



## Corrosion Inhibition of Mild Steel In (1 M HCl) Solution Using Plant Extract and The Synergistic Effect of Iodide Ions

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### Abstract

The corrosion inhibitive impacts of a mixture (4:1) of Citrus Limon leaf (CLL) extract and potassium iodide additives when the mild steel was exposed to the corrosive solution (1M HCl) were evaluated using the weight-loss method at temperatures of (303, 313, 323, and 333) K. It was noted that the mixture acts as an inhibitor of mild steel corrosion at concentrations of (1.25, 2.5, 3.75, 5, and 6.25) ml/L. It was observed also that the inhibition efficiency (%I) of the mixture increased with an increase in temperature in the presence of the synergistic effect of the iodide ion. It was found that at the highest mixture concentrations and temperatures, the inhibition competence increased to 95.20%. Inhibitor adsorption characteristics were reached by the Langmuir isotherm and were compatible. The adsorption thermodynamic parameters that were calculated supported the mixed-adsorption of the mixture on a mild steel surface. A surface analysis technique (SEM) used to confirm the occurrence of an adsorption process on the surface.

**Keywords:** Corrosion, Mild steel, Inhibition efficiency, Adsorption, Potassium iodide, CLL extract



## تنشيط التآكل للصلب الطري في محلول (1 M HCl) باستخدام مستخلص نباتي مع التأثير التآزري لأيونات اليوديد

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### الخلاصة

تم تقييم التأثيرات المثبطة للتآكل لخليط بنسبة (4 : 1) من مستخلص أوراق الليمون الحامض (CLL) و يوديد البوتاسيوم عند تعرض الفولاذ الطري لمحلول تآكل (1 M HCl) باستخدام طريقة إنقاص الوزن عند درجات حرارة (313,303 K, 323, 333) ، تم اكتشاف أن الخليط يعمل كمثبط لتآكل الفولاذ الطري بتركيز 1.25 ، 2.5 ، 3.75 ، 5 ، 6.25 ml/L. لوحظ أن كفاءة التثبيط (% I) للخليط تزداد مع زيادة درجة الحرارة في وجود التأثير التآزري لأيون اليوديد. وجد أن كفاءة التثبيط تزداد إلى 95.20% عند أعلى تراكيز الخليط ودرجات الحرارة. تم الوصول إلى خصائص الامتزاز المانع من خلال Isotherm Langmuir حيث كانت متوافقة. دعمت الدوال الترمودينمكية للامتزاز التي تم حسابها الامتزاز المختلط للخليط على سطح الفولاذ الطري تم استخدام تقنية تحليل السطح (SEM) التي أكدت حدوث عملية الامتزاز على السطح.

**الكلمات المفتاحية:** التآكل، الفولاذ الطري، كفاءة التثبيط، الامتزاز، يوديد البوتاسيوم، مستخلص CLL، 1 M HCl

### Introduction

The corrosion process is an essential problem that possesses a significant influence on the industrialized machinery and construction sectors [1]. Mild steel is commonly used as a primary structural material with different industrial applications like heat exchangers, oil and gas pipelines, mining equipment, and cooling towers due to its comparably good cost and mechanical efficiency [2]. Nonetheless, mild steel's corrosive sensitivity in aggressive settings, particularly acidic environments, remains a significant issue. This sort of issue has prompted several research types of research aimed at improving metal corrosion prevention. Corrosion inhibitors have long been recognized as one of the most effective strategies for improving metal corrosion prevention [3]. Inhibitors are chemicals that, when applied in tiny amounts to a



corrosive medium, prevent or reduce the metal's interaction with the media. [4]. The known hazardous effects of most synthetic corrosion inhibitors are the motivation for the use of some natural products as corrosion inhibitors. So, natural compounds have performed important as a readily accessible, renewable, and ecologically acceptable source for a variety of inhibitors. They are rich sources of compounds with excellent inhibitory efficiency [5]. Most efficient inhibitors include heteroatoms like N, S, and O as well as multiple bonds in their molecules that allow ions to be adsorbed on the metal surface. It has been observed that adsorption is mostly determined by the inhibitor group's physicochemical properties, like functional groups,  $\pi$ -orbital character, the density of electron at a donor atom, and a molecule's electronic structure [4]. Most of the previous literature shows that halide additions synergistically increase the inhibition efficiency of most organic molecules in the natural inhibitor of the order  $\text{Cl} < \text{Br} < \text{I}$  in different environments. Iodide ions (I) have an effect on the corrosion of metals in various aqueous aggressive environments and thus on the corrosion inhibition efficiency with many organic inhibitors, including polymers, natural products of vegetable origin, organic dyes, and drugs in widely different experimental conditions, as in much of the previous literature. [6]

## Experimental

### **Material preparation**

Mild steel segments taken from crude oil pipelines had chemical analysis (C (0.176%), Si (0.261%), Mn (0.955%), P (<0.0005%), S (0.001%), Cr (0.047%), Mo (0.0358%), Ni (0.024%), and the rest Fe, and were mechanically shaped into  $3\text{cm} \times 1\text{cm} \times 0.1\text{cm}$  to be used in weight loss studies. It was hardened for 1h at  $600\text{ }^\circ\text{C}$  in an electric furnace and then cooled to room temperature using a desiccator [7]. The metal samples' surfaces were prepared with emery papers of various grades (220, 400, 600, 800, 1000, 1500, and 2000). The mild steel strips, which had an exposed area of  $6.8\text{ cm}^2$  ( $1.054\text{ inch}^2$ ), were employed. It was performed benzene degreasing, water washing, acetone dipping, and air drying procedures before being kept in desiccators. A four-digit electronic balance model was used to accurately weigh the samples [8].



The acidic test solution was prepared at a concentration of 1 M using the dilution method for 37% laboratory-grade of hydrochloric acid with a molecular weight of 36.46 g/mol.

The concentrated KI solution was prepared by weighing 140 g of KI (molecular weight = 166 gm/mole) and diluting it in (200) ml of distilled water at a standard temperature to have a molar concentration of (4.216 M).

