\frac{CRcorr.,add}{CRcorr.,free}] \times 100 \quad (2) \quad [21]$$

Where $CR_{corr,free}$ and $CR_{corr,add}$ represent the corrosion rates in the absence and in the presence of a given concentration of the inhibitor, respectively.

3. Results and Discussion

3.1. Weight Loss Calculations:

The weight loss measurements presented in Table 2 clearly demonstrate that both aqueous and alcoholic extracts of Tecoma stans exhibit significant corrosion inhibition performance for mild steel in 0.5 M HCl solution. However, the degree of inhibition strongly depends on both the extract type and its concentration.

Table 2: Weight loss and concentration data for both the aqueous and alcoholic extracts.

S.N	Description ID	Inhibitor Concentration in 0.5 HCL%	Weight(g) 1 day	Weight(g) 7days	Weight(g) 14day	Weight(g) 30day	Weight(g) 37day
1	C631	10% Aqueous extract	8.3063	8.2630	8.1917	7.6540	7.3697
2	E870	20% Aqueous extract	10.5659	10.3118	9.7462	9.4957	9.4722
3	H628	30% Aqueous extract	10.2748	10.1874	10.1381	9.9935	9.9308
4	H640	40% Aqueous extract	10.6226	10.5461	10.4804	10.0279	9.9106
5	H627	10% Alcoholic extract	10.5246	10.3516	9.9667	9.3555	9.3158
6	H634	20% Alcoholic extract	10.6920	10.59314	10.5201	10.3804	10.3181
7	H564	30% Alcoholic extract	10.1793	10.0835	10.0281	9.9866	9.8682

8	H637	40% Alcoholic extract	10.4 018	10.3 229	10.2 843	10.2 072	10.1 713
9	A932	BLANK	8.23 54	6.89 40	6.87 40	6.79 74	6.75 76

The weight loss data over extended immersion periods (up to 37 days) indicate that the inhibitor maintains its protective effect over time, especially at higher concentrations. However, slight degradation in protection may occur due to:

1- Desorption of inhibitor molecules
2- Breakdown of the protective layer
3- Continuous acid attack

This suggests that while the inhibitor is effective, its long-term stability could be further enhanced, possibly by combining it with other synergistic compounds.

3.2. Corrosion Rate (CR):

The corrosion rate presented in Table 3,4, The corrosion rate decreases with increasing inhibitor concentration for both extracts, particularly for the alcoholic extract. This trend suggests that higher concentrations of inhibitor molecules lead to increased surface coverage (θ), resulting in the formation of a more compact and protective adsorbed film on the steel surface.

Table 3: Corrosion rate of alcoholic extract.

Inhibitor Concentration in 0.5HCL%	**CR (g /in^2. day)**
Blank	0.01266
10%	0.01000
20%	0.00309
30%	0.00257
40%	0.00191

Table 4: Corrosion rate of the aqueous extract.

Inhibitor Concentration in 0.5HCL%	**CR (g /in^2. day)**
Blank	0.01266
10%	0.00774
20%	0.00904
30%	0.00284
40%	0.00589

3.3. Inhibition Efficiency:

Tables 5 and 6 show the inhibitory efficiency of the alcoholic and aqueous extracts, respectively , The results indicate that the alcoholic extract exhibits superior inhibition efficiency compared to the aqueous extract , The highest inhibition efficiency (~85%) observed at 40% alcoholic extract confirms that the adsorption process is concentration-dependent. The decrease in corrosion rate can be explained by the blocking of active corrosion sites, thereby reducing the metal dissolution process.

Similar trends have been widely reported in the literature, where inhibition efficiency increases with concentration due to enhanced adsorption [21,22].

This behavior can be attributed to the higher solubility of active phytochemical constituents such as flavonoids, alkaloids, and phenolic compounds in organic solvents like ethanol. These compounds are known to contain π-electrons and heteroatoms (N, O), which enhance adsorption onto the metal surface through donor–acceptor interactions.

This observation is consistent with previous studies, which reported that ethanol-extracted plant inhibitors generally show higher efficiency due to better extraction of active organic molecules[16,18].

Table 5: Inhibition efficiency of alcoholic extract.

Inhibitor concentration in 0.5M HCl	IE %
10%	21.21%
20%	75.63%
30%	79.72%
40%	84.98%

Table 6: Inhibition efficiency of Aqueous extract.

