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Recycling of Expired Lactulose Drugs as Eco-Friendly Corrosion Inhibitor for Steel Alloys in Acidic Environment: Gravimetrical and Electrochemical Studies

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Lactulose is a synthetic sugar that is used to treat constipation and liver disease. The sweet taste of this medicine makes it appealing to children, putting their lives in danger. The consumption of unused or expired medicines is increasing the number of child deaths. The current article proposes using expired water-soluble lactulose as a corrosion inhibitor for the carbon steel electrode in a 1.0 M HCl acidic environment. The effectiveness of the expired Lactulose drug's ability to inhibit was assessed using electrochemical and gravimetric methods. Investigated were the effects of expired drug concentration, reaction temperature, and pH. Corrosion inhibition rose as concentration grew, fell as the temperature rose, and rose yet further when pH fell. Gravimetric methods include direct mass loss and atomic absorption spectroscopy (AAS). The expired medications impede both the anodic and the cathodic potential, according to data from potentiodynamic polarization (PDP), proving that they are mixed-type inhibitors. An electrochemical impedance spectroscopy (EIS) analysis revealed that the expired medication enhances polarization resistance by adhering to the metal/electrolyte contact. This kind of adsorption was modeled using the Langmuir adsorption isotherm. The viability of employing expired Lactulose medicines as potential harmless green corrosion inhibitors for steel in an industrial setting at lower pH is indicated by the good agreement between the applied methodologies (±2 %).

Keywords: Expired drugs; eco-friendly inhibitors, Gravimetric; AAS; Potentiodynamic polarization; electrochemical impedance spectroscopy.

1. INTRODUCTION

The consumption of unused or expired medicines is increasing the number of child deaths **[1-3].** Lactulose is a synthetic sugar that is used as a medicine to treat constipation and liver disease. Lactulose is available as a liquid for oral administration. Constipation is normally treated with it once day, while liver disease is typically treated with it three to four times daily. It is transformed into products in the colon that draw water from the body and into the colon. This water softens the stools. Patients with liver disease can also use lactulose to reduce the amount of ammonia in their blood. It works by drawing ammonia from the blood and removing it from the body through the colon. Because the sweet taste of this medicine makes it appealing to children, it is extremely dangerous to leave it in the environment after it expires because it is harmful to children. In general, drugs are one of the most well-known chemical materials that we use on a daily and continuous basis in our homes. Expired drugs, which are considered dangerous materials in the environment, kill over 2000 children each year **[1-3].**. In other nations, unused medications are discarded in desert pits, poisoning groundwater with dangerous substances. Reda Abdel Hameed was intrigued by all of these observations and began seeking for fresh uses for outdated medications. Reda Abdel Hameed pioneered the use of expired medications as corrosion inhibitors for metals in 2009 and 2011 **[1, 2]** when he used expired ranitidine medications as a potentially eco-friendly, nontoxic corrosion inhibitor for aluminum in hydrochloric acid solution. Other scientists were intrigued by his discovery, and they started looking at several outdated medications. Additionally, studies on underutilized drugs have focused on preventing carbon steel from corroding in various aggressive media **[3–7].** Green corrosion inhibitors, also known as eco-friendly and potentially harmless corrosion inhibitors, have been the focus of scientific research in the field of corrosion inhibition for the past ten years. The most recent initiatives include the use of outdated medications to address the issue of solid waste accumulations as well as to introduce a potential nontoxic inhibitor. This will save time and money spent on the manufacturing or shipping of chemical corrosion inhibitors, which accounts for about 7% of all income **[8–12].** From a green chemistry perspective, using expired drug components as inhibitors helps to 1) prevent the deleterious effects of some toxic inhibitors on humans, and 2) conserve energy and organic solvent required in the manufacture of corrosion inhibitors. 3) No waste is produced when employing the pharmaceuticals as inhibitors, and 4) drug waste accumulation, which is harmful to children and groundwater, is avoided. Because they are brought straight from the pharmacy to the lab, where they are used in their pharmacological form that is safe for both people and the environment in very small concentrations, expired drugs are therefore regarded as green inhibitors because there is no waste in the process of using them as inhibitors. In addition, corrosion is the process by which the environment oxidizes metals, resulting in corrosion products and the deterioration of the metal lattice. A tremendous waste of money and natural resources, this phenomenon. Because steel corrodes and changes from a hard, useful metal to a corrosive product that is detrimental to the environment, corrosion control of steel is considered to be a green process. As a result, corrosion control of steel is of technological, economic, and environmental relevance. The materials used incur substantial maintenance and protection expenditures as a result of corrosion damage. Finally, since they are innocuous to people, especially at very low doses, expired medications are referred to as "green inhibitors." Furthermore, as corrosion is a dreadful waste of both natural resources and money, preventing corrosion in steel is crucial for the environment. In earlier investigations **[13,14],** expired paracetamol and indomethacin were employed to prevent steel from corroding in conditions with acid and sodium chloride. For evaluating a wide range of materials as corrosion inhibitors for metals and alloys in a variety of corrosive aqueous environments involving acids, alkalis, and aqueous salts, electrochemical techniques are very effective and often utilized **[15–30].** The expired lactulose medication was tested in this study as a green corrosion inhibitor for steel alloy in a 1.0 M hydrochloric acid corrosive environment using gravimetrical and electrochemical methods. Investigations were also conducted into the effectiveness of corrosion inhibition as a function of expired drug concentrations, reaction temperature, and pH.

