International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 37 العدد
Part 1 المجلد

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

http://www.doi.org/10.62341/mgra1730

Received	**2025/07/02**	**تم استلام الورقة العلمية في**
Accepted	**2025/07/29**	**تم قبول الورقة العلمية في**
Published	**2025/07/31**	**تم نشر الورقة العلمية في**

Inhibition of corrosion for medium carbon steel using the aqueous extract of *saussurea costus* at temperature of 35 °C

Masouda Farhat[1], Salah Aldeen S.Altahbao[1], Itawel oumrou Taleb amar [2], Sulayman M.Adabu[1], Noaf A.Zidan[1], Mashri A. Ahmad [3], Fares Fenniche [4,5], Yasmina Khane [4], Fatma Alarbi[6] and Elfitouri K. Ahmied[7]

[1] materials and corrosion engineering department, Faculty of Engineering, Sebha University, sebha, Libya
[2] Laboratory of Materials Chemistry, Faculty of Science and Technology, University of Nouakchott Al Aasriya (UNA), Nouakchott, Mauritania.
[3,] Faculty of Scenic, Sebha University, sebha, Libya
[4] Materials, Energy Systems Technology and Environment Laboratory, Faculty of Sciences and Technology, University of Ghardaia, 47000 Ghardaia, Algeria.
[5] Department of Process Engineering, Faculty of Sciences and Technology, University of Ghardaïa, BP 455, 47000 Ghardaïa, Algeria.
[6] Chemical Department, faculty of science, Fezzan University, Libya
[7] Faculty of Engineering, Sirte University, Libya

E-mail address: sal.altahbow@sebhau.edu.ly

Abstract

This study investigates the corrosion inhibition of medium carbon steel in 1 M HCl using the weight loss method to analyze reaction kinetics and corrosion rates. *Saussurea costus* extract formed a protective layer on the metal surface, effectively mitigating acidic corrosion, with inhibition efficiency increasing at higher concentrations. Kinetic and thermodynamic adsorption studies revealed adsorption following the Langmuir isotherm *via* a physisorption mechanism, as confirmed by an adsorption free energy (ΔG°ads) of -38.35 kJ/mol. These findings provide valuable insights for developing efficient and sustainable acidic corrosion inhibitors.

http://www.doi.org/10.62341/mgra1730

Keywords: Saussurea costus, Corrosion inhibition; Carbon steel; Hydrochloric acid; Activation energy, Aqueous extract, Weight loss method.

تثبيط تآكل الفولاذ متوسط الكربون باستخدام المستخلص المائي لنبات القسط الهندي عند درجة حرارة 35 درجة مئوية

مسعودة فرحات[1]، صلاح الدين سالم التحبو[1]، اطوال طالب عمر[2]، سليمان ادعابو[1]، نوف زيدان[1]، مشاري احمادي[3]، فارس فنتش[4,5]، ياسمينة خان[4]، فاطمة العربي[6]، الفيتوري خليفة احميد[7].

[1]قسم هندسة المواد و التاكل ، كلية الهندسة، جامعة سبها، ليبيا

[2]مختبر كيمياء المواد، كلية العلوم والتقنيات، جامعة نواكشوط العصرية/نواكشوط/ موريتانيا.

[3]قسم الكمياء، كلية العلوم جامعة سبها/سبها/ ليبيا

[4]مختبر المواد وتكنولوجيا أنظمة الطاقة والبيئة، كلية العلوم والتكنولوجيا، جامعة غرداية، غرداية، الجزائر.

[5]قسم هندسة الطرائق، كلية العلوم والتكنولوجيا، جامعة غرداية، غرداية، الجزائر.

[6]قسم الكيمياء، كلية العلوم / جامعة فزان، ليبيا

[7]كلية الهندسة ، جامعة سرت، / ليبيا

المخلص:

تتناول هذه الدراسة تثبيط تآكل الفولاذ متوسط الكربون في محلول حمض الهيدروكلوريك بتركيز 1 مولاري، باستخدام طريقة فقدان الوزن لتحليل حركية التفاعل ومعدلات التآكل. وقد كوَّن مستخلص القسط الهندي (Saussurea costus) طبقةً واقيةً على سطح المعدن، مما خفف بشكل فعال من التآكل الحمضي، مع زيادة كفاءة التثبيط عند التركيزات الأعلى. وكشفت دراسات الامتزاز الحركية والديناميكية الحرارية أن الامتزاز يتبع متساوي الامتزاز لانجمير (Langmuir isotherm) من خلال آلية الامتزاز الفيزيائي، وهو ما تؤكده طاقة الامتزاز الحرة (ΔG°_{ads}) البالغة −38.35 كيلو جول/مول. تقدم هذه النتائج رؤىً قيمةً لتطوير مثبطات تآكل حمضية فعالة ومستدامة.