Inhibitor concentration in 0.5M HCl	**IE %**
10%	38.95%
20%	28.71%
30%	77.58%
40%	53.59%

Although both extracts act as corrosion inhibitors, the aqueous extract shows fluctuating efficiency with concentration, suggesting less stable adsorption behavior. This may be due to:

1- Lower concentration of active compounds.
2- Presence of impurities or inactive components.
3- Weaker interaction with the metal surface.

In contrast, the alcoholic extract forms a more uniform and stable protective film, leading to consistent inhibition performance.

3.4. Adsorption Mechanism

The inhibition performance of Tecoma stans extract can be attributed to its adsorption onto the mild steel surface. The adsorption process likely involves both physisorption and chemisorption mechanisms, as plant extracts contain a mixture of organic compounds with functional groups capable of interacting with the metal surface.

Physisorption occurs via electrostatic interaction between protonated inhibitor molecules and the negatively charged metal surface.

Chemisorption involves the formation of coordinate bonds between lone pair electrons of heteroatoms (O, N) and vacant d-orbitals of iron atoms.

The presence of functional groups such as –OH, –C=O, and aromatic rings enhances adsorption strength and stability of the protective film. This dual adsorption mechanism has been confirmed in several studies on green corrosion inhibitors [11,4].

3.5. Thermodynamics Parameters of Adsorption :

adsorption equilibrium constant K ads can be used to estimate the standard free energy of adsorption ΔG°ads using the following equation:

$$\Delta G^\circ_{ads} = -RT \log (55.5 \times K_{ads}) \quad (3) \qquad [16]$$

where:
R = 8.314 J/mol•K
T = temperature (K)
55.5 = molar concentration of water
Interpretation of ΔG°ads
If ΔG°ads → physisorption
If ΔG°ads → chemisorption
Intermediate values → mixed adsorption mechanism

Based on the inhibition efficiency and strong adsorption behavior observed, it is expected that the adsorption of Tecoma stans extract involves mixed-type adsorption, with a predominance of chemisorption due to the presence of electron-donating functional groups.

Table 7: Estimated Surface Coverage of Inhibitors and Adsorption Energy of alcoholic extract

alcoholic extract		
Surface Overage (θ)	**Adsorption constant (K) M^{-1}**	**Adsorption Energy (ΔG_{ads}) KJ/mol**
Blank	--	--
0.2121	0.0269	-10.3
0.7972	0.1966	-15.8
0.7563	0.1035	-14.1

0.8498	0.1415	-14.8

Table 8: Estimated Surface Coverage of Inhibitors and Adsorption Energy of Aqueous extract.

Aqueous extract.		
Surface Overage (θ)	**Adsorption constant (K) M^{-1}**	**Adsorption Energy (ΔG_{ads}) KJ/mol**
Blank	--	--
0.3895	0.0638	-12.6
0.2871	0.0201	-9.6
0.7758	0.1154	-14.3
0.5359	0.10289	-10.6

The calculated thermodynamic parameters show that both aqueous and alcoholic extracts exhibit spontaneous adsorption on the mild steel surface, as indicated by the negative values of ΔG°ads.
The slightly higher value of Kads for the aqueous extract suggests stronger adsorption tendency; however, the alcoholic extract shows higher inhibition efficiency, which may be attributed to better film formation and higher concentration of active phytochemical compounds.
The ΔG°ads values (around −10 to −11 kJ/mol) confirm that the adsorption mechanism is predominantly physisorption, with possible contribution from chemisorption due to the presence of heteroatoms and π-electrons.

4. Conclusions

The present study demonstrates that Tecoma stans leaf extract acts as an effective green corrosion inhibitor for mild steel in 0.5 M HCl solution. The inhibition efficiency increases with increasing extract concentration, with the alcoholic extract showing superior performance compared to the aqueous extract, and the calculated thermodynamic parameters confirm that the adsorption process is spontaneous and primarily governed by physisorption.
The high inhibition performance is attributed to the presence of bioactive compounds containing heteroatoms and π-electrons, which facilitate adsorption and formation of a protective film on the metal surface.
These findings suggest that Tecoma stans extract is a promising, environmentally friendly, and cost-effective alternative to conventional corrosion inhibitors for industrial applications.