2. EXPERIMENTAL

2.1. Materials and Test Solution

The aggressive 1.0 M hydrochloric acid used in this work has a pH of 0.0 and was created by diluting analytical grade 37% HCl (Sigma Aldrich) with double-distilled water, titrating it against 1.0 M Na_2CO_3, and then diluting it to the necessary pH, which is 0.0. (pH 1, pH 2, and pH 3). To ensure reproducibility, each experiment was performed in aerated stagnant solutions and at least three times under identical circumstances. The average of the three replicated values was then used for further data processing. The gravimetric composition of the steel components utilized in this study is displayed in Table 1 **[43–45].** It shares characteristics with the carbon steel material that is used to make petroleum pipe lines **[43–45].**

Table 1. Gravimetric composition of the used steel materials (**[43-45]).**

Element	Mn	Si	S	P	C	Fe
Composition Weight (%)	0.517	0.201	0.009	0.007	0.157	About 99 %

Tabuk Pharmaceutical Mfg. Co. KSA produces Lactulose, which is taken from our home. After the 6-month expiration date, it was used as an inhibitor in the form of tablets. In this study, it is used as a green corrosion inhibitor for steel, and its chemical structure and composition are shown in **figure 1.**

2.2. Gravimetric Studies

The gravimetric approach is popular because it has the benefit of being straightforward and does not call for sophisticated tools or processes. Each experiment was carried out three times, and the recorded data was averaged with a (± 0.1) error. The weight loss measurement and the concentrations of the metal passing in solution by atomic absorption spectroscopy were two different gravimetric tests used in this investigation.

2.2.1. Weight Loss measurement

The method is based on calculating the weight loss (WL) of a sample (coupon) of the surface (S) that has been submerged in the abrasive solution for a period of time (t). The tests are carried out in non-aerated media in 100 ml glass vials at room temperature. The iron samples are cleaned with distilled water, degreased with acetone, and then dried before and after the 8-hour immersion. The following relationship (1) was used to calculate the corrosion rate W:

$$W = \frac{mi - mf}{St} \quad (1)$$

where W ($mg.cm^{-2}.h^{-1}$) is the corrosion rate, m_i (mg) and m_f (mg) are the mass before and after exposure to test solution, respectively, S (cm^2): is the surface of area of specimen, t (h): is the immersion time. Regarding the inhibitory efficiency I.E.% and the surface coverage (θ), which represents the part of the metal surface covered by the inhibitors molecules, were calculated according to the following equations:

$$\% \text{ I.E} = ([W^O - W] / W^O) \times 100 \quad (2)$$

$$\theta = ([W^O - W] / W^O) \quad (3)$$

where W^o and W represent the corrosion rates in the absence and presence of the inhibitors, respectively.

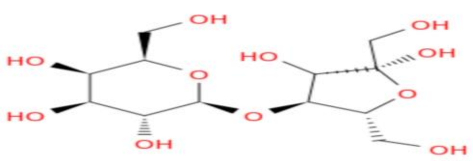
Drug name	Lactulose (Lac)
Molecular Formula	$C_{12}H_{22}O_{11}$
Drug IUPAC name	(2S,3R,4S,5R,6R)-2--[(2R,3S,4S,5R), -4,5-dihydroxy -2,5-bis-(hydroxymethyl)oxolan-3-yl]-oxy-6-(hydroxymethyl)oxane-3,4,5-triol
Chemical Structure Formula	
3 D Structure Formula	

Figure 1. Structure and composition of **Lactulose (Lac)** Drugs (used as inhibitor)

2.2.2. Atomic absorption Spectroscopy (AAS) measurements

The total number of iron ions in corrosive solutions was measured using atomic absorption spectroscopy in both the presence and absence of the drugs used as corrosion inhibitors (AAS). On a

Varian Spectra AA 220, atomic absorption spectroscopy was employed to concentrate the ferric ions added to the solution. To evaluate the quantities of iron ions in the corrosive solution both while the inhibitor was missing and present, we dispersed the corrosive medium with aqua regia **[10-14].**

2.3. Open Circuit Potential Measurement

In a corrosive solution of 1.0 M HCl solution at 30°C, the potential of a carbon steel electrode was measured in the absence and presence of varying concentrations of expired lactulose medicines against a saturated calomel electrode (SCE). Until the steady-state potentials were attained, Multi-tester was used for all measurements **[45-55].**

2.4. The Potentiodynamic Polarization (PDP)

In the electrochemical experiments, a Volta master and a radiometer analytical are employed (PGZ301, DYNAMIC ELS VOLTAMMETRY). A saturated calomel electrode (SCE) serves as the reference electrode, to which all potentials are referred, and a platinum wire serves as the counter electrode. the cylinder-shaped electrode for working steel (1 cm2). Prior to each test, silicon carbide abrasive sheets of grades 600, 1000, 1200, 1500, and 2000 were used to repeatedly abrade the working electrode surface. This was followed by degreasing in ethanol, washing with distilled water, and cleaning with distilled water. The working electrode is kept in place for 50 minutes before being submerged in a free corrosion potential. The scan rate was 1 mV/s. Using the following equation, the corrosion inhibitory efficiency% I.E. was calculated **[45-55].**:

$$\% \text{ I. E.} = ([i - i^o]/ i) \times 100 \qquad (4)$$

Where i and i^o are the corrosion current densities values in absence and presence of the inhibitors respectively. The cathodic and anodic Tafel slopes were obtained from the Tafel plot and the corrosion potential (E_{corr}), corrosion current (I_{corr}) and Tafel constants (βa & βc) were calculated and tabulated.