الكلمات المفتاحية: القسط الهندي، تثبيط التأكل، صلب كربوني، حمض الهيدروكلوريك، طاقة التنشيط، مستخلص مائي، طريقة الفقد في الوزن.

http://www.doi.org/10.62341/mgra1730

1.Introduction

Corrosion is a fundamental process resulting in the degradation of metal surfaces due to chemical interactions with their surroundings. In industrial sectors such as oil and gas, corrosion-related failures in pipelines and structural components contribute to approximately 25–30% of total economic losses [1]. Steel, a widely utilized metallic material, primarily consists of iron and carbon, with variations incorporating additional alloying elements [2–5]. Its carbon content typically ranges from 0.05% to approximately 1.2% [5]. Plain carbon steel—containing only carbon as an alloying element—exhibits varying degrees of strength and hardness depending on its carbon composition [4,6,7]. However, carbon steels are highly susceptible to corrosion in industrial environments, necessitating effective inhibition strategies to enhance their durability and economic viability [8]. Corrosion is an intrinsic process driven by the tendency of metals and alloys to revert to their most stable thermodynamic states upon environmental exposure. Except for noble metals like gold and platinum, most metals occur naturally as stable oxides or sulphides [9]. Consequently, corrosion serves as a spontaneous mechanism through which metals achieve a lower energy state [10], influenced by both natural and anthropogenic factors. Generally, corrosion is defined as the inevitable deterioration of metal properties due to interaction with specific environmental agents [11]. Various strategies mitigate corrosion, including selecting corrosion-resistant materials, electrochemical protection, surface coatings, and corrosion inhibitors [12,13]. Among these, incorporating corrosion inhibitors (CIs) is regarded as one of the most efficient and cost-effective techniques. These inhibitors significantly reduce metal degradation rates when added in low concentrations to corrosive media [14]. With increasing emphasis on environmental sustainability and green chemistry, research has shifted toward developing eco-friendly corrosion inhibitors as alternatives to hazardous synthetic compounds [15]. Plant-derived extracts have emerged as promising candidates due to their abundance, cost-effectiveness, and ease of extraction [16,17]. Studies demonstrate that bioactive constituents in plant extracts can exhibit corrosion inhibition efficiencies comparable to synthetic inhibitors [18]. In this context, *Saussurea costus* extract has been identified as a potential corrosion inhibitor for carbon steel due to its reported effectiveness. This research aims to explore the inhibitory action of *Saussurea costus* aqueous extract

http://www.doi.org/10.62341/mgra1730

on carbon steel corrosion and examine surface analysis techniques for evaluating corrosion resistance with and without the inhibitor.

2. Materials and methods

A 1 M hydrochloric acid (HCl) solution was used as the corrosive medium in this study. The chemical composition of the medium carbon steel was determined using energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, and the results are shown in Table 1.

Table 1 shows the chemical composition of the sample.

Fe	C	Mn	Si	S	Al	P	Cu
95%	0.45%	0.911%	1.3%	0.25%	0.46%	0.11%	0.49%

Fig1.illustrates the steel specimens fabricated into cylindrical shapes

Figure 1 illustrates the steel specimens fabricated into cylindrical shapes (40 mm length × 10 mm diameter). Prior to experimentation, these samples underwent a surface preparation process involving sequential polishing with different grades of sandpaper, degreasing with acetone, rinsing with double-distilled water, thorough drying, and storage in a desiccator to prevent contamination.

