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Preventing Mild Steel Corrosion in 1.0 M HCl with Waterer Egyptian Wormwood Leaves and Stems (WEWLS) (Analyzing Thermodynamic and Adsorption Parameters)

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Abstract:

Mild steels are particularly prone to corrosion in acidic environments, such HCl, which causes industries to suffer significant financial losses that are estimated to be in the billions of dollars each year. One tactic to reduce corrosion is to use corrosion inhibitors. Research has indicated that organic molecules—particularly those containing N, S, and O—have exhibited noteworthy inhibitory efficacy when it comes to the majority of synthetic organic corrosion inhibitor compounds. Unfortunately, most of these compounds are not only expensive but also toxic to living things. The main goal of this experiment was to determine the effects of adding different weights of Waterer Egyptian Wormwood Leaves and Stems (WEWLS) extract to a one mole aqueous HCl solution on mild steel material corrosion. The corrosion rate (CR), inhibitor efficiency (IE%), adsorption constants ($K_{ads.}$), adsorption energies ($\Delta G_{ads.}$), and adsorption isotherm models (Langmuir, Temkin, and Adejo Ekwenchi) were all taken into account in the weight loss technique. The weight loss experiment's results showed that when inhibitor concentration increases, corrosion inhibition increases gradually. At an inhibitor concentration of (300 ppm), the maximum inhibition efficiency of (93.07%) was achieved. The effective adsorption of the inhibitor on the metal surface is confirmed by the adsorption measurements.

Keywords: Mild steels, HCl Corrosion, Wormwood, Thermodynamics parameters, Adsorption isotherm models.

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منع تآكل الفولاذ الطري في مول من حمض الهيدروكلوريك باستخدام أوراق وسيقان الشيح المصري المروي (تحليل معاملات الديناميكا الحرارية وآلية الامتزاز)

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الملخص
يكون الفولاذ الطري عرضة بشكل خاص للتآكل في البيئات الحمضية، مثل حمض الهيدروكلوريك، مما يتسبب في تكبد الصناعات خسائر مالية كبيرة تقدر بمليارات الدولارات كل عام. يعد استخدام مثبطات التآكل إحدى الإستراتيجيات لتقليل التآكل. ظهرت الدراسات التي أجريت على غالبية المواد الكيميائية العضوية المثبطة للتآكل أن الجزيئات العضوية، خاصة تلك التي تحتوي على النيتروجين والكبريت والأوكسجين، أظهرت كفاءة مثبطة ملحوظة. ومن المؤسف أن غالبية هذه المواد ليست باهظة الثمن فحسب، بل إنها ضارة أيضًا بالكائنات الحية. كان الهدف الأساسي من هذه التجربة هو تحديد تأثير إضافة أوزان مختلفة من مستخلص أوراق وسيقان الشيح المصري المروي. إحدى المشكلات الواضحة المرتبطة بالتلوث البيئي التي تسببها شجرة البوينسيانا هي تساقط القرون الحاوية للبذور على الأرض، مما يؤدي إلى تشويه المنظر البيئي وتستلزم تنظيفها بإستمرار. الهدف الأساسي من هذا البحث هو دراسة تأثير إضافة أوزان مختلفة من مركب مستخلص أوراق وسيقان الشيح المصري المروي إلى مول من محلول حمض الهيدروكلوريك المائي على تآكل الفولاذ الطري. تقنية فقدان الوزن: (معدل التآكل و كفاءة المثبط) و المعاملات الثرموديناميكية: (الطاقة الحرة للإمتزاز و ثابث الإمتزاز) ونماذج الإمتزاز الأيزوثرمية: (لانجموير وتيمكين وأديجو إيكوينشي) تم أخذها بعين الاعتبار. أثبتت نتائج تجارب تقنية فقدان الوزن أنه مع زيادة تركيز المثبط، يزداد تثبيط التآكل تدريجياً. أقصى كفاءة للمثبط كانت (93.07%) عند أقصى تركيز مستخدم للمثبط وهو (300 جزء من المليون).

الكلمات المفتاحية: الفولاذ الطري، تآكل حمض الهيدروكلوريك، نبات الشيح ، معاملات الديناميكا الحرارية ، نماذج الأمتزاز الأيزوثرمية.

Introduction

In industry, mild steels are used extensively. Metal materials are frequently treated on their surface using pickling techniques. Because acidic solutions like hydrochloric and sulphuric acids are aggressive, the presence of metal corrosion inhibitors is essential for decreasing metal corrosion during pickling processes [1-2]. Steel corrosion can be prevented or reduced using a variety of techniques that have been developed over time [3-5]. These methods include corrosion inhibitors, cathodic protection, protective coatings, galvanization, and antirust solutions. Most conventional inorganic or organic metal corrosion inhibitors, however, have a high potential to harm the environment [6–7]. Corrosion inhibitors have shown to be very successful in protecting metals from deterioration in harsh industrial environments [8–9]. The capacity of these inhibitors to attach to the metal surface through specific interactions—atomic rings, conjugated double bonds, and heteroatoms of nitrogen, sulphur, and oxygen- is responsible for their potent corrosion inhibition [10–12]. However, there are worries over the possible harm that corrosion inhibitors could do to the environment and public health due to their extensive use and incorrect disposal. The body's enzyme systems can be upset by corrosion inhibitors, which can also permanently or temporarily harm particular organs like the liver or kidneys [13 -15]. Effective inhibitors must be used to limit hydrochloric acid's attack on the base metal surface. These severe circumstances, with intense hydrochloric acid and temperatures ranging from (0 to 60 °C), should not affect the inhibitors' ability to function [16]. Herbal oils are highly concentrated, hydrophobic liquids that are extracted from the leaves or stems of plants, capturing the essence of the plant components used to make them [17 -18]. There are several ways to obtain essential oil, including mechanical extraction, steam extraction, and dry distillation. They are a good option for use as corrosion inhibitors in severe settings, such as hydrochloric acid, due to their benign and biodegradable nature [19 -21].