2.5. Electrochemical Impedance Spectroscopy (EIS)

With a frequency range of 100 kHz to 50 mHz and a 4 mV sine wave as the excitation signal at open circuit potential, electrochemical impedance was measured using a Voltalab 40. A Nyquist Plot results from plotting the real component on the X-axis and the imaginary part on the Y-axis of a chart. The difference between the impedance at lower and higher frequencies was used to obtain the charge transfer resistance values (Rct). The diameter of the semicircle in Nyquist form is used to calculate the polarization resistance Rp **[45-55].**

3. RESULTS AND DISCUSSION

3.1 Gravimetric Measurements

3.1.1. Effect of Inhibitor Concentrations

The corrosion rate and corrosion inhibition efficiency%I.E of expired Lactulose medicines for the various concentrations of LAC inhibitor were determined using gravimetric techniques (pH 1,2, and 3). After 7 hours of immersion of steel coupon in the hydrochloric acid corrosive environment of varying pH, **Table 2** provides the corrosion rate (W) and corrosion inhibition efficiency (%I.E) data. **Figure 2** is also. According to gravimetric data, adding the expired Lactulose pharmaceuticals (LAC) green inhibitor causes weight loss, which in turn lowers the corrosion rate and boosts inhibition efficiency. This behavior was exacerbated by raising the LAC inhibitor concentrations. It is clear that when inhibitor concentration rises, the efficiency of the inhibition increases, reaching 97% at 300 ppm. The inhibitory efficiency% I.E and the surface coverage (), which measures the percentage of the metal surface that is covered by the inhibitor molecules, were calculated using equations 2 and 3 that are described in the experimental part. According to **Table 2**, the values of inhibitory efficiency increase as drug concentration rises and decrease as medium pH falls. **Figure 2** demonstrates how adding more expired LAC medications reduces the weight loss of carbon steel samples. This demonstrated that these drugs work as inhibitors since their presence slowed the rate at which iron dissolved in 1.0 M HCl solution. The connection between weight loss over time in 1.0 M HCl under unrestricted and inhibited conditions is linear. This demonstrates how there are no surface coatings that are insoluble during corrosion. In order to stop corrosion in this case, the inhibitors first become adsorbed onto the metal surface, following which they either obstruct the anodic and cathodic reaction sites completely or alter the mechanism of the partial anodic and cathodic processes **[25–30].** The greatest inhibitory efficiency obtained with 300 ppm of expired lactulose medications is 97%, which is higher than the efficiency attained in the mentioned sources' prior works **[10-14].**

3.1.2. Effect of temperature

At several temperatures, including 303,313,323,333K, gravimetric (weight loss) measurements were taken in order to understand the mechanism of inhibition and pinpoint the kinetic factors influencing the corrosion process. The percentage of steel that is inhibited in the presence of the inhibitor is graphically depicted in **Figure 3** as being affected by temperature. Indicating that the protective film of these compounds generated on the steel surface is less stable at higher temperatures, the values of%I.E clearly reduced as the temperature increased. This could be because more of the metal is exposed to the acidic environment at higher temperatures as certain molecules that have been adsorbed to the steel's surface start to desorb **[36–45].** Each experiment was run three times, with a (0.1) error in the average of the recorded data.

Table 2. The impact of increasing LAC drug concentration on steel corrosion characteristics in HCl solutions of various pH values as determined by weight loss measurements at 303 k.

	pH = 1		pH = 2		pH = 3	
Expired drugs Concentrations ppm	**I.E. %**	**θ**	**I.E. %**	**θ**	**I.E. %**	**θ**
Blank	-	-	-	-	-	-
100 ppm	90.4	0.90	93.7	0.937	93.8	0.938
200 ppm	91.9	0.919	94.6	0.946	95.3	0.953
300 ppm	93.5	0.935	95.3	0.953	96.0	0.960
400 ppm	94.6	0.946	96.0	0.960	96.9	0.969