Regarding the preparation of *Saussurea costus* extract, the plant material was first dried and finely ground before undergoing aqueous extraction. To prepare the stock solution, 20 grams of the dried and powdered *Saussurea costus* were heated in a round-bottom flask equipped with an air condenser at 70°C for 24 hours in the presence of 500 mL of distilled water. The resulting solution was then left to stand overnight to ensure complete extraction of bioactive compounds before further processing.

http://www.doi.org/10.62341/mgra1730

3. Analytical methods

3.1 Weight loss method

The weight loss technique was used to evaluate the corrosion inhibition efficiency of Saussurea costus extract on medium carbon steel. Prior to immersion, each test specimen was accurately weighed and then placed into a 100 mL solution of 1 M hydrochloric acid (HCl), both with and without the inhibitor at varying concentrations (0.01%, 0.02%, 0.03%, and 0.04% v/v). The samples were completely submerged in the test solution for 3 hours at a controlled temperature of 308 K. After the exposure period, the specimens were carefully removed, dried, and reweighed to determine the weight loss. All experiments were conducted at the Center for Scientific Research and Consultations, Sebha University.

The corrosion rate (CR) was computed using Equation (1):

$$CR = \frac{\Delta W}{A.t} \qquad (1) \quad [19]$$

Where:

- **ΔW** represents the weight loss of the steel sample,
- **A** is the total surface area of the specimen (cm^2), and
- **t** is the immersion time (minutes)

The inhibition efficiency (IE%) and surface coverage (θ) were determined by comparing the weight loss in both the absence (Wo) and presence (W) of the inhibitor, following Equation (2):

$$\%\,IE = \theta\, x\, 100 = \left[1 - \left(\frac{W1}{Wo}\right)\right] x\, 100 \qquad (2) \quad [20]$$

Where Wo and W1 correspond to the weight loss of the sample without and with the inhibitor, respectively.

The degree of surface coverage (θ) was further calculated using Equation (3):

$$\theta = \mathrm{IE}/\,100 \qquad (3) \quad [21]$$

Where:

- **θ** represents the surface coverage, and
- **IE** (%) denotes the inhibition efficiency.

http://www.doi.org/10.62341/mgra1730

3.2 Corrosion inhibition mechanism

The inhibition of corrosion is primarily attributed to the presence of bioactive compounds such as alkaloids, flavonoids, phenols, and terpenes, which exhibit antioxidant properties and can effectively interact with the steel surface. These compounds facilitate the adsorption process, leading to the formation of a protective barrier that limits direct contact between the metal and the corrosive medium.

Additionally, temperature plays a crucial role in the corrosion process, as the rate of metal deterioration generally increases with rising temperatures. Therefore, evaluating the efficiency of the inhibitor under such conditions provides valuable insights into its potential practical applications in moderate industrial environments.

4 .Results and discussion

4.1 Effect of temperature

Temperature plays a crucial role in influencing the electrochemical corrosion rate of metals. In acidic environments, an increase in temperature typically accelerates the corrosion process due to the reduction in hydrogen evolution potential. The interaction between the metal, acid, and inhibitor is highly complex, as elevated temperatures can lead to rapid surface etching, removal of the protective inhibitor layer, and, in some cases, degradation or structural rearrangement of the inhibitor itself. Despite the general trend of increasing corrosion rates with rising temperature, it has been observed that inhibition efficiency tends to improve both with higher temperatures and greater inhibitor concentrations. Experimental investigations conducted at approximately 308 K in a 1 M hydrochloric acid solution demonstrated that the maximum inhibition efficiency reached 57.13%, as summarized in Table 2.

http://www.doi.org/10.62341/mgra1730

Table 2: Data corrosion rate and inhibition efficiency.

Sample No.	Inhibitor (Concentration)	CR (mg/cm^2 min*10^{-3})	Efficiency of Inhibitor (IE) (%)
1	Blank	44.516	--
2	0.01	34.529	22.434
3	0.02	28.157	36.748
4	0.03	21.361	52.015
5	0.04	19.083	57.132

The adsorption of bioactive constituents from the extract onto the surface of mild steel likely facilitated the formation of a protective molecular layer. This adsorbed layer serves as a barrier, minimizing direct contact between the metal and the corrosive acidic environment, thereby significantly reducing the corrosion rate. The observed inhibitory effect can be attributed to this protective mechanism. These findings are consistent with previous research studies that have reported similar adsorption-driven corrosion inhibition mechanisms [22–24].