The stock solution of the leaf extract of citrus Limon was prepared as reported in the previous literature [9] The dried leaves were ground to powder form and then passed through a sieve (75  $\mu\text{m}$ ) to obtain fine particles. It took 25 grams of dry powder and putting them in a Soxhlet apparatus thimble, which is usually used to carry out the extraction process. Then the solution extraction was filtered and concentrated using a rotary evaporator at 40  $^{\circ}\text{C}$  to obtain the extract prepared for use, which was stored in a cool place at 4  $^{\circ}\text{C}$  until used.

## Weight loss measurements

Weight loss measurements were carried out at the following temperatures (303, 313, 323, and 333) K by using six coupons of the sample used, weighing them before starting immersion, marking them, and hanging them from the hole in the coupon with a thread made of polyethylene, and then immersing them in beakers containing 250 ml of hydrochloric acid at a concentration of 1M for three hours in the presence and absence of different concentrations of the mixture (extract-potassium iodide solution) as an anti-corrosion inhibitor at the concentrations following (0, 1.25, 2.5, 3.75, 5, and 6.25 ml/L) of the mixture [10].

After three hours of immersion, the submerged samples were taken out, washed with plain water, rinsed with acetone, and then exposed to warm air to dry [11]. It was weighed samples after making sure that it was completely dried ( $W_1$ ). The weight of the coupons was calculated after immersing ( $W_2$ ) and record the weight loss ( $\Delta W$ ). From the weight loss values, the equation (2) was used to calculate the corrosion rate in the presence and absence of the mixture as an inhibitor with units (mpy) [12].



$$\Delta W = W_1 - W_2 \dots\dots\dots (1)$$

$$CR(mpy) = \frac{534 \Delta W}{DAT} \dots\dots\dots (2)$$

where  $W$  denotes weight loss ( $mg$ ),  $A$  denotes surface area ( $inch^2$ ),  $D$  denotes metal density ( $g/cm^3$ ), and  $T$  is exposure period (hour). Additionally, the expression indicated in the equation was used to calculate the inhibitory efficiency (IE) (3) [13]:

$$IE = 1 - \frac{W_{inh}}{W_{uninh}} * 100 \dots\dots\dots (3)$$

Where  $W_{uninh}$  represents weight loss without any of the inhibitor and  $W_{inh}$  means weight loss with the inhibitor.

## Results and discussion

Equations (2) and (3) were used to compute the corrosion rate and inhibition efficiency, respectively. The findings are listed in the table (1).

**Table 1:** Corrosion rate (mpy) and inhibition efficiency (IE%) that were obtained from the weight-loss test for varied concentrations of (CLL extract + KI solution) as an inhibitor of mild steel corrosion in 1 M HCl solution at different temperatures

$C_i$ ml/L		303K		313K		323K		333K	
		$C_R$ (mpy)	IE%	$C_R$ (mpy)	IE%	$C_R$ (mpy)	IE%	$C_R$ (mpy)	IE%
CLL+KI	0 + 0	66.691	0	133.354	0	445.231	0	1210.94	0
	1 + 0.25	19.362	70.96	30.118	77.41	92.507	79.22	234.496	80.64
	2 + 0.5	17.210	74.19	27.967	79.03	68.842	84.54	165.653	86.32
	3 + 0.75	15.059	77.41	25.816	80.64	38.724	91.30	88.205	92.71
	4 + 1	12.908	80.64	23.664	82.25	36.572	91.78	66.691	94.49
	5 + 1.25	10.756	83.87	15.059	88.70	32.270	92.75	58.086	95.20

### Corrosion rate and inhibitor efficiency

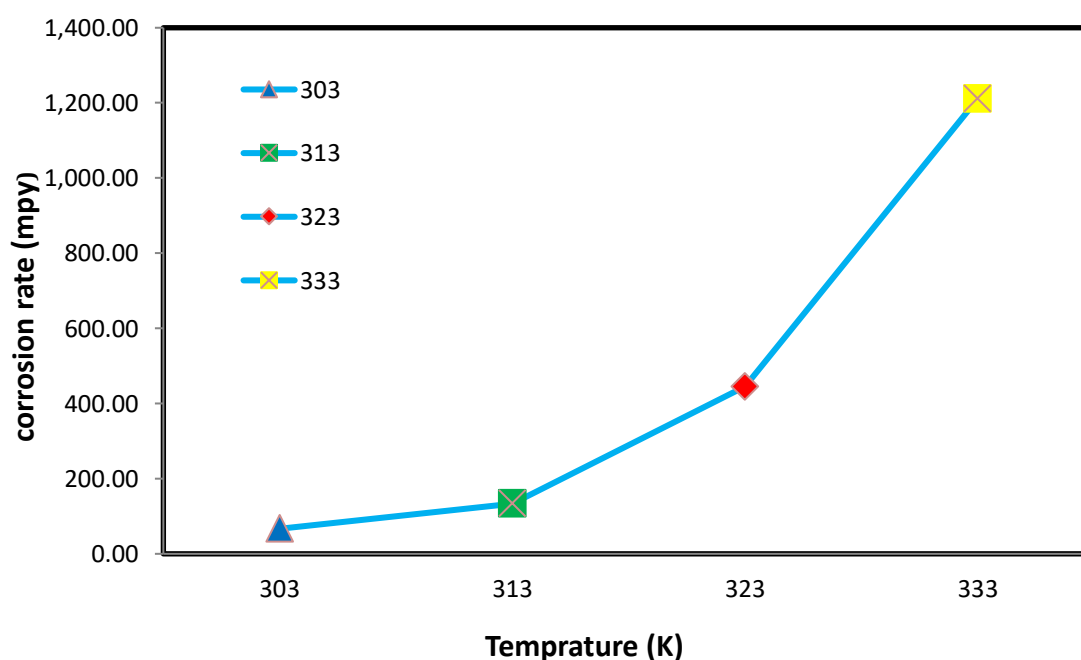
Through the weight loss results, the corrosion rate and inhibitor efficiency were determined for samples immersed in 1 molar with and without the mixture used as an inhibitor at different temperatures as shown in the table (1). It is clear that the corrosion rate increases with increasing temperature and decreases with an increase in inhibitor concentration. This is what was reached