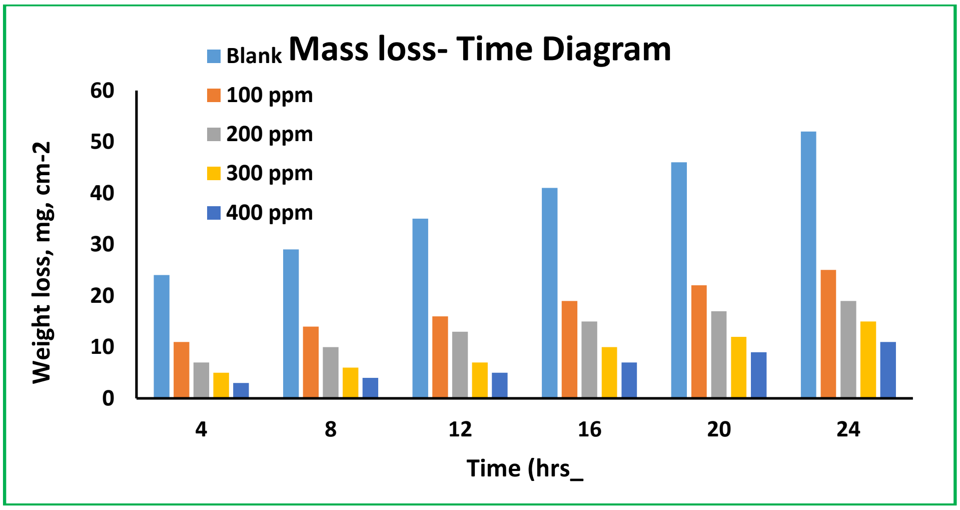


Figure 2. Depicts the weight loss of steel over time, in 1.0 M HCl with and without expired LAC medications serving as a green steel corrosion inhibitor.

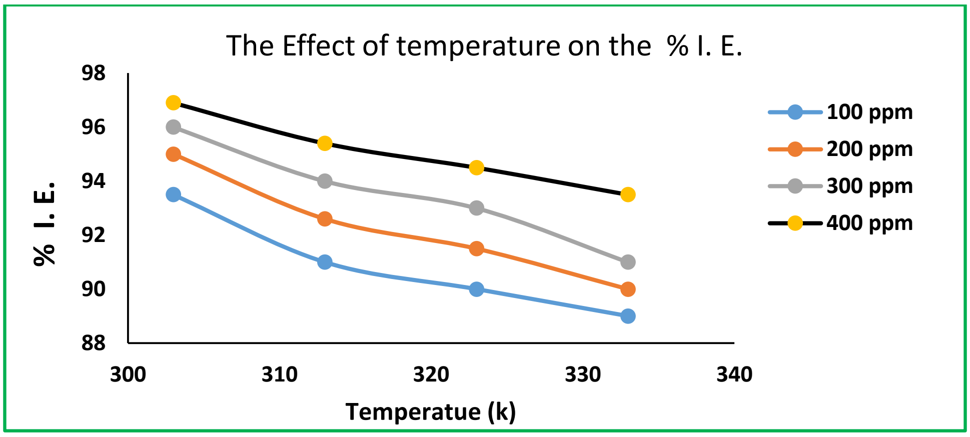


Figure 3. The data obtained from the weight loss at pH = 3 and the effect of temperature on the percentage I.E. for steel in 1.0 M HCl in the presence of various concentrations of expired LAC medicines as the green inhibitor.

3.2. Atomic Absorption Spectroscopy(AAS)

Costs are reduced because aqueous, acidic, or basic solution analysis requires a lot fewer stages when using atomic absorption spectroscopy (AAS). The industrial usage of atomic absorption for regular analysis is divided into four main categories: (1) the incoming inspection of all raw materials, (2) production testing, (3) final inspection of all products, and (4) environmental analysis. Atomic absorption is largely of indirect use for rapid examination during the production process because of the sequential character of the approach and the impossibility to complete a thorough analysis of steel or slag in less than two to three minutes **[10-14].** Based on the fundamental chemistry of corrosion's solubility, AAS was used to predict the rate of corrosion in various media, including acidic, basic, and neutral media. The AAS method was used to evaluate the presence of Fe ions in natural and mineral waters **[10-14].** The iron ions released into the solution due to corrosion were quickly recognized using atomic absorption spectroscopy, and their concentration was quantified using a calibration curve. The corrosion of the iron samples in the solution was accelerated by temperatures, a low pH, the presence of chloride ions, and high salinity **[10-14].** Iron corrosion is a complex process that occurs when iron is exposed to oxygen, humidity, and chloride ions. You can estimate how expensive the deterioration of iron structures or other components will be to society by paying attention to the properties of the corroding material **[10-14].** In the current experiment, the total amount of iron ions dissolved in the corrosive solution was determined using atomic absorption spectroscopy. can happen as a result of acidic HCl corrosion of steel at different pH levels (AAS). The ions flowing into the solution were concentrated using AAS in order to measure the total amounts of iron ions in the corrosive solution both while the green inhibitor was absent and present. Table 3 shows the atomic absorption spectroscopy (AAS) findings and reveal that the total quantity of iron ions concentrations in the corrosive medium were decreased by both lowering the pH of the solution and raising inhibitor concentrations. In this graph, the rate of corrosion is plotted against the concentration of ferrous ions; as the concentration of iron ions in the solution increases, so does the rate of corrosion. Every action is impacted by the inclusion of an inhibitor. According to **Table 3**, which is in good agreement with the results of the gravimetric (weight loss) method, the addition of expired medications prevents steel from corroding in an acidic environment and slows the process of iron dissolution (the total amount of iron ions in this environment) at lower pH levels**[10-14].**

Table 3. shows how the AAS technique's ferrous ion concentrations are affected by pH and inhibitor concentrations.