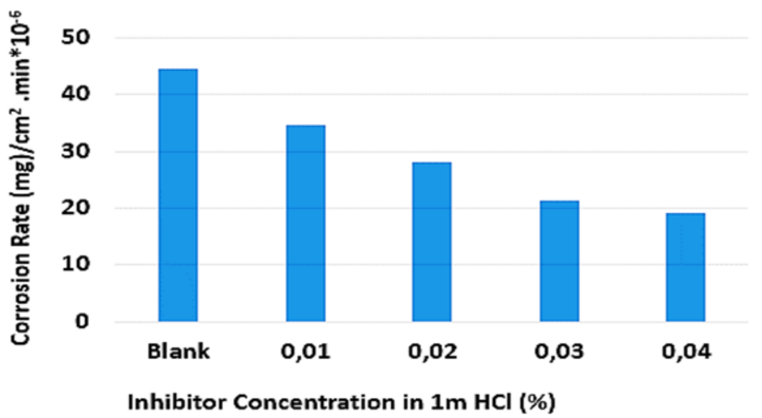

Figure. 1: Variation of corrosion rate with the concentration of the inhibitor

As the concentration of the extract increased, the inhibition efficiency also improved, reaching a maximum of 57%, as illustrated in Figure. 2. Phytochemical analysis of the Saussurea costus leaf extract revealed the presence of flavonoids, tannins, alkaloids, and phenols [23, 26, 27]. The strong inhibitory effect

http://www.doi.org/10.62341/mgra1730

observed can be attributed to these bioactive compounds, which are known for their corrosion protection properties. Upon adsorption onto the metal surface, these constituents act as barriers to charge transfer, thereby limiting the interaction between the metal and its corrosive environment.

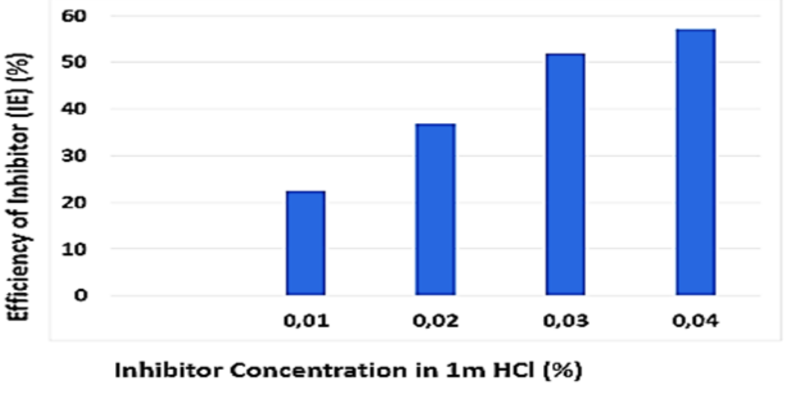

Figure3. 2: Variation of inhibition efficiency with the concentration of the inhibitor for mild steel in 1 M HCl

4.2. Analysis of Adsorption Models:

Adsorption isotherms provide crucial insights into the interaction between the inhibitor molecules and the metal surface. The surface coverage (Θ) values at 308 K were analyzed to determine the most suitable adsorption model. Various isotherms, including Langmuir, Freundlich, and Temkin, were tested to evaluate the adsorption mechanism. The equations for these models are as follows:

- **Langmuir Isotherm:**

  $Log(C\theta)=Log\ Kad-LogC$ (4) [28]

- **Temkin Isotherm:**

  $\mathrm{Exp}\ (f\theta)=KC$ (5) [27]

- **Freundlich Isotherm:**

  $Log\ (\theta)=Log\ K+1nLogC$ (6) [28]

http://www.doi.org/10.62341/mgra1730

Where:

- Θ represents the surface coverage,
- K is the adsorption equilibrium constant,
- C is the inhibitor concentration,
- f is the heterogeneity factor of adsorption sites.
- n is the Freundlich constant related to adsorption intensity.

Among the tested models, the Langmuir isotherm provided the best fit, with the regression coefficient (R^2) values being very close to one, indicating monolayer adsorption of the inhibitor molecules on the mild steel surface. The adsorption of organic molecules from the aqueous phase onto the electrode surface can be considered as a quasi-substitution process, where water molecules are displaced by inhibitor molecules:

$$Org_{(sol)} + XH_2O_{(aq)} = Org_{(aq)} + H_2O_{(sol)}$$

Where X represents the number of water molecules replaced by each inhibitor molecule on the metal surface.