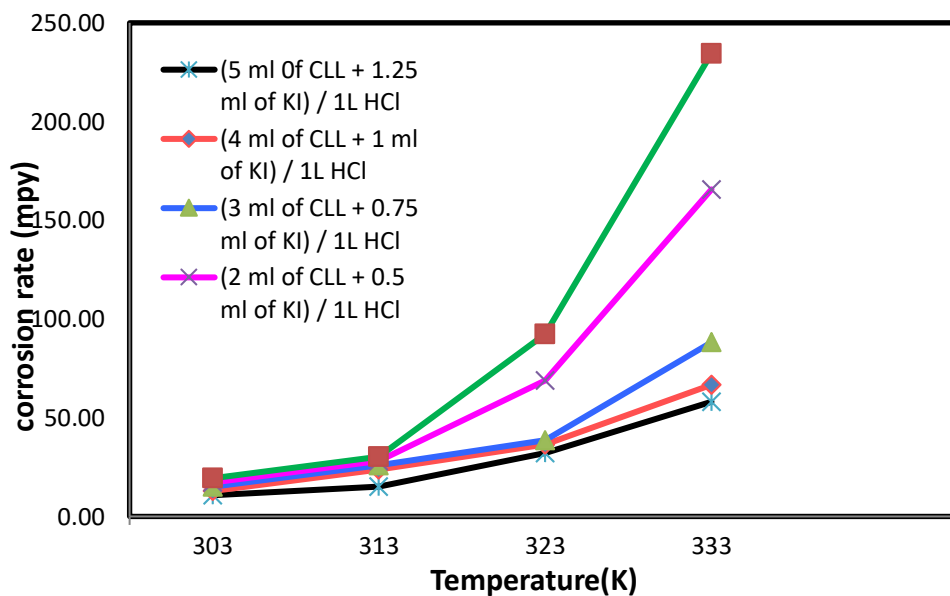
in similar studies, where they discovered that the concentrations of extracts and temperature have an effect on the corrosion rate and the efficiency of inhibition, as mentioned in the previous literature [14-18].

## The effect of temperature

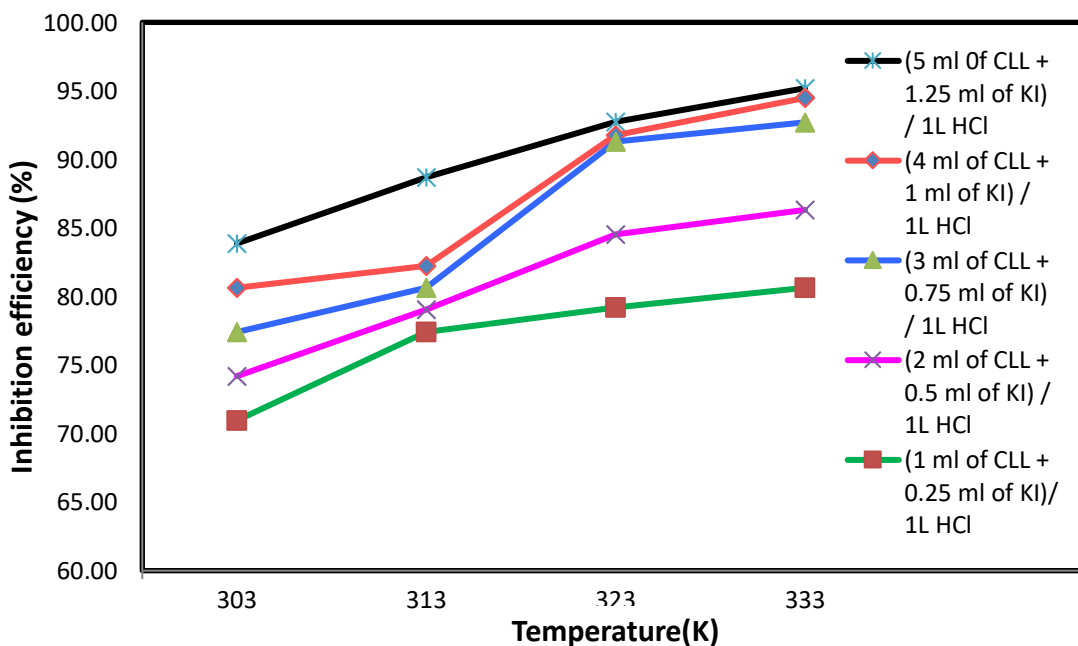
The temperature has a very clear effect on increasing the corrosion rate in the case of the uninhibited system, and this effect decreases in the case of the inhibited system. It was found that increasing the temperature from 303 to 333 K in acid without additives increases the corrosion rate, as shown in figure 1. It has also been observed that the corrosion rate increases less with increasing temperature in the presence of a certain concentration of inhibitor as shown in figure 2. The explanation for this is that when the temperature rises, the kinetic energy of the interacting particles will increase [19]. As for the effect of temperature on the efficiency of the inhibitor, figure 3 shows that the efficiency increases with the increase in temperature concentration for a certain concentration and the maximum value was at 333 K.