The percentage of adsorbent on the adsorbent as a function of concentration or pressure at a specific temperature is known as adsorption. Usually, the adsorption process is studied using adsorption isotherm graphs. The mass of the adsorbent is typically used to normalize the amount absorbed in order to facilitate comparisons across different materials. As per the previously mentioned details, adsorption ceases at saturation pressure, also known as "Ps," signifying that the adsorbent's surface has a limited quantity of open spaces. All of the sites are occupied after a specific high-pressure point, and further pressure rise has no influence on the adsorption process. At high pressure, adsorption is independent of pressure [22]. In strong acid media, inhibitor adsorption at the metal-solution interface is thought to be the first stage of the inhibitors' activity. There are numerous ways to express the adsorption isotherms. An appropriate isotherm model should be used to create the adsorption process, and one of the isotherm models must include the data's isotherm analysis [22]. Adsorption kinetics describes the duration of adsorbates' residence on the solid-liquid interface as well as the rate of solute adsorption. Adsorption isotherms are used to determine the ideal adsorbent capacity as well as the interaction between the adsorbent and adsorbate [23]. Adsorption can take place by physical (physisorption) or chemical (chemisorption) processes. Van der Waals dipole moment produces weak, short-range electrostatic attractive forces that lead to physical adsorption, whereas bond formation between the adsorbent and adsorbate occurs during chemisorption. It's critical to distinguish between absorption and adsorption. Adsorption is the attraction and/or bonding on the surface of an adsorbent, while absorption is the process by which a solute is taken up into a structure or over a membrane. One of the best methods for eliminating impurities from solutions is adsorption [24].

Numerous research organizations have demonstrated that natural chemicals, such the oil from wormwood plants, are efficient in reducing metal corrosion in both acidic and alkaline situations.

In (2023), A. Hbika, et, al., they generated two crude aqueous extracts of wormwood (Artemisia absinthium), using the decoction extraction method. A comparison analysis was started using the first extract, which is representative of our plant's leaves (AQL), and the second extract, which is representative of the stems (AQS). The two extracts' inhibitory action was investigated using a variety of methodologies, including weight loss. At (308 K), with a concentration of (0.2 g/L), they get an efficiency of (82%) for (AQS) and (85%) for (AQL). The inhibitory efficiency rose as the concentration grew. During adsorption, two wormwood extracts that are used to stop mild steel from corroding stick to the Langmuir adsorption isotherm. In the case of extracts, 3,4-dihydroxybenzoic acid is the predominant constituent, accounting for (42.4%) of (AQL) and (42.2%) of (AQS) [25].

In (2023), Mingming Zhang, et, al., In this research paper, the effectiveness of Artemisia capillaries leaf extract (ACLE) in preventing (Q235) steel from corroding at temperatures between (25 and 65 °C) in (1 M) HCl was examined using a variety of techniques, including weight loss measurements. According to the results, (ACLE) can significantly affect corrosion inhibition. At (10g/L) of (ACLE), corrosion inhibition efficiency can reach (99%) at (25 °C); however, as temperature rises, inhibition efficiency falls. Although it may tilt towards physisorption, the adsorption of active molecules in (ACLE) on the steel surface may entail both chemisorption and physisorption. Caffeic acid (0.55 wt%) is believed to be a substantial and effective component in (ACLE). According to the Langmuir adsorption principle, (ACLE) adsorbs spontaneously on the surface of (Q235) steel [26].

In (2021), Siham Echihi, et, al., This study investigated the effects of Artemisia herba alba (MEAHA) methanolic extract as a possible green inhibitor on the corrosion behaviour of mild steel in (1M) HCl solution at different concentrations (200 to 500 ppm). A range of methodologies, including the weight loss (WL) method, the Langmuir adsorption isotherm, and kinetic thermodynamic parameters, were used in this investigation. The obtained results show that when the concentration of (MEAHA) increases, the anti-corrosive protection efficiencies, which are (91%) for (WL), increase as well. The (MEAHA) adsorption model was used after the Langmuir adsorption isotherm model. Moreover, the green inhibitor (MEAHA) is extremely successfully adsorbed by the active centres on the MS area [27].