Sample	Inhibitor Concentration	The total amount of iron ions dissolved in the corrosive solution , ppm		
		pH = 1	pH = 2	pH = 3
Blank	Free	133	125	119
Expired Lactulose	100 ppm	42	29	20
	200 ppm	27	23	15
	300 ppm	21	17	11
	400 ppm	17	11	9

3.3. Open Circuit Potential Measurements

The open circuit potential of the used carbon steel in 1.0 M HCl was measured against the SCE reference electrode for 50 minutes at 30 ^{0}C with varied concentrations of the used, expired Lactulosedrugs green inhibitor present. According to **Figure 4,** which displays the results. In an unconstrained 1.0M HCl solution, the E value of steel first shifts to greater negative potentials before starting to move somewhat in the opposite direction. It was then kept at a fairly steady value after that.

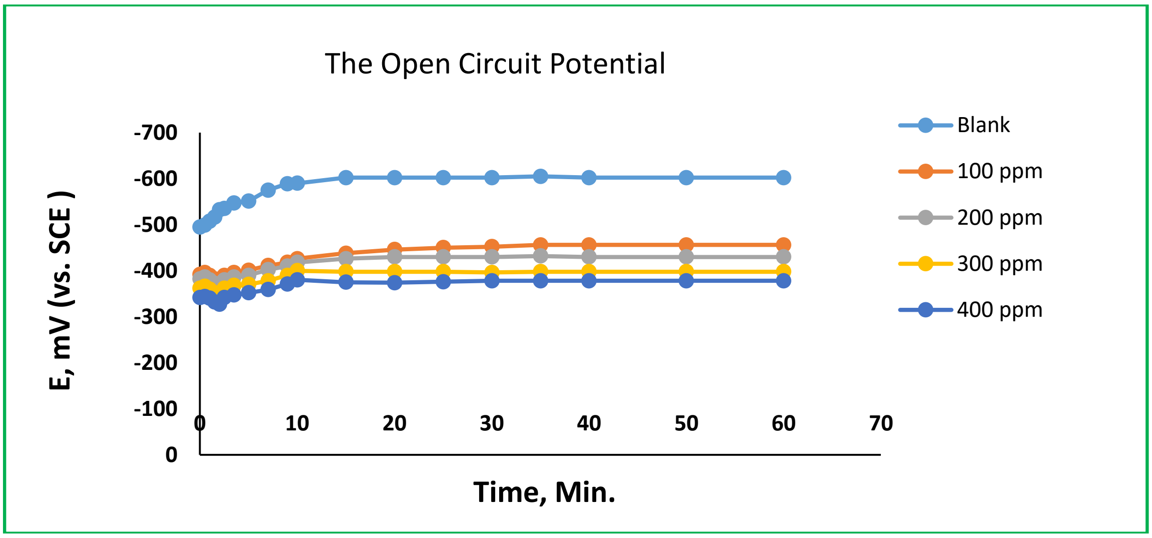


Figure 4. Demonstrates the potential-time curves for carbon steel soaked in 1.0 M HCl at 30 0C with and without the green inhibitor, an expired Lactulose.

The addition of an inhibitor results in the same behavior, but the steady-state potential that was generated by the addition of the inhibitors altered to greater levels. Inhibitors raise the steel's free corrosion potential in compared to the control solution (move it to more noble values). In every curve, the steady-state values are consistently lower than the immersion potential, demonstrating that the steel oxide layer must dissolve before the steady-state condition is reached **[37-40].**

3.4. Potentiodynamic polarization technique

Figure 5 shows the potentiodynamic polarization curves for a carbon steel electrode in 1.0 M HCl solution, both without and with various amounts of expired Lactulosedrugs. The linear section of the polarization curves was used to calculate the values of some electrochemical corrosion parameters, such as the cathodic ((β_c) and anodic ((β_a) Tafel slopes. The intersection of the cathodic and anodic lines with the corrosion potential yielded the values of corrosion current density (I_{corr}) ($E_{corr.}$). In the experimental part, equation number 1 was used to determine the percentage inhibition efficiency (%I.E) percentage from the corrosion current density values, and equations **[37-40]** were used to calculate the surface coverage values.

$$\boldsymbol{\theta} = \left[1 - \frac{I_{add}}{I_{free}}\right] \qquad \textbf{(5)}$$

where, I_{free} and I_{add} are the corrosion current densities in the free and inhibited acid solutions, respectively. The values of β_a, β_c , E_{corr} ,I_{corr} and %I.E. are collected in **Table 4**. Review of **Table 4.** It is concluded that the approximate small changes in the values of the β_a and β_c Tafel slopes demonstrated that these drugs functioned as mixed inhibitors. Without changing the reaction's process, the surface area available for cathodic hydrogen evolution and anodic iron dissolution diminishes. Ecorr readings gradually turn negative, showing that these inhibitors are primarily cathodic and are of mixed type. The values of Icorr drop, and as a result, the values of IE rise, showing that omeprazole medications have an inhibitory effect on iron corrosion in a corrosive environment with hydrochloric acid **[37-40].**

Table 4. Potentiodynamic Polarization data of steel electrode in 1.0 M HCl solution with various concentrations of expired Lactulosedrugs at 30 ^{0}C.