**Figure 1:** Effect of temperature on corrosion rates in the absence of inhibitor.



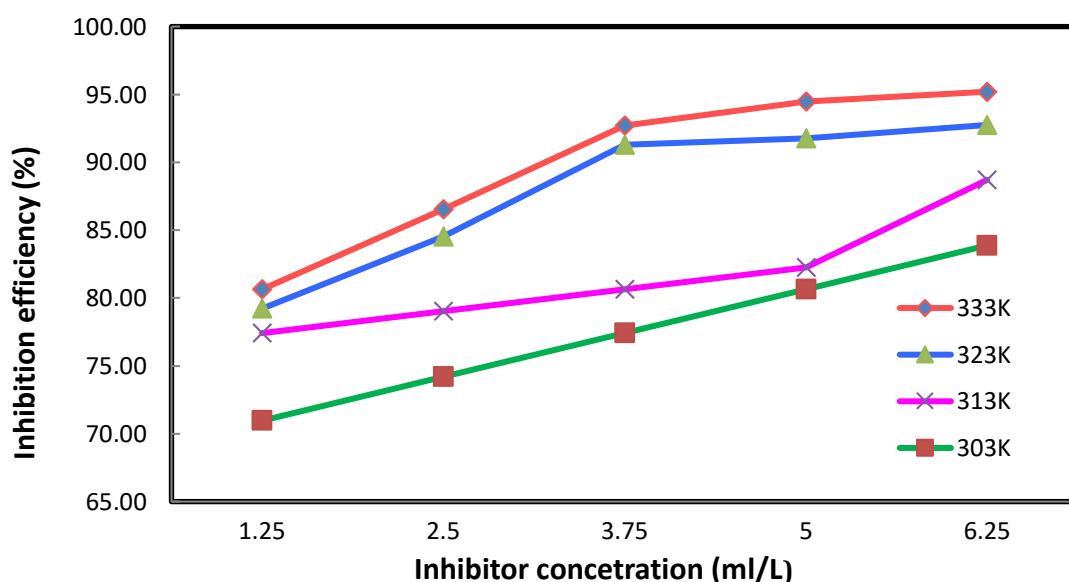
**Figure 2:** Effect of temperature on the corrosion rate of mild steel immersed in **1M HCl** at different concentrations of mixture (CLL extract - KI) as inhibitor.



**Figure 3:** Effect of temperature on inhibition efficiency of mixture (CLL extract-KI) as an inhibitor for mild steel corrosion in **1M HCl**.

## The effect of inhibitor concentration

The presence of the mixture of Citrus Limon leaf (CLL) extract and potassium iodide solution with the concentrations mentioned above in the studied acidic medium led to a significant reduction in corrosion rates, and this was evident in the values recorded in the table (1). Figure 4 depicts the change in corrosion rate as a function of inhibitory concentration at various temperatures. It is believed that the reason for the inhibition is the many phytochemicals available in the plant extract, although it is not known that the process of inhibition by the compounds of the inhibitor has been synergistic because of the presence of components or maybe by one component only [20] However, the addition of halides enhances the adsorption of extract molecules on the surface layer [21]



**Figure 4:** Effect of mixture (CLL extract – KI) concentration as an inhibitor on the corrosion rate of mild steel immersed in **1 M HCl**.

## Isotherm of Adsorption

It is necessary to calculate the surface coverage ( $\theta$ ) data using equation (4) that is used to calculate the degree to which various inhibitor concentrations cover the surface to determine the adsorption isotherm [22].





$$\theta = \left(1 - \frac{W_{inh}}{W_{uninh}}\right) \dots\dots\dots (4)$$

Where  $\theta$  is coverage surface,  $W_{uninh}$  implies weight loss without the use of the inhibitor, and  $W_{inh}$  signifies weight loss with the use of the inhibitor. Once it has been determined which adsorption isotherm best matches the adsorption data, the adsorption free energy may be calculated using the equation below.

$$\Delta G_{ads} = -RT \ln(55.5 K) \dots\dots\dots (5)$$

where  $R$  denotes the ideal gas constant,  $T$  denotes the absolute temperature (in Kelvin), and  $55.5$  denotes the water concentration.

It is possible to identify the mechanism of interaction between the inhibitor molecules and the surface of the mild steel by an adsorption isotherm. Two models were proposed to identify the adsorption mechanism of the mixture (CLL extract + KI) on the metal surface. The first is Langmuir isotherms that were calculated using the equation (6) and the second is Freundlich isotherms that were calculated using the equation (7). It was found that the Langmuir isotherm was the ideal isotherm for adsorption.

$$\frac{C_i}{\theta} = C_i + \frac{1}{K_{ads}} \dots\dots\dots (6)$$

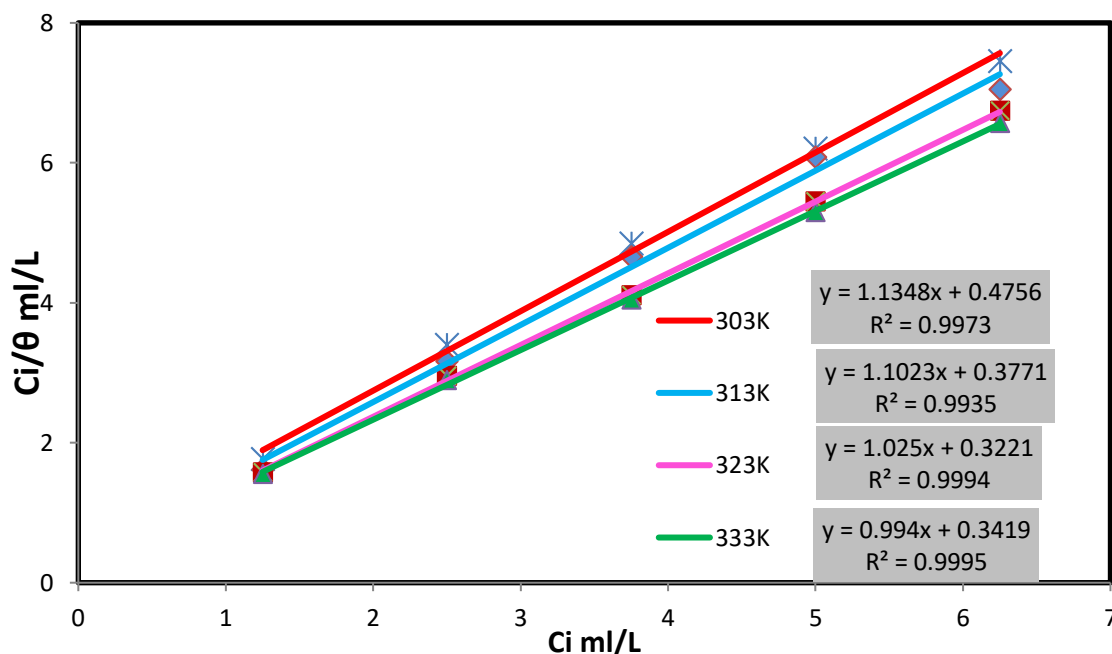
$$\ln\theta = \ln K_{ads} + n \ln C_i \dots\dots\dots (7)$$

where  $\theta$  denotes the surface coverage,  $C$  inhibitor concentration,  $n$  denotes slope and  $K_{ads}$  equilibrium constant of the adsorption process.