In (2017), AbdelKader Benmenine, et. al., Here, a potentiokinetic analysis of the plant extract inhibitory effectiveness resulting from (X52) steel corrosion in an acidic medium was reported. The results demonstrated that the inhibitory efficiency increases with extract concentration. A Tafel curve analysis revealed that the inhibition rate was roughly (98.29%). The plant seems to be an excellent cathodic type corrosion inhibitor based on the data [28].

Material and methods

Mild steel material

The local market (Nob Steel Company, Khaled Bin Al Walid Street, Sheraton Residences, Heliopolis, Cairo, Egypt) is where the mild steel material was bought. The chemical composition of this material is displayed in Table (1), which complies with the requirements (ASTM A283-2000, Grade C) [29]. A mild steel specimen used for a corrosion test, measuring (20x10.1x1.5 mm), is depicted in Figure (1). After using emery paper sheets (400, 800, 1200, and 2000) to give them a thorough cleaning and polish, they were rinsed in alcohol.

Table 1: Mild Steel's Chemical Composition [29].

Chem. Comp.	C	Si	Mn	S	P	Cu	Fe
Wt. %	0.24	0.15-0.4	0.90	0.04	0.035	0.20	Balance

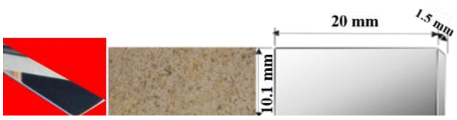


Figure 1: Mild Steel Specimen's and Dimensions, Both Before and After Polishing Process.

Wormwood extract inhibitor (WEWLS) sample collection

The (WEWLS) is a little, dwarf plant that the Egyptians refer to as "Sheeh." It is commonly used to make rabbit feed and in the wood industry, as well as to extract wormwood essential oils. In Egypt's countryside, farmers cultivate it. The plant's leaves and petals are gathered, sun-dried, and then marketed as raw materials for making oil fragrances and medications. The stems are fed to animals as feed. Medical study has revealed that the (WEWLS) extracts possess antifungal, leishmanicidal, antidiabetic, and antibacterial properties [30-32]. The location of Al-Jilani Village, Abshway Centre, Fayoum Governorate, in the northern upper Egypt region of the western desert, southwest of Egypt (29°25'41.3"N 30°42'10.4"E), was selected as the sample collection site for the dry leaves and stems of the Waterer Egyptian Wormwood Leaves and Stems (WEWLS). The town, which is roughly (30 km) from the Fayoum Governorate and (90 km) from the Cairo Governorate, the harvest was completed on (December 30, 2023). The sample that was obtained weighed approximately (1 kg). The location of the (WEWLS) collection site, the sample of (WEWLS), and the wormwood herp in the field are depicted in Figure (2). Powdered (WEWLS) showed in Figure (3).

(WEWLS) inhibitor extraction

One kilogram of a sample of a mixture of leaves and stems of the (WEWLS) herb, which was harvested ten months ago, was taken. The (WEWLS) sample was shade dried for three to six days, then further dried in a home oven and hydro distilled for three hours. After being dried over anhydrous sodium sulphate (Na_2SO_4), the resultant oil was refrigerated at (-4°C) until it was needed [30]. Figure (2) below showing (A) The field where (WEWLS) sample was collected, (B) Location of the (WEWLS) collection site on google map, (C), The crop of (WEWLS), (D) and (E) The (WEWLS) herp in the field, (F) The first grinding stage of (WEWLS) and (G) The second grinding stage of (WEWLS).

Figure 2: (A) Acre of Wormwood, (B) Acre on Google Map, (C), Dry leaves &stems, (D) & (E) Herp, (F) &(G) First & Second Grinding Stages.

Hydrochloric acid

The Marketing Bureau for Laboratory Facilities Products (Al-Kasr Al-Aini, Cairo) provided the hydrochloric acid needed for the laboratory tests to examine mild steel corrosion. Six samples, one mole of acid per sample, were produced by dissolving three-eighths HCl acid in distilled water. Because (38%) of HCl has a pH of (1.1) and vaporizes strongly in damp air, skin tissue and eyes were protected by masks and eyeglasses [33].

Materials for assessing corrosion

Table 1 displays the basic chemical composition of the samples by weight. Prior to beginning any treatment, the material previously mentioned is polished using a range of emery paper sheets, numbered (180–1200). Following a thorough cleaning and degreasing process using distilled water and acetone, respectively, all of the samples are then dried.

Six solution samples were created in order to study the corrosion of mild steel both with and without an inhibitor. The first solution sample had only (38%) hydrochloric acid (HCl); in the other five solution samples, (WEWLS) powder extract was gradually added to the (HCl) acid at concentrations of (25, 50, 100, 200, and 300 parts per million (ppm)). An electronic balance was used to balance the mild steel sample, and it was subsequently submerged in electrolyte for a full day. The sample was then dried and rinsed with distillated water. Ultimately, every sample was rebalanced to determine the weight decrease.

Results and discussion

(WEWLS) Analysis of the extract

The chemical composition of the mixed leaves and stems of the (WEWLS) extract was ascertained by comparing their retention periods and UV spectra using high performance liquid chromatography linked to a diode array detector (HPLC-DAD). Their contents are shown in Figure (3) showing the chromatograms patterns of (WEWLS) extract. The chemical structures of the compounds found in this extract are displayed in Figure (4).