Inhibitors	Conc., ppm	$-E_{corr}$ mV (SCE)	I_{corr} mA cm^{-2}	β_a $mVdec^{-1}$	β_c $mVdec^{-1}$	% I.E.	θ
Blank		492	1.3	103	125	-	-
Expired Lactulose	100 ppm	527	0.17	125	139	86.9	0.869
	200 ppm	539	0.12	129	147	90.7	0.907
	300 ppm	51	0.10	138	152	92.3	0.923
	400 ppm	547	0.08	141	158	93.8	0.938

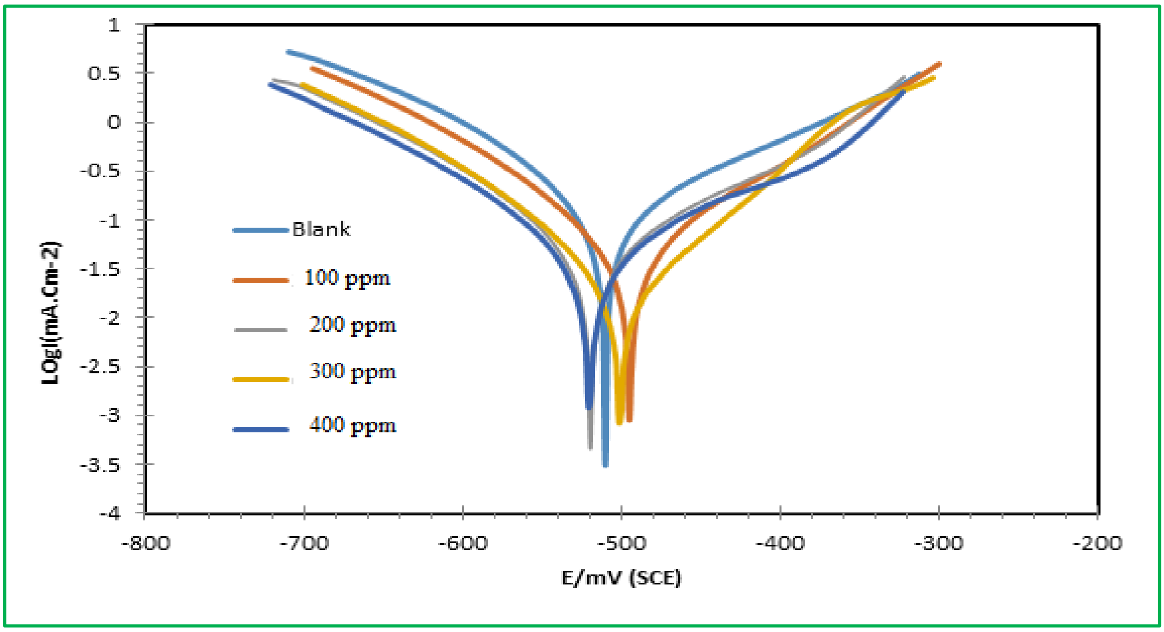


Figure 5. Potentiodynamic polarization curves for steel in 1.0 M HCl solution containing different concentrations of expired Lactulose drug at 30 ^{0}C.

3.5. Electrochemical Impedance Spectroscopy (EIS)

Figure 6 displays the electrochemical impedance spectra Nyquist plots for the suppression of steel corrosion in 1.0 M HCl with several concentrations of the expired Lactulosedrugs as green inhibitor at 30 ^{0}C. The Nyquist plots have a depressed semicircle with the real axis at the center. The semicircle's size grows as inhibitor concentration rises, pointing to the charge transfer mechanism as the primary regulating element of steel corrosion. The figures clearly show that as the concentration of the expired drug inhibitor has increased, so has the impedance of the inhibited solution. **Table5** provides the experimental findings from EIS measurements for the corrosion of iron in 1.0 M HCl in both the presence and absence of an expired Lactulose inhibitor.

Table 5. Data on the AC impedance of a steel electrode in 1.0 M HCl at 30^{0}C in the absence and presence of various amounts of lactulose that have expired.

Sample	Rct Ohm cm^2	Rs Ohm cm^2	Cdl µF cm^{-2}	IE%	θ
Blank	93.84	2.6	39.0	---	---
100 ppm	960.5	1.75	1.42	90.2	0.902
200 ppm	998.6	1.63	1.34	90.6	0.906
300 ppm	1090.5	1.52	1.23	91.4	0.914
400 ppm	1215.3	1.39	1.11	92.3	0.923