The values of  $C/\theta$  were plotted against  $C$  for the Langmuir equation (6) at four temperatures (303, 313, 323, 333) K. The straight lines that are formed in the graph as shown in figure 5 with values of correlation coefficient ( $R^2$ ) suggest that the Langmuir equation is better suited to the equilibrium data for adsorption of the mixture used on the sample surface as an anticorrosion inhibitor in 1M HCl. This isotherm of adsorption indicates how inhibitor molecules adsorb as a monolayer and do not interact with further species [23]. Finding the intercept of a line's path

with the  $C/\theta$  axial yields  $K_{ads}$  values, and the slope of these lines is almost one, implying that each molecule populates one active location on the surface of the specimen [24]. It was noted from the results that the value of  $K_{ads}$  increases with increasing temperature from 303 to 333 K, this confirms the adsorption of the inhibitor molecules on the surface of the sample [25].

The standard free energy of adsorption ( $\Delta G_{ads}^{\circ}$ ) for the mixture (CLL extract + KI) on the surface was calculated using equation (4.2) from the values of the equilibrium constant of adsorption calculated from the slope in the figure, and all data were included in table (2). The negative values of the adsorption free energy  $\Delta G_{ads}^{\circ}$  ranging between  $(-19.271 \text{ KJ/mol})$  and  $(-22.093 \text{ KJ/mol})$  indicate that the adsorption process occurred spontaneously. In general, it has already been found that values of  $\Delta G_{ads}$  equal to  $-20 \text{ kJ/mol}$  are compatible with physical adsorption or those up to  $-40 \text{ kJ/mol}$  or above with chemical adsorption[26]

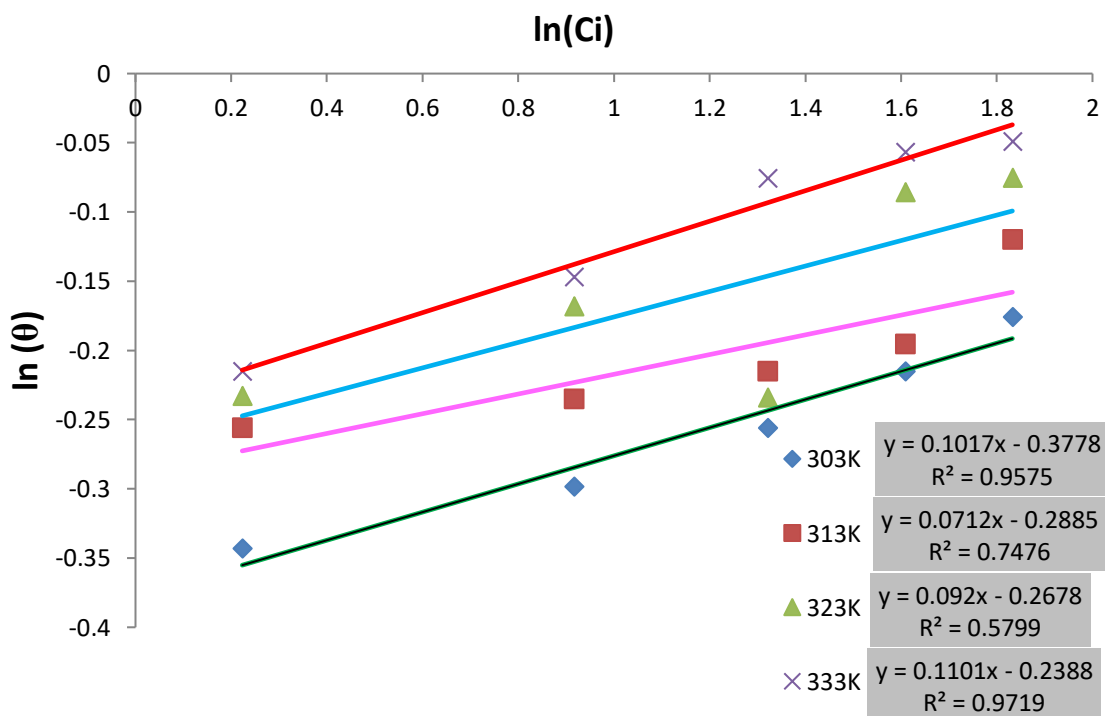


**Figure 5:** Langmuir adsorption isotherm of mixture (CLL-extract + KI) on mild steel in 1 M HCl

**Table 2:** Equilibrium constant ( $K_{ads}$ ), standard adsorption free energy ( $\Delta G_{ads}^{\circ}$ ), and coefficient of correlation ( $R^2$ ) for Langmuir type adsorption isotherm of mixture (**CLL – extract + KI**) on mild steel in **1 M HCl** at different temperatures

Temperature (K)	$K_{ads}$ (L/ml)	$\Delta G_{ads}^{\circ}$ KJ. mol <sup>-1</sup>	$R^2$
<b>303</b>	2.1026	– 19.271	0.9973
<b>313</b>	2.6518	– 20.511	0.9935
<b>323</b>	3.1046	– 21.589	0.9994
<b>333</b>	2.9248	– 22.093	0.9995

Using equation (7), the values of the parameters of the Freundlich adsorption isotherm were calculated as in table (3) through the slope and intercept, which represent the values of (n") and (Kads) respectively, after plotting between (lnθ) versus (lnCi) as shown in figure 6. Given the low correlation coefficient values of the Freundlich isotherm, it does not seem appropriate to describe the adsorption mechanism of molecules on the adsorbent surface [27]



**Figure 6:** Freundlich adsorption isotherm of mixture (CLL-extract + KI) on mild steel in 1 M HCl



**Table 3:** Equilibrium constant of the adsorption process ( $K_{ads}$ ), the slope ( $n$ ), in addition to the correlation coefficient ( $R^2$ ) for the Freundlich-type adsorption isotherm of (**CLL – extract + KI**) on mild steel in 1 M HCl at different temperatures.