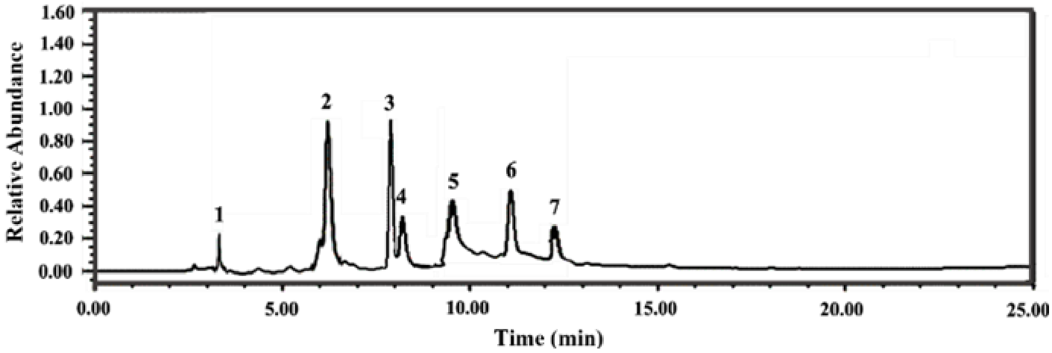


Figure 3: Chromatograms Patterns of (WEWLS) Extract.

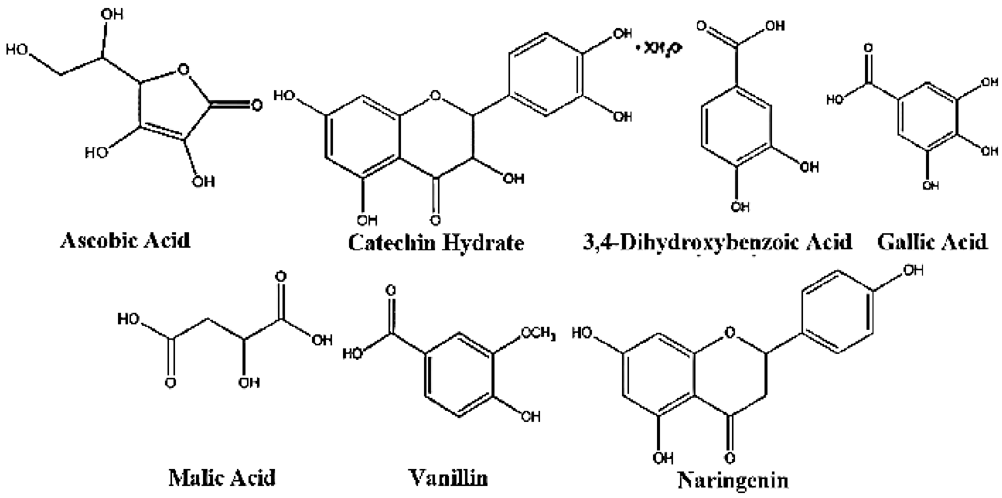


Figure 4: Chemical Compounds Structures of (WEWLS) Extract.

Weight loss

With and without (WEWLS) inhibitor, mild steel weight loss of specimens submerged in (HCl) was computed using the following equation:

$$\text{Corrosion Rate (CR)} = 87.6\,\frac{W_{loss}}{DAT}\ \text{(mm/yr)} \ldots\ldots\ldots\ (1)\ [34].$$

In this case, A is the specimen area (4.03 cm²), T is the period of metal exposure in hours (24 hours), W_{loss} is the weight loss in grammes, and (D) is the metal density (7.85g/cm³). Table (1) shows weight loss findings for mild steel immersed in HCl both with and without an inhibitor.

Efficiency of inhibitor (IE%)

To get the inhibitor efficiency (IE%), the following formula was utilized [35].

$$\text{Inhibitor Efficiency (IE\%)} = \frac{W_i - W_o}{W_i} \times 100\,\%\ (\%) \ldots\ldots\ (2)$$

where W_i and W_o stand for the mild steel specimen's weight loss in grammes before and after the corrosion test, respectively.

The statistics for inhibitor efficiency (IE%) are shown in Table (2). Figure 5(a) shows the relationship between the inhibitor concentration (I_{inh}) and the rate of corrosion of a mild steel specimen in an HCl solution with different inhibitor concentrations. Figure 5 (b) shows the relationship between the ($\log I_{inh}$) and the (IE%). A hydrophobic organic film, which is most likely composed of several antioxidant polyphenol molecules generated in combination with other filming macromolecules such as fatty acids or pectin, is associated with inhibitory activity [36].