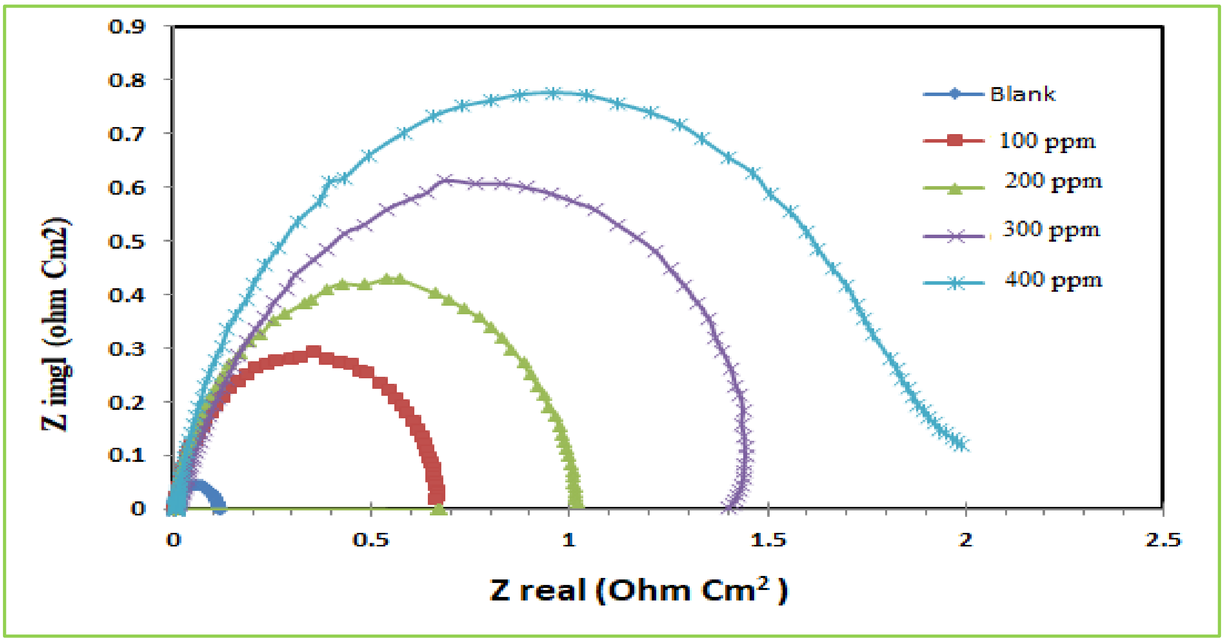


Figure 6. For a carbon steel electrode in 1.0 M HCl solution at 30^{0}C with varying concentrations of expired Lactulose as a green inhibitor, create a Nyquist plot.

It is evident that the polarization resistance (Rp) value rose as the inhibitor's concentration increased. While the values of the interface's capacitance (C_{dl}) start to fall as inhibitor concentration rises, this is likely because the local dielectric constant has decreased or the thickness of the electrical double layer has increased. This indicates that the inhibitor functions through adsorption at the metal/solution interface **[37-40]** and that the decline in C_{dl} values is brought on by the gradual replacement of water molecules by the inhibitor molecules through adsorption on the electrode surface, which lessens the extent of the metal dissolution process. The following equation **[25–30]** yields the inhibition efficiency **[37-40]:**

$$\% \text{ I.E. } (R_p) = \frac{R_p(inhi) - R_p}{R_p(inhi)} \times 100 \quad (6)$$

Where R_p is polarization resistance without inhibitor, and R_p(inhi) is polarisation resistance with inhibitor. C_{dl} value is obtained from the following equation **[45-55]:**

$$\omega \max = 2\pi f_{max} = 1/ R_pC_{dl} \quad (7)$$

Where, f_{max} is the frequency at the top of the semicircle (where-Z" is maximum). The proposed equivalent circuit is represented in **figure 7** the electrode impedance, Z, in this case given by the mathematical equation **[45-55]:**

$$Z = Rs \left[\frac{Rt}{1+(2\,\pi\, f\, Rt\, Cdl)^{\alpha}}\right] \quad (8)$$

Where α denotes an empirical parameter ($0 \leq \alpha \leq 1$) and f is the frequency in Hz. Because of surface heterogeneity, the roughness effect, inhibitor adsorption, and variations in the characteristics or In terms of a distribution of time constants, this equation explains the departure from the ideal RC-Behavior in terms of the composition of surface layers. In the equivalent circuit depicted in **figure 7 [45-55],** the double-layer capacitance (Cdl) is linked in parallel to the charge transfer resistance (Rt), which is connected in series to the parallel inductive (Rs).

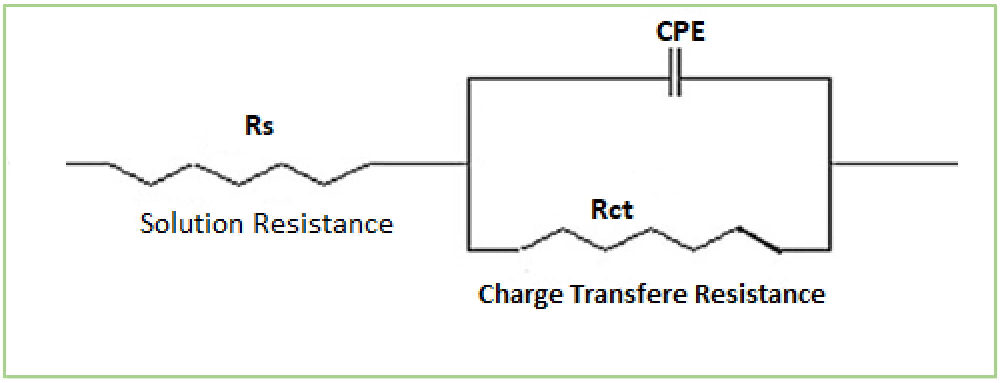


Figure 7. For the electrochemical impedance measurements for steel electrodes in 1.0 M HCl solution with various concentrations of Lactulose medication at room temperature, Randles equivalent circuit model is used.