<b>Temperature (K)</b>	$K_F(L/ml)$	$n$	$R^2$
303	1.459	0.1017	0.9575
313	1.3344	0.0712	0.7476
323	1.307	0.092	0.5799
333	1.2697	0.1101	0.9719

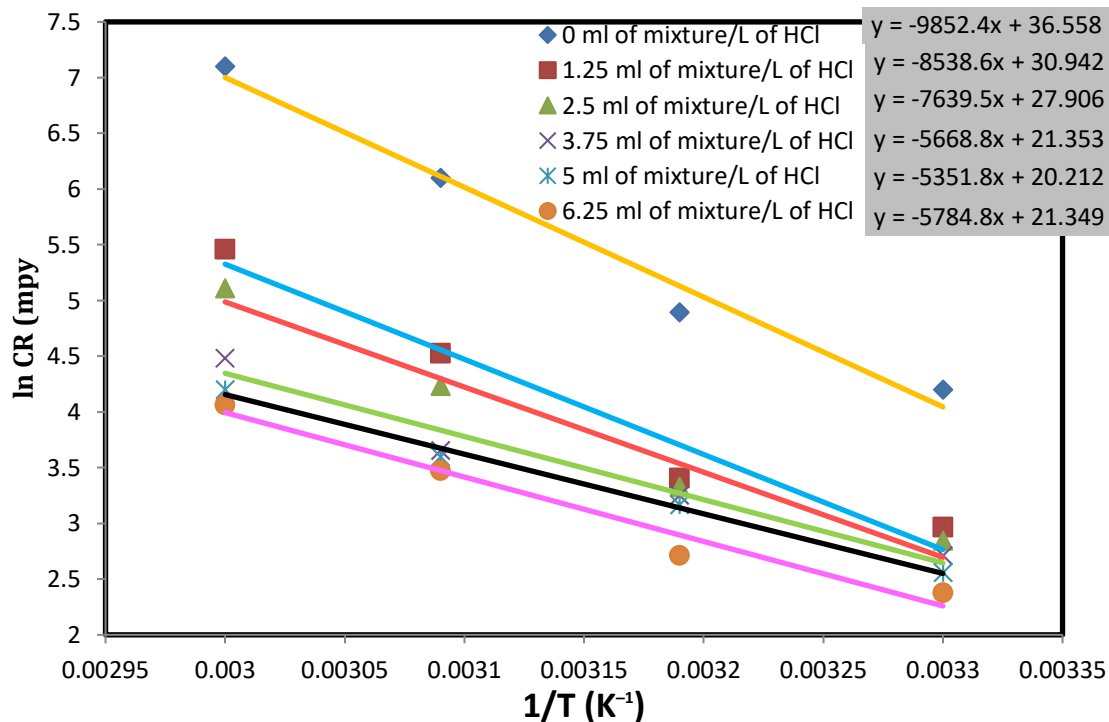
### Thermodynamic Studies

The value of activation energy ( $E_a$ ) using equation (8) of the corrosion of mild steel in 1 M HCl was calculated in the presence and absence of the mixture studied.

$$\ln(CR) = \ln A - \frac{E_a}{RT} \quad (\text{Arrhenius equation}) \dots\dots\dots (8)$$

Where ( $A$ ) denotes the frequency factor, ( $E_a$ ) denotes the activation energy ( $KJ/mol$ ), ( $R$ ) denotes the gas constant ( $8.314 J. mol^{-1}. K^{-1}$ ), and ( $T$ ) denotes the absolute temperature (K).

From Arrhenius equation (8) and data of table (4) was determine activation energy value by plotting ( $\ln CR$ ) versus ( $1/T$ ) as in the figure 7, which resulted in straight lines with slopes equal to ( $-E_a/R$ ) and whose values are listed in the table (3). The meaning of the decrease in the activation energy values in the results shown the table with an increase in the concentration of the inhibitor is the decrease in the energy barrier for the inhibition reaction. Previous literature indicates that the high value of the activation energy indicates physical adsorption, while the low value of the activation energy indicates chemical adsorption.[28]. The increase in the inhibitor concentration led to a decrease in the activation energy values. This indicates that the greater the inhibitory effect, the lower the ( $E_a$ ) values in general[29,30].



**Figure 7:** Arrhenius plot of the corrosion of mild steel in (1 M HCl) containing different concentrations of CLL extract at various temperatures.

Activation entropy ( $\Delta S^*$ ) and activation enthalpy ( $\Delta H^*$ ) of the corrosion of mild steel in 1 M HCl were calculated in the presence and absence of the mixture studied by using the transition state equation (9).

$$\ln(CR/T) = (\ln R/Nh + \Delta S^*/R) - (\Delta H^*/RT) \dots\dots\dots (9)$$

Where  $h$  denotes the plank's constant,  $N$  denotes Avogadro's number,  $S^*$  denotes the entropy of activation, and  $H^*$  denotes the enthalpy of activation.