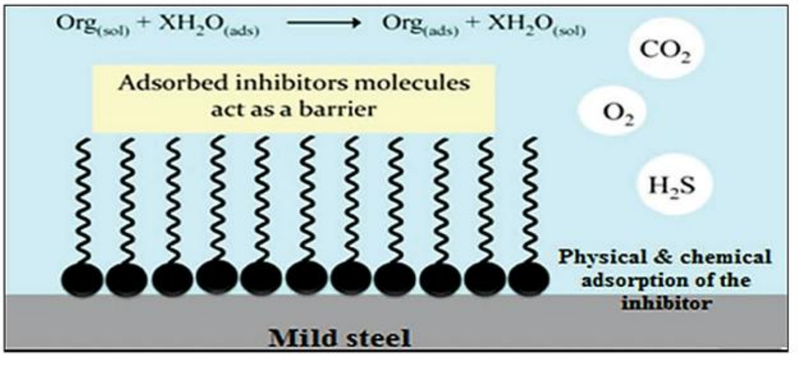

Figure. 3: An illustration depicting the possible orientation of active organic inhibitor components during the adsorption phenomenon on the surface of mild steel [28]

The calculation of **ΔG°ads** for *Saussurea costus* extracts was performed using Equation 7, which indicates that the free energy change of adsorption (**ΔG°ads**) is directly related to **K** at a given temperature (**T**):

$$\Delta G^0_{ads} = RT \ln (K\ ads \times 55.5) \qquad (7) \quad [29]$$

http://www.doi.org/10.62341/mgra1730

A ΔG°ads value of -38.35 kJ·mol^{-1} was obtained. The adsorption process was spontaneous, as indicated by the negative value. Generally, physical adsorption is characterized by ΔG°ads values around -20 kJ/mol, while chemical adsorption is associated with values more negative than -40 kJ/mol [30, 31]. As shown in Table 2, the obtained values of the adsorption constant were used to determine the Gibbs free energy of adsorption (ΔG°ads).

Table 2: Adsorption data for steel samples in the aqueous extract of *Saussurea costus*.

Sample No.	Surface Coverage (θ)	Adsorption Constant (Kads) (g −1)	Adsorption Energy (ΔG°ads) (kJ/mol)
1	--	--	--
2	0.22434	0.2892	-31.2524
3	0.36748	0.8310	-36.693
4	0.52015	2.0724	-38.3569
5	0.57132	3.3484	-38.4488

The values show an increase in the adsorption equilibrium constant (K ads) with the rise in inhibitor concentration, confirming the effectiveness of the protective layer.
According to the statistics presented in Table 2:

1. The values of K_ads increase with increasing inhibitor concentration.

2. The ΔG°_ads values exceed -20 kJ·mol^{-1}, indicating that the adsorption process is predominantly physical.

Additionally, the Temkin adsorption isotherm (Figure.4) was applied to describe the nature of the inhibitor's adsorption.

Figure. 4 illustrates that the inhibitor follows the Langmuir isotherm, as evidenced by the high R^2 values across all temperatures. The Langmuir model assumes that molecules adsorb in a dense monolayer on the metal surface [32]. The linear plot, with a high correlation coefficient (R^2 = 0.9915 for the Langmuir isotherm), clearly indicates that the adsorption of Saussurea costus on mild steel surfaces adheres to the Langmuir adsorption model.

http://www.doi.org/10.62341/mgra1730

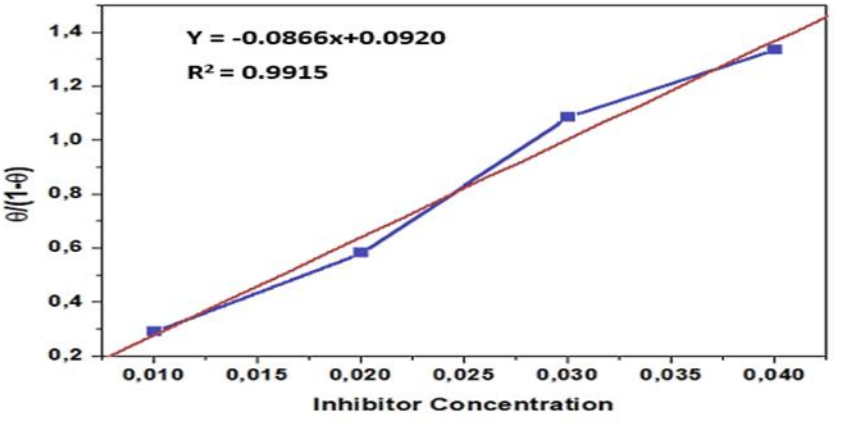

Figure. 4: Langmuir isotherm curve.