Thermodynamic characteristics of (WEWLS) extract adsorption on the surface of a mild steel specimen

Understanding the parameters of thermodynamics is essential to understanding the inhibitive process. Adsorption from solutions has thermodynamic properties that provide information about the nature and mechanism of the adsorption process. To characterise the interaction between adsorbed molecules and mild steel surfaces, the free energy of adsorption ($\Delta G°_{ads}$) was computed using the following formula. [35]:

$$\Delta G°_{ads} = -\mathbf{2.303}\ R\ T \log (55.5 \times K_{ads}) \ldots\ldots\ldots (3)$$

The absolute temperature in Kelvin (298.15 K), the gas constant (8.314 J K^{-1} mol^{-1}), the adsorption equilibrium constant (K_{ads}), and the water concentration in solution (mol/L) are all expressed in this equation. Equation: The free energy of adsorption can be calculated using the equilibrium constant (K_{ads}) of adsorption [35]:

$$K_{ads} = \frac{(\frac{\theta}{1-\theta})}{I_{inh}} \ldots\ldots\ldots (4)$$

Table (3) displays a thermodynamic parameter for the adsorption of pomegranate peel extract in (HCl) solution. Negative ($\Delta G°_{ads}$) ensures the stability of the absorbed layer on the electrode surface. If ($\Delta G°_{ads}$) values are negative, more than (- 40 KJ/mol) they indicate that electrons are being shared or transferred from the inhibitors to the metal surface to form a coordinate type of bond (chemisorption), whereas values up to (-20 KJ/mol) are usually constant with the electrostatic interaction between charged molecules and charged metal (physisorption.

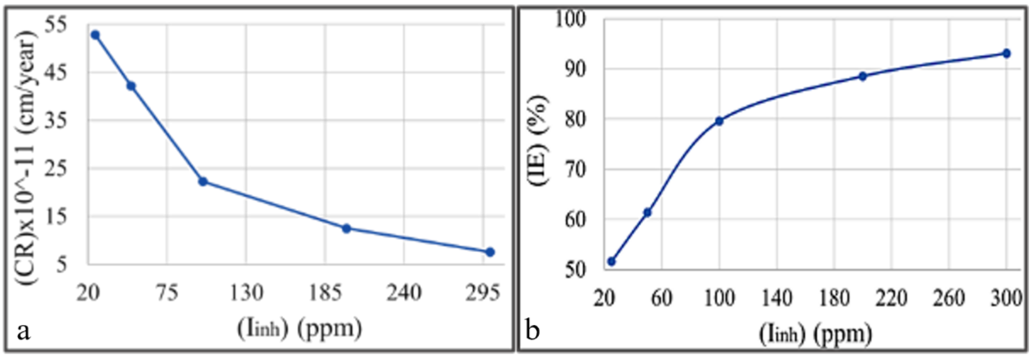


Figure 5: (a) Relationship between (I_inh) and (CR), (b) Relationship between (logI_inh) and (IE%) of (WEWLS) Inhibitor Extract on the Mild Steel Surface.

Table 2: Results Data of Corrosion Test of Mild Steel Specimens in (1.0 M) HCl.

Sample No.	Weight Before Immersion (g)	Weight After Immersion (g)	Weight Loss (W) (g)	Area (cm^2)	Corrosion Rate (cm/year)	Inhibitor (Concentration) (I_{inh}) (ppm)	Efficiency of Inhibitor (IE) (%)
Blank	0.1570	0.15693	7.25363×10^{-5}	4.03	1.0906×10^{-09}	000.00	00.00
1	0.1570	0.15696	3.51094×10^{-5}	4.03	5.2788×10^{-10}	025.00	51.60
2	0.1570	0.15697	2.80488×10^{-5}	4.03	4.2172×10^{-10}	050.00	61.33
3	0.1570	0.15698	1.47979×10^{-5}	4.03	2.2249×10^{-10}	100.00	79.60
4	0.1570	0.15699	8.31780×10^{-6}	4.03	1.2506×10^{-10}	200.00	88.53
5	0.1570	0.15699	5.50295×10^{-6}	4.03	7.5619×10^{-11}	300.00	93.07

Adsorption isotherm models

One way to think about the adsorption of inhibitor molecules in an aqueous solution is as a quasi-substitution process between water molecules at the electrode surface and organic compounds in the aqueous phase. The experimental results can be used to determine how surface inhibitor molecules interact with one another [34]. The Langmuir, Temkin, and Adejo Ekwenchi adsorption isotherms are the most frequently used in determining the mechanism of organo-electrochemical reactions. The overall structure of every one of these isotherms:

$$f(\theta, x) \exp(-2a\,\theta) = K_{ads}\, I_{inh} \;\ldots\ldots\ldots (5)$$

where (a) is the molecular interaction parameter, The size ratio (x) denotes the total number of water molecules that one organic inhibitor molecule displaces, (K_{ads}) is the adsorption equilibrium constant, and θ is the surface covering degree. In the isotherm's development, the physical model and its underlying assumptions have a significant impact on the configuration factor, f (θ, x). It's widely accepted that applying and maintaining a protective coating is the best strategy to stop corrosion on metal surfaces [37]. To calculate the surface coverage (θ), it was assumed that the inhibitor efficacy mostly comes from the adsorbed species' blocking effect, which results in a (IE% = 100] [38]. The surface coverage values were theoretically fitted into a range of adsorption isotherms in order to obtain insight into the inhibitor adsorption process on the steel surface. Next, the value of the correlation coefficient (R^2) was utilised to identify the best-fitting isotherm [38].