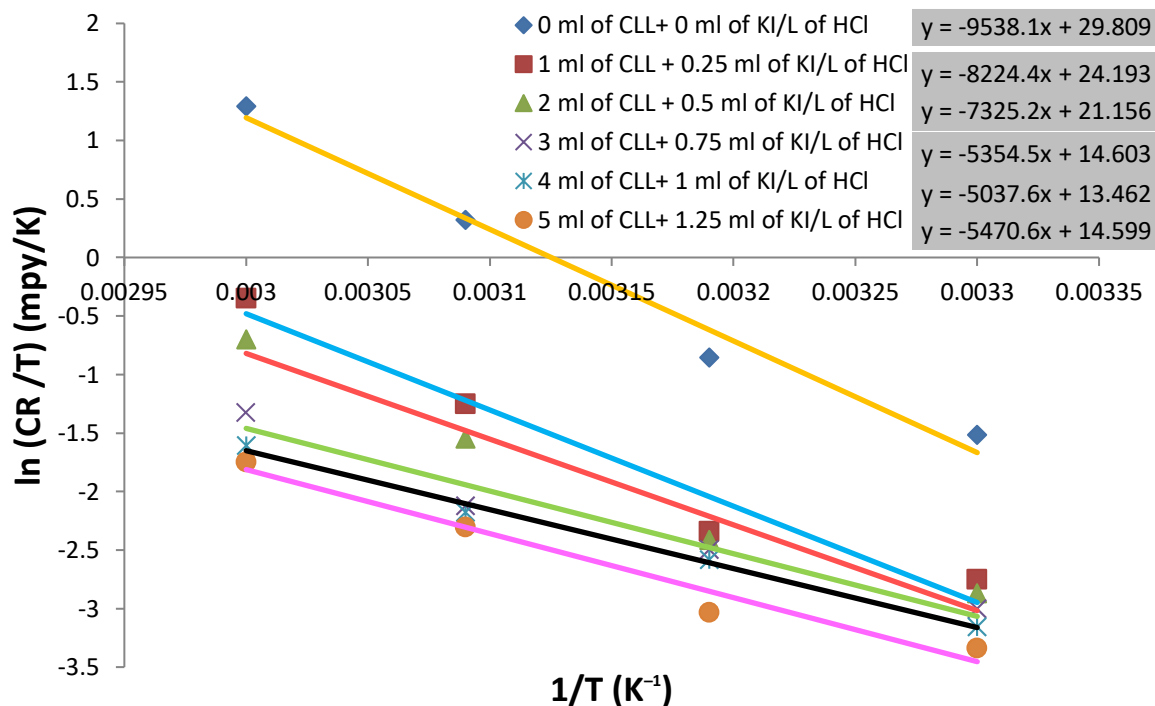
The thermodynamic parameters ( $\Delta H^*$ ,  $\Delta S^*$ ) were calculated for the slope and intercept when plotting data in the table (4),  $\ln (CR/T)$  against  $(1/T)$ , where the slope ( $-\Delta H_{ads}/R$ ) and the intercept ( $\ln R/Nh + \Delta S_{ads}/R$ ) represented as shown in Figure 8, and their values are recorded in the table (3). The positive sign of the enthalpy value indicates that the reaction was endothermic [31]. According to the literature, an exothermic process is either physical



adsorption or chemical adsorption, but an endothermic process is chemical adsorption [28]. The positive value of ( $\Delta S^*$ ) indicates an increase in the randomness and freedom of movement of species in the solution during the adsorption process, while with the adsorption process happening, the inhibitor molecules will be adsorbed on the surface, which leads to a decrease in entropy due to an increase in the orderliness of the molecules and a decrease in randomness. [32,33].

**Table 4:** Corrosion rate data in 1 M HCl solution using different concentrations of the mixture (CLL extract + KI) as a mild steel corrosion inhibitor at different temperatures

No.	$C_{inh}$ (ml/L)	CR (mpy)	T (K)	1/T	CR/T	lnCR	Ln(CR/T)
1.	0	66.691	303	0.0033	0.2201	4.2000	-1.5136
2.		133.354	313	0.00319	0.4260	4.8930	-0.8533
3.		445.231	323	0.00309	1.3784	6.0985	0.3209
4.		1210.942	333	0.00300	3.6364	7.0991	1.2909
5.	1 + 0.25	19.362	303	0.0033	0.0639	2.9633	-2.7504
6.		30.118	313	0.00319	0.0962	3.4051	-2.3413
7.		92.507	323	0.00309	0.2863	4.5272	-1.2507
8.		234.496	333	0.00300	0.7041	5.4574	-0.3508
9.	2 + 0.5	17.210	303	0.0033	0.0567	2.8454	-2.4453
10.		27.967	313	0.00319	0.0893	3.3310	-2.4157
11.		68.842	323	0.00309	0.1976	4.2318	-1.6215
12.		165.653	333	0.00300	0.4975	5.1098	-0.6981
13.	3 + 0.75	15.059	303	0.0033	0.0496	2.7119	-3.0037
14.		25.816	313	0.00319	0.0824	3.2509	-2.4961
15.		38.724	323	0.00309	0.1198	3.6564	-2.1219
16.		88.205	333	0.00300	0.2648	4.4796	-1.3287
17.	4 + 1	12.908	303	0.0033	0.0436	2.5578	-3.1326
18.		23.664	313	0.00319	0.0756	3.1639	-2.5822
19.		36.572	323	0.00309	0.1132	3.5992	-2.1785
20.		66.691	333	0.00300	0.2002	4.2000	-1.6084
21.	5 + 1.25	10.756	303	0.0033	0.0354	2.3754	-3.3410
22.		15.059	313	0.00319	0.0481	2.7119	-3.0344
23.		32.270	323	0.00309	0.0999	3.4741	-2.3035
24.		58.086	333	0.00300	0.1744	4.0619	-1.7464



**Figure 8:** Transition state plot for mild steel corrosion in (1M HCl) in absence and presence of different concentrations of mixture (CLL extract + KI).

**Table 5:** The values of the activation energy, enthalpy, and entropy of corrosion of mild steel in **1 M HCl** in the absence and presence of different concentrations of the **CLL** extract.