The Temkin isotherm model for adsorption includes a factor that explicitly accounts for the interactions between ions in the aqueous solution and the membrane (adsorbent-adsorbate). The extracted correlation coefficient (R^2) at a temperature of 308 K was 0.9723. Since R^2 at this temperature is very close to one, it indicates a stronger adherence to the Temkin adsorption isotherm model compared to the same inhibitor at 35°C.

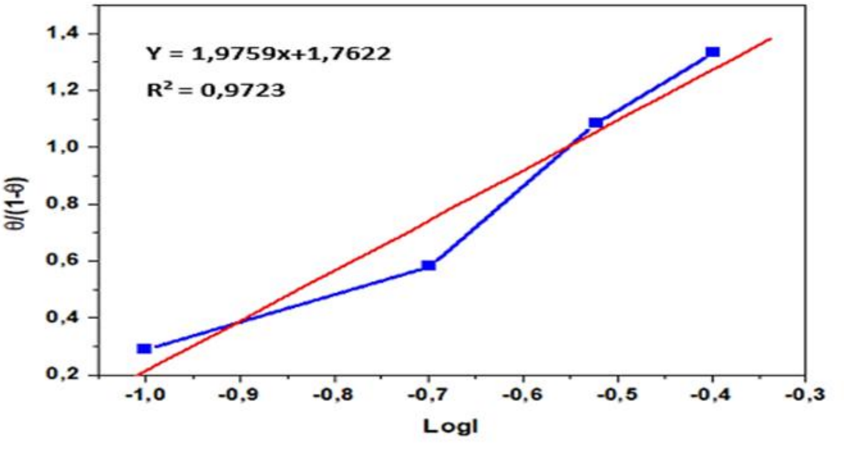

Figure 5: Temkin isotherm curve.

The Freundlich model was chosen to evaluate the adsorption capacity of both the adsorbent and the adsorbate solution. As shown

http://www.doi.org/10.62341/mgra1730

in Figure 6, an almost perfectly linear graph was obtained, with a correlation coefficient (R^2) of 0.99437.

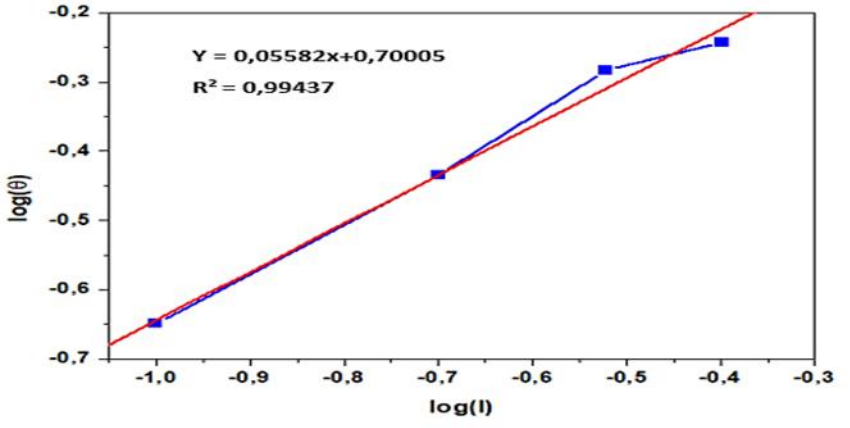

Figure. 6: Freundlich isotherm curve.

5. Conclusions

The results demonstrate that *Saussurea costus* extract acts as an effective inhibitor of mild steel corrosion in an acidic medium. The data show that the inhibition efficiency (%IE) increases with the extract concentration, indicating a strong interaction between the bioactive compounds in the extract and the metal surface. This inhibitory effect is attributed to the adsorption of active components, such as flavonoids, alkaloids, phenols, and tannins, onto the steel surface, forming a protective barrier that prevents direct contact between the metal and the corrosive medium.