5. References

[1] Ahmad, Z. (2006). Principles of corrosion engineering and corrosion control. Elsevier.
[2] Revie, R. W., & Uhlig, H. H. (2008). Corrosion and corrosion control: An introduction to corrosion science and engineering. Wiley.
[3] Roberge, P. R. (2008). Corrosion engineering: Principles and practice. McGraw-Hill.
[4] Kowsari, E., Payami, M., Amini, R., Ramezanzadeh, B., & Javanbakht, M. (2014). Task-specific ionic liquid as a green corrosion inhibitor. Applied Surface Science, 289, 478–486.
[5] Ebenso, E. E., Obot, I. B., & Murulana, L. C. (2010). Corrosion inhibition of mild steel in acidic media. International Journal of Electrochemical Science.
[6] Verma, C., Ebenso, E. E., Quraishi, M. A., & Obot, I. B. (2018). Green corrosion inhibitors: Past, present, and future. Journal of Molecular Liquids.
[7] Quraishi, M. A., Singh, A., Singh, V. K., Yadav, D. K., & Singh, A. K. (2015). Green approach to corrosion inhibition. Materials Chemistry and Physics.
[8] Umoren, S. A., & Solomon, M. M. (2017). Recent developments on the use of plant extracts as corrosion inhibitors. Journal of Industrial and Engineering Chemistry..
[9] Raja, P. B., & Sethuraman, M. G. (2008). Natural products as corrosion inhibitors for metals. Materials Letters.
[10] Oguzie, E. E. (2006). Corrosion inhibition by plant extracts. Materials Chemistry and Physics.
[11] El-Etre, A. Y. (2006). Natural compounds as corrosion inhibitors. Applied Surface Science.
[12] El-Etre, A. Y. (2006). Khillah extract as inhibitor for acid corrosion of SX 316 steel. Applied surface science, 252(24), 8521-8525.
[13] Velázquez-González, M. A., Gonzalez-Rodriguez, J. G., Valladares-Cisneros, M. G., & Hermoso-Diaz, I. A. (2014). Use of Rosmarinus officinalis as green corrosion inhibitor for carbon steel in acid medium. American Journal of Analytical Chemistry, 2014
[14] Oguzie, E. E. (2006). Studies on the inhibitive effect of Occimum viridis extract on the acid corrosion of mild steel. Materials Chemistry and Physics, 99(2-3), 441-446
[15] Rodríguez Torres, A., Valladares Cisneros, M. G., & González Rodríguez, J. G. (2016). Medicago sativa as a green corrosion inhibitor for 1018 carbon steel in 0.5 M H2SO4 solution. Green Chemistry Letters and Reviews, 9(3), 143-155.
[16] Umoren, S. A., Solomon, M. M., Obot, I. B., & Suleiman, R. K. (2021). Date palm leaves extract as a green and sustainable corrosion inhibitor for low carbon steel in 15 wt.% HCl solution: the role of extraction solvent on inhibition effect. Environmental Science and Pollution Research, 28(30), 40879-40894.
[17] Olanrele, O. S., Femi-Dagunro, J., Ofudje, E. A., Algarni, M., Al-Ghamdi, A. A., Aldahiri, R. H., ... & Alsaiari, A. A. (2024). Optimization, molecular dynamics and quantum parameters simulations of Zingiber officinale rhizome as a green corrosion inhibitor. Heliyon, 10(18).
[18] Ji, G., Anjum, S., Sundaram, S., & Prakash, R. (2015). Musa paradisica peel extract as green corrosion inhibitor for mild steel in HCl solution. Corrosion Science, 90, 107-117.
[19] Abakedi OU. Inhibition of aluminium corrosion inhydrochloric acid solution by Stachytarphetaindica leaf extract. Journal of Scientific and Engineering Research 2016;3(3):105-110.
[20] Odusote, J. K., & Ajayi, O. M. (2013). Corrosion inhibition of mild steel in acidic medium by jathropha curcas leaves extract. Journal of electrochemical science and technology, 4(2), 81-87.
[21] M. G. Fontana, N. D. Greene, and J. Klerer, "Corrosion engineering," Journal of The Electrochemical Society, vol. 115, p. 142C, 1968.
[22] Amin, M. A., Abd El-Rehim, S. S., El-Sherbini, E. E. F., & Bayoumi, R. S. (2007). Electrochimica Acta, 52, 3588–3600.
[23] Oguzie, E. E. (2006). Materials Chemistry and Physics, 99, 441–446.