$C_i$ (ml/L)	$E_a$ (kJ/mol)	$\Delta S^*$ (J / mol.K)	$\Delta H^*$ (kJ / mol)
0	81.912	50.2	79.299
2	70.989	3.5	68.377
4	63.514	-21.6	60.901
6	47.130	-76.1	44.517
8	44.494	-85.6	41.882
10	48.094	-76.1	45.482

### Synergistic effect

Synergistic effect means the effect between iodide ions and inhibitor molecules due to co-adsorption and either competitive or cooperative [34]. The synergy coefficient was calculated using the equation (10) [35].

$$S_{\theta} = \frac{1 - (\theta_1 + \theta_2 - \theta_1\theta_2)}{1 - \theta_{1+2}} \dots\dots\dots (10)$$



where  $\theta_1$  denotes the surface coverage for an anion,  $\theta_2$  denotes the surface coverage for a cation, and  $\theta_{1+2}$  denotes the surface coverage for both an anion plus a cation.

Synergistic effect means the effect between iodide ions and inhibitor molecules due to co-adsorption and either competitive or cooperative. Table (3) shows the synergy factor for each used concentration of the mixture. If the value of the synergy coefficient ( $S_\theta$ ) is close to one, this means that there are no interactions between the iodine ion and the inhibitor molecules. If it is greater than one or smaller, this means that the adsorption effect is of a cooperative or competitive type, respectively [36]. Competitive adsorption verified the S values obtained for the system studied.

**Table 6:** The values of the Synergism Parameter of the mixture (CLL + KI) at different conditions

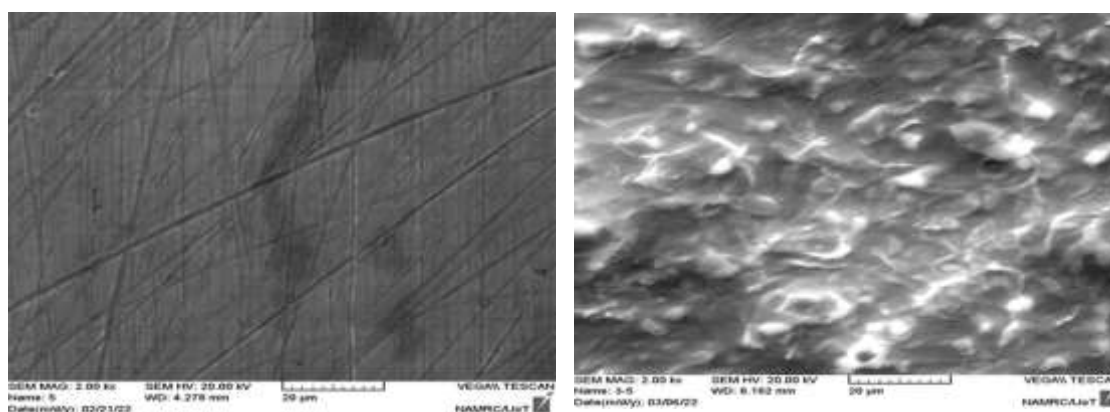
$T$ (K)	Synergism Parameter ( $S_\theta$ ) (1 ml/L of CLL+ 0.25 ml/L of KI)	Synergism Parameter ( $S_\theta$ ) ( 2 ml/L of CLL+ 0.5 ml/L of KI)	Synergism Parameter ( $S_\theta$ ) (3 ml/L of CLL+ 0.75 ml/L of KI)	Synergism Parameter ( $S_\theta$ ) (4 ml/L of CLL+ 1 ml/L of KI)	Synergism Parameter ( $S_\theta$ ) (5 ml/L of CLL+ 1.25 ml/L of KI)
303	0.8601	0.7863	0.7096	0.6988	0.6999
313	0.7855	0.5657	0.5565	0.4983	0.6632
323	0.4246	0.3156	0.455	0.3805	0.3369
333	0.2505	0.1854	0.1894	0.1791	0.0987

## Scanning Electron Microscope (SEM) study

The benefit of the SEM analysis is to know whether the adsorption of particles on the surface of the mineral sample occurs or not [37]. The morphology of the surface was studied before and after being immersed in 1 M HCl for 3 h with and without the mixture (CLL extract + KI) that was used as an inhibitor for corrosion of mild steel at the highest temperatures (333) K using SEM type TESCAN, Vega III model. Figure (9A) represents an image of the sample before the immersion process in the acidic media occurred, while figure (9B) represents the image of the sample after being immersed in the acid in the absence of a mixture of CLL extract and KI that appeared rough and severely destroyed. Figure (9C) represents the image of the sample after immersion in acid in the presence of 6.25 ml/L of the mixture that appeared to have a smooth surface. The SEM analysis revealed that the corrosion rate decreased due to the

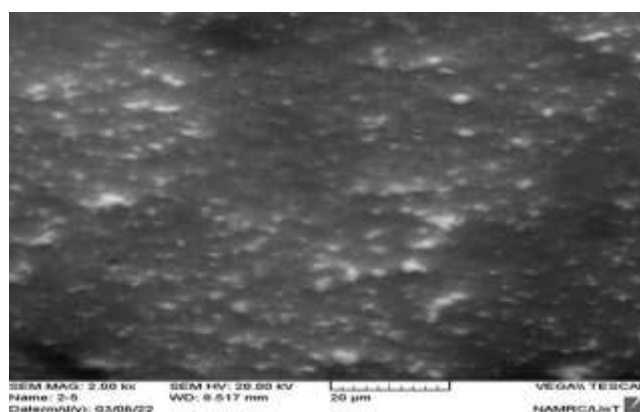


inhibitory effect of the mixture attributed to its existence in the corrosive solution, this is consistent with the results of weight loss experiments [38, 39].



(A) Before immersion in 1 M HCl

(B) After immersion in 1 M HCl and in the absence of an inhibitor at 333 K for 3 h



(C) After immersion in 1 M HCl and in the presence of CLL extract at a concentration of 10 ml/L of

**Figure 9:** SEM (2.00kx) micrographs of mild steel

## Conclusions

We conclude that the mixture of lime leaf extract and potassium iodide is suitable to be a good inhibitor to reduce the corrosion of mild steel used in many industrial applications in an acidic medium at a concentration of 1 M of HCl by the combined effect in synergy with the plant extract molecules with high efficiency and that the temperature and concentrations of the inhibitor have an effect on the adsorption process, thereby, the inhibition efficiency.



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