Langmuir adsorption isotherm

The Langmuir model is only applicable to homogeneous surface since it is based on a monolayer of the adsorbed adsorbate [39]. Langmuir's theory of monolayer formation relied on the unique binding interaction between discrete solid surface locations and adsorbate molecules. The original image was derived from studies with hydrogen and other tiny molecules in the presence of extremely low pressure, heated metal filaments [40]. The definition of gas-solid phase adsorption is provided, along with a comparison and quantification of the adsorptive capabilities of different adsorbents [41]. The definition of gas-solid phase adsorption is provided, along with a comparison and quantification of the adsorptive capabilities of different adsorbents [42].

$$\frac{I_{inh}}{\theta} = \frac{1}{K_{ads}} + I_{inh} \;\ldots\ldots\ldots (6)$$

A linear connection was obtained when (I_{inh}/ θ) was plotted against (I_{inh}), as Figure (6) illustrates. The kinetics approach is usually used in conjunction with a few assumptions to generate the Langmuir adsorption isotherm equation. When the adsorption isotherm is linear, the resulting curves are almost the same [43]. The kinetics approach is typically used to generate the Langmuir adsorption isotherm equation based on a few assumptions. Typically, these assumptions are not sufficiently supported by the mechanisms and methods used to compute the adsorption constants [44]. Table (3) displays the parameters of the Langmuir isotherm. The (R^2) result of (**0.9992**), which is extremely near to unity, shows that the inhibitor extract of (WEWLS) adheres to the Langmuir adsorption isotherm. [35]. The adsorption rate is determined by the incidence probability at an open adsorption site and the molecular incidence rate on the surface [41].

Table 3: Adsorption Parameters for Adsorption of (WEWLS) Inhibitor Extract on the Mild Steel Surface.

Sample No.	Surface Coverage (θ)	$\frac{I_{inh}}{\theta}$ (ppm)	$\frac{\theta}{1-\theta}$	Adsorption Constant (K_{ads}) (ppm) $^{-1}$	Adsorption Energy ($\Delta G°_{ads}$) (kJ/mol)
1	0.5160	048.450	01.27790	0.05112	- 2.627
2	0.6133	081.526	01.58598	0.03172	- 1.425
3	0.7960	125.628	03.90196	0.03902	- 1.947
4	0.8853	225.912	07.71840	0.03892	- 1.940
5	0.9307	322.338	13.43001	0.04477	- 2.293

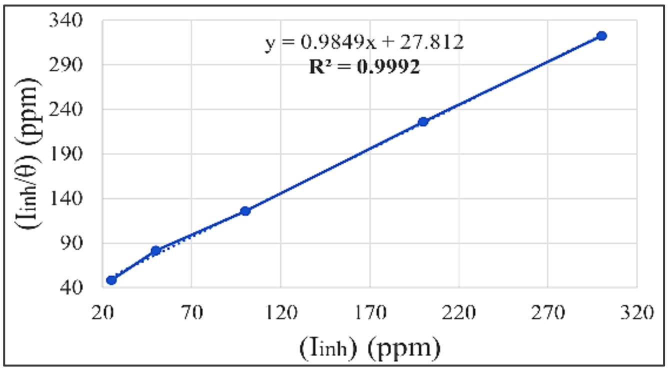


Figure 6: Langmuir Isotherm for Adsorption of (WEWLS) Inhibitor Extract on the Mild Steel Surface.

Temkin adsorption isotherm

The Temkin adsorption isotherm relates the inhibitor concentration (I_{inh}) to the degree of surface coverage (θ) using the following equation: [45–47]:

$$\text{Exp.}\ (-\ 2\ a\ \theta) = K_{ads}\ I_{inh}\ \ldots\ldots\ldots\ (7)$$

Figure (7) displays plots of θ against log (I_{inh}). The (R^2) value of (**0.9486**) was discovered. The parameters of the Temkin isotherm are shown in Table (4).

Table 4: Temkin Parameters for Adsorption of (WEWLS) Inhibitor Extract on the Mild Steel Surface.

Sample No.	Surface Coverage (θ)	Logarithm Inhibitor (Concentration) log (I_{inh}) (ppm)
1	0.5160	- 09.27747
2	0.6133	- 09.37509
3	0.7960	- 09.65269
4	0.8853	- 09.92356
5	0.9307	- 10.12137

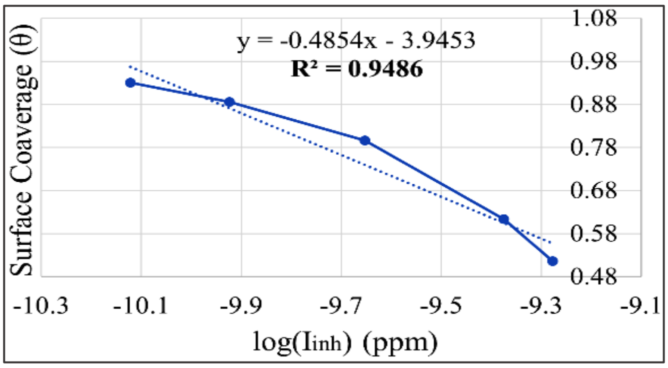


Figure 7: Temkin Isotherm for Adsorption of (WEWLS) Inhibitor Extract on the Mild Steel Surface.