3.7. Adsorption Isotherm

The primary factors influencing the adsorption process are the charge and type of the metal surface, its electronic properties, the adsorption of solvent and other ionic species, the temperature at which corrosion occurs, and the electrochemical potential at the solution interface. The derivatives' inclusion of electro-repelling or electro-donating or electro-donating groups

To get the values of surface coverage (θ) at various drug doses and to explain the best-fit isotherm for the adsorption process, Tafel polarization is utilized. According to the following equation **[37-40],** the Langmuir adsorption isotherm best fits the results:

$$C_i / \theta = 1/K_{ads} + C_i \qquad (6)$$

where K and C, respectively, represent the equilibrium constants of the drug concentration and the adsorption process.

Figure 8 illustrates the straight line obtained by plotting C/ θ vs C. The intercept of the line with approximately a unit slope is 1/K. The equation: is used to determine the standard free energy of adsorption, $\Delta G°_{ads}$.

$$K_{ads} = 1/55.5 \exp(-\Delta G_{ads} / RT) \qquad (7)$$

Where T is the absolute temperature, R is the gas constant, and 55.5 moles/liter of water are present in the majority of the solution. K_{ads} is the adsorption equilibrium constant. ΔG_{ads} has a computed value of -35.62 kJ/mol. The absence of a positive result for ΔG_{ads} denotes spontaneous drug molecule adsorption on the metal surface **[37-40].** The resulting value, however, is lower than the -40 kJ/mol threshold value needed for chemical adsorption, indicating that the process of adsorption is physical **[45-55].** It is widely acknowledged that the investigated compound—an expired drug—inhibits corrosion by adhering at the metal/solution contact. Additionally, it's thought that the development of a solid organic molecule complex with the metal atom has drawn a lot of interest **[45-55].**

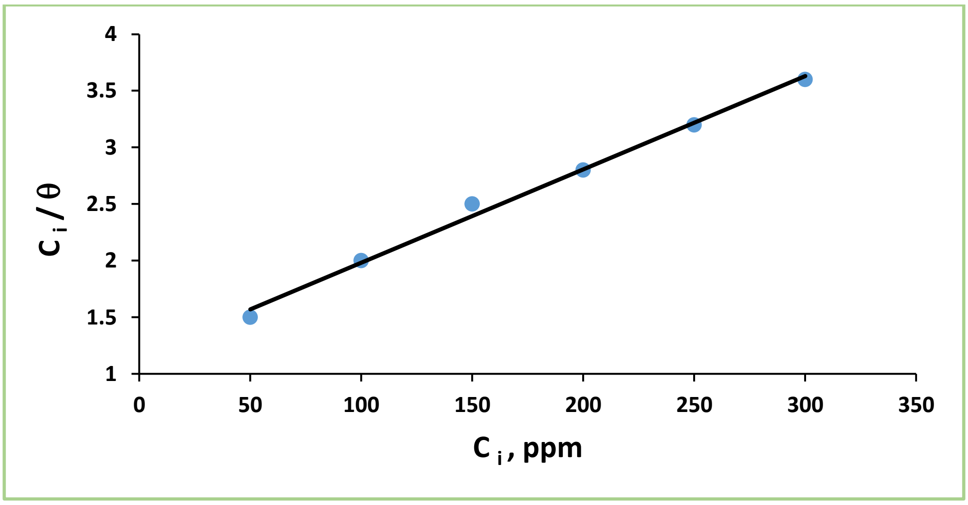


Figure 8. When utilized as an inhibitor, the used-up Lactulose inhibitor at 30^0C hindered the Langmuir adsorption isotherm for carbon steel in 1.0 M HCl.

4. CONCLUSIONS

a. Expired Since lactulose drugs are safe for humans even at very low quantities, they are referred to as green corrosion inhibitors. Additionally, since rust is a terrible waste of money and resources, protecting steel from corrosion is crucial for the environment.

b. Electrochemical and gravimetric methods are useful for figuring out how quickly steel corrodes in an acidic atmosphere.

c. By increasing expired Lactulose drug inhibitor concentrations, the efficiency of corrosion inhibition increases, reaching 97 % at 400 ppm.

d. The findings of the potentiodynamic polarization studies showed that E_{corr} values slowly changed to negative values, indicating that expired Lactulose inhibitors were mixed-type inhibitors.

e. The semicircle size increases as the inhibitor concentration falls, according to electrochemical impedance spectroscopy, indicating that the charge transfer mechanism is the main factor controlling the steel dissolution process.

f. The adsorption and adherence of expired Lactulose medications on the metal surface and the creation of a barrier film that isolates the metal from the corrosive media are what prevent corrosion, and the inhibitor's adsorption followed the Langmuir adsorption isotherm.

g. Incorporating expired Lactulose drugs prevent steel corrosion in