The adsorption mechanism was analyzed using various isotherm models, which revealed that the adsorption follows the Langmuir isotherm, suggesting the formation of a monolayer on the metal surface. Furthermore, the values of $\Delta G°_{ads}$ indicated that the adsorption process occurs primarily through physisorption. This mechanism facilitates the removal of the inhibitor from the surface when necessary, making it an environmentally viable option. The inhibition efficiency was also evaluated at different temperatures, with results showing that efficiency increased as the temperature rose, indicating the stability of the adsorbed layer under the studied conditions.

http://www.doi.org/10.62341/mgra1730

Based on these findings, *Saussurea costus* extract is a promising eco-friendly corrosion inhibitor and a viable alternative to conventional chemical inhibitors, which may pose environmental hazards. However, further studies are recommended to gain a deeper understanding of the adsorption mechanism, investigate the influence of additional factors such as time and PH, and assess the inhibitor's effectiveness in various industrial environments to enhance its potential for large-scale applications.

References

[1]- Abd El-Lateef, Hany M., K. Shalabi, and Ahmed H. Tantawy. "Corrosion inhibition of carbon steel in hydrochloric acid solution using newly synthesized urea-based cationic fluorosurfactants: Experimental and computational investigations." New Journal of Chemistry 44, no. 41 (2020): 17791-17814.

[2]- Hardy Mohrbacher, Andreas Kern, Nickel alloying in carbon steel fundamentals and applications, Alloys, 2 (2023), PP 1-28.

[3]-Fatahalla, Nabil, Aly Abu El Ezz, Moenes Semeida, Si and Ni as alloying elements to vary carbon equivalent of austenitic ductile cast iron Microstructure and mechanical properties, Materials Science and Engineering 2 (2009) PP 81-89.

[4]- Cunat, Pierre Jean, Alloying elements in stainless steel and other chromium-containing alloys, Euro Inox, 2004 (2004) PP 1-24.

[5]- Santofimia, Maria Jesus, Microstructural development during the quenching and partitioning process in a newly designed low-carbon steel, Acta Materialia 15 (2011) 6059-6068.

[6]- Link, Schmitt, Iron Carbon Steel and Alloy Steel Materials of Construction Review Industrial Engineering Chemistry, 53 (1961) PP 590-595.

[7]- Schlegel, Joachim, The World of Steel, Springer, (2023) PP 45-49.

http://www.doi.org/10.62341/mgra1730

[8]-Kadhim, Betti, Al-Bahrani, Al-Ghezi, Gaaz, Kadhum, Alamiery, A mini review on corrosion, inhibitors and mechanism types of mild steel inhibition in an acidic environment, International Journal of Corrosion and Scale Inhibition, 10 (2021) PP 861-884.

[9]-Quadri, T.W, Olasunkanmi, L.O, Fayemi, O.E, Ebenso, E.E, Fundamentals of corrosion chemistry. In Environmentally Sustainable Corrosion Inhibitors, Springer, (2022) PP (25-45)

[10]- Rani, Basu, Green inhibitors for corrosion protection of metals and alloys an overview. International Journal of corrosion (2012) 380217.

[11]-Balamurugan, Rajeswari, Balossier, Rebelo, Ferreira, Corrosion aspects of metallic implants An overview. Materials and corrosion, 11 (2008) PP 855-869.

[12]-Popoola, Olorunniwo, Corrosion resistance through the application of anti-corrosion coatings Developments in corrosion protection, 13 (2014) PP 241-270.

[13]-Ates, Murat, A review on conducting polymer coatings for corrosion protection. Journal of adhesion science and Technology, 30 (2016) 1510-1536.

[14]-Assad, Thakur, Bharmal, Sharma, Ganjoo, Kaya, Corrosion inhibitors fundamental concepts and selection metrics Corrosion Mitigation, (2022) PP 19-50.

[15]- Al Jahdaly, Maghraby, Ibrahim, Shouier, Alturki, El-Shabasy, Role of green chemistry in sustainable corrosion inhibition a review on recent developments Materials Today Sustainability, 20 (2022) 100242.

[16]- Salzman, Driscoll, Renner, André, Shen, a molecular phylogeny and investigation of biogeographic origins and floral evolution for the genus Costus Systematic Botany, 40 (2015) PP 104-115.