Adejo Ekwenchi adsorption isotherm

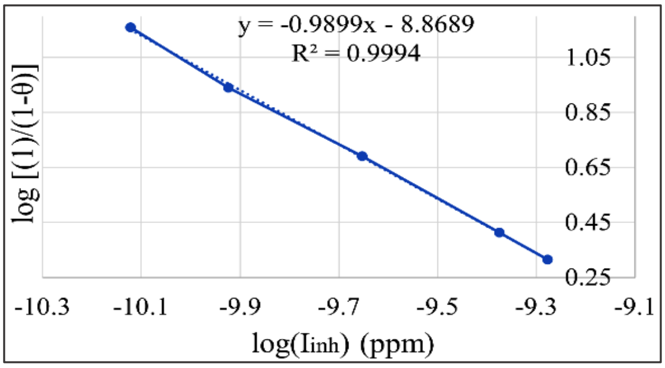
The Adejo Ekwenchi isotherm establishes the inverse relationship between the portion of the adsorbate covered at a given temperature, before reaching the maximum value of surface cover, and the amount of adsorbate uptake from the bulk concentration [48]. It is provided by the equation that follows:

$$\log\ (1/1\text{-}\ \theta) = \log K_{ads}\ +\ b\ \log I_{inh}\ \ldots\ldots\ldots\ (8)$$

where the (b) parameter is used to determine the inhibitor's mode of adsorption on the metal surface. The parameters of the Adejo Ekwenchi isotherm are shown in Table (5). Plotting (log (1/1-θ)) vs. ($\log I_{inh}$) yields a linear relation with a (R^2) value of (**0.9994**), as shown in Figure (8).

Table 5: Adejo Ekwenchi Parameters for Adsorption of (WEWLS) Inhibitor Extract on the Mild Steel Surface.

Sample No.	$\frac{1}{1-\theta}$	$\log(\frac{1}{1-\theta})$	Logarithm Inhibitor Concentration log (I_{inh}) (ppm)
1	02.06612	0.31515	- 09.27747
2	02.58598	0.41263	- 09.37509
3	04.90196	0.69037	- 09.65269
4	08.71840	0.94044	- 09.92356
5	14.43001	1.15926	- 10.12137



Results Discussion

Chemical composition of (WEWLS) inhibitor

The most abundant compound was catechin hydrate with almost identical percentages of (26.31%) for the (WEWLS) extract, followed by 3,4-dihydroxybenzoic acid with (25.00 %) also contain gallic acid with (08.92%), naringenin with (06.60%) and finally ascorbic acid with only (1.425 %).

Weight loss

The corrosion rate falls off when the concentration of the inhibitor (WEWLS) inhibitor extract increases, as shown in Figure (3.3a). When (300 ppm) of the inhibitor concentration (I_{inh}) was added to the (HCl) solution, the rate of corrosion was reduced by (93.17%); however, only (51.60%) of the orrosion rate was reduced when the inhibitor concentration (I_{inh}) was added to the (1.0 M HCl) solution because only (25 ppm) of an inhibitory chemical derived from (WEWLS) inhibitor extract was present. It is also evident that the inhibitor's concentration dramatically lowers the corrosion rate.

Inhibitor efficiency

As the value of (I_{inh}) increases, Figure (3.3b) illustrates the resulting curve that indicates a gradual increase in inhibitor efficiency (IE%). The addition of (25 ppm) of inhibitor caused the (IE%) to increase from (0.00% to 51.60%). At inhibitor concentrations of (50, 100, 200, and 300 ppm), the corresponding inhibitor efficiency was (61.33, 79.60, 88.53, and 93.07%). This demonstrated that the (WEWLS) inhibitor extract has a high level of inhibition against mild steel corrosion in a solution containing (HCl) solution.

Inhibitor adsorption

Type of adsorption

Based on Brunauer's classification [49–50], the curve's final shape was an S, as shown in Figure (3.3b). It was a Type I isotherm with one point of inflection. Usually, a Type I isotherm with the phrase "approaches a limiting value" is used to describe adsorption on microporous adsorbents [51].

Thermodynamics parameters

When levels of ($\Delta G°_{ads}$) (<-40 kJ/mol) are reached, the physisorption mechanism is preferred; however, if values are (-20 kJ/mol) or lower, the chemisorption technique is typically selected [52]. The ($\Delta G°_{ads}$) values for inhibitor samples (1, 2, 3, 4, and 5) are shown in Table (3). The range of these values is (-2.293 kJ/mol to -1.425 kJ/mol). A strong chemisorption process appears to be occurring based on these results. According to reference, the adsorbed layer's stability and the spontaneity of the adsorption process are indicated by negative values of (K_{ads}) [53]. When an anion is adsorbed on a metal surface, charged species may interact coulombically with it, increasing

Gibb's free energy ($\Delta G°_{ads}$) even in the absence of chemical bond formation [54]. It is well known that the strength of adsorption or desorption between the adsorbent and the adsorbate is represented by (K_{ads}). More effective adsorption is correlated with larger values of (K_{ads}). The (K_{ads}) values found in this investigation range from (0.03172/ppm) and (0.05112/ppm). The degree of adsorption, represented by the values of (K_{ads}). The more (WEWLS) inhibitor extract was adsorbed on the mild steel surface, according to higher (K_{ads}) values [55].

Adsorption isotherm models

The resulting correlation coefficient (R^2) values of the three employed adsorption isotherm models (Langmuir, Temkin, and Adejo Ekwenchi) were, respectively, (**0.9992**, **0.9486**, and **0.9994**). Since the result is close to unity, the (R^2) value of the Langmuir, Temkin and Adejo Ekwenchi adsorption isotherms indicates that the (WEWLS) inhibitor extract adsorption on the surface of mild steel is highly strong [56]. In comparison to the adsorption of inhibitor on the surface of the mild steel was more obeying to the Adejo Ekwenchi isotherm model, followed by Lungmuir isotherm model, then Temkin model's.

Results comparison

The following titles can be used to summarize the comparisons made between the findings of this inquiry and those of earlier investigations:

The First: Examining the following in terms of pollution control and environmental protection: The study's findings indicate that, in comparison to the *(WEWLS) inhibitor extract*, the *creatinine inhibitor extracted from the bovine urine* has a lower inhibitory efficiency, at (03.23%). The Langmuir isotherm model's correlation factor (R^2) was slightly higher in case of the *creatinine inhibitor extracted from the bovine urine* with about (00.02%), indicating that the later inhibitors' has more strong adsorption on the mild steel surface is almost identical [57].

The second: Comparison of the acid corrosion type investigation's findings (in HCl solution) as given in the reference [58]. According to the findings, the *sulphur inhibitor containing an organic compound* (*in H_2SO_4 solution*) had a smaller rate of (16.34%) of inhibition efficiency than the *(WEWLS) inhibitor extract*. The Langmuir isotherm models also show that the adsorption was less strong with (08.45%).

The Third: Analogous comparison using an inhibitor taken from an alternative source: Comparison of research findings on (*Acacia concinna pod extract*) from the study referenced in [59]. As per the Langmuir isotherm model, there was a marginal difference of 0nly (0.06%) in the *(WEWLS) inhibitor extract* compared to *Acacia concinna pod extract*. When *Acacia concinna pod extract* was used, the inhibitory efficacy was found to be higher, increasing by roughly (02.08%).

The Forth a comparative analysis of identical inhibitor solution source materials: a comparison with the results of the research on *Wormwood Leaves and Stems* in reference [25]. When employed, it was discovered that (*WEWLS) inhibitor extract* had a higher inhibitory efficacy; this difference was almost (04.45%) and (05.13%) compared with *wormwood leaves and stems inhibitor extract respectively* [25]. The *(WEWLS) inhibitor extract* however, appears to have a weaker adsorption on the surface of mild steel material compared to wormwood leaves inhibitor extract, but had stronger adsorption compared to wormwood stems inhibitor extract, according to the Langmuir isotherm model, albeit this change was only marginal (03.92%) and (00.03%) for the wormwood leaves and stems inhibitor extract respectively.

The Fifth: Analyzing the same inhibitor solution source materials in contrast to the findings of a study on white *wormwood-derived essential oils* [60]. When used, it was shown that the inhibitor extract from (WEWLS) had a greater inhibition efficiency; this difference was about (01.15%) when compared to *essential oils made from white wormwood*. demonstrating the higher corrosion inhibition of the inhibitor utilized in the current study.

Conclusion

The following results may arise from the impact of Waterer Egyptian Wormwood Leaves and Stems (WEWLS) extract on mild steel (0.17 C) corrosion in (1.0 M HCl) at (30°C):

I. As the concentration of (WEWLS) inhibitor extract increases, mild steel corrodes more slowly. The highest percentage of inhibitor efficiency (IE%) was (93.07%) at a dosage of (300 ppm). Economically speaking, it was the optimal inhibitor concentration (I_{inh}), lowering the corrosion rate by approximately (93.00%).

II. In relation to the (I_{inh}), a drop in (IE%) occurs along with an increase in (I_{inh}). The obtained (IE%) of the (WEWLS) inhibitor extract corroborated the findings.

III. The mild steel surface's adsorption free Gibb's energy ($\Delta G°_{ads.}$) has negative values, indicating a strong interaction between the molecules of the (WEWLS) inhibitor extract. The chemisorption process of adsorption was carried out according to the value of the ($\Delta G°_{ads.}$).

IV. The three distinct adsorption isotherms; Adejo Ekwenchi, Temkin, and Langmuir were compared and investigated. The results of the adsorption isotherm plots show that the Langmuir and Adejo Ekwenchi isotherm models were more closely correlated with each other and provided a better fit to the experimental data on the adsorption of (WEWLS) inhibitor extract onto mild steel. The adsorption of used inhibitor was less obeying to Temkin isotherm models.

VI. In extremely corrosive situations, such (38% HCl), natural plant extracts, like (WEWLS) inhibitor extract, can be a cheap and efficient mild steel corrosion inhibitor. In an almost pure aqueous media, the extraction procedure can be finished with a few easy steps.

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