[17]- Sasidharan, Chen, Saravanan, Sundram, Latha, Extraction isolation and characterization of bioactive compounds from plants extracts African journal of traditional complementary and alternative medicines, 8 (2011).

http://www.doi.org/10.62341/mgra1730

[18]- Zakeri, Bahmani, Aghdam, Plant extracts as sustainable and green corrosion inhibitors for protection of ferrous metals in corrosive media A mini review Corrosion Communications, 5 (2022) PP 25-38.

[19]- G. W.Castellan, "Physical Chemistry" 3rd ed., Wesley, New York (1983).

[20]- Khaled, M.A.; Ismail, M.A.; El-Hossiany, A.A.; Fouda, A.S. Novel pyrimidine-bichalcophene derivatives as corrosion inhibitors for copper in 1 M nitric acid solution. RSC Advances(2021), 11, 25314-25333, https://doi.org/10.1039/D1RA03603C

[21]- Dahmani M, Et-Touhami A, Al-Deyab SS, Hammouti B, Bouyanzer A. Corrosion inhibition of C38 steel in 1 M HCl: A comparative study of black pepper extract and its isolated piperine. Int J Electrochem Sci. (2010) Aug 1; 5(8): 1060-9.

[22]- 48. Akpan IA, Offiong NO "Effects of ethanolamine and ethylamine on the entropy content of the corrosion of mild steel in 1 mol/l HCl solution". Indian J Phys Chem 8(3) (2013): PP 112–117

[23]- B. I. Ekemini and E. U. Uwemedimo, Phytochemical profile, Adsorptive and Inhibitive
behaviour of Costus afer extracts on aluminium corrosion in hydrochloric acid. Der Chemica Sinica, (2012), 3(6):1394-1405.

[24]- I. M. Mejeha, A. A. Uroh, K. B. Okeoma, G. A. Alozie, The inhibitive effects of Solanum melongena L. Leaf extract on the corrosion of aluminium in tetraoxosulphate (VI) acid. Afr. J. Pure Appl. Chem., (2010) 4(8): 158-165.

[25]- E. E. Oguzie, Corrosion inhibitive effect and adsorption behaviour of Hibiscus sabdariffa on mild steel in acidic media. Portugaliae Electrochemica Acta., (2008), 26: 303-314.

[26]- C. F. Ukpabi, K. N. Agbafor, O. K. Ndukwe, A. Agwu, S. N. Nwachukwu, Phytochemical Composition of Costus afer Extract and Its Alleviation of Carbon Tetrachloride – induced Hepatic Oxidative Stress and Toxicity. International Journal of Modern Botany (2012), 2(5): 120-126.

http://www.doi.org/10.62341/mgra1730

[27]- M. M. Akpan, C. S. Odeomena, , C. N. Nwachukwu, B. Danladi, Asian journal of plant science and research, (2012), (2): 335-341.

[28]- Li X., Deng S., Fu H., (2011), Inhibition by Tetradecylpyridinium Bromide of the Corrosion of Aluminium in Hydrochloric Acid solution, Journal of Corrosion Science. Volume 53, Issue 4, April (2011), Pages 1529-1536,

[29]- Kumar, H.; Yadav, V.; Kumari, A. Adsorption, corrosion inhibition mechanism, and computational studies of Azadirachta indica extract for protecting mild steel: Sustainable and green approach. Journal of Physics and Chemistry of Solids. (2022), 165, 110690, https://doi.org/10.1016/j.jpcs.2022.110690.

[30]- L. A. Nnanna, B. N. Onwuagba, I. M. Mejeha, K. B. Okeoma, Inhibition effects of some plant extracts on the acid corrosion of aluminium alloy. Afr. J. Pure Appl. Chem., (2010),

[32]- L. A. Nnanna, W. O. John, E. C. Emenike, U. Ihekoronye, I. I. Dike, Corrosion Inhibition effect of Anthocleista djalonesis on mild steel in 1.0M HCl. IJERR (2015), Vol. 3, Issue 4, pp: (31-36).

[31]- M. Iannuzzi, G. S. Frankel, Mechanisms of corrosion inhibition of AA2024-T3 by vanadates. Corros. Sci., (2007), 49: 2371-2391

[32]- H. Hassannejad et al, Sunflower seed hull extract as a novel green corrosion inhibitor for mild steel in HCl solution, Journal of Molecular Liquids, 254, (2018), PP 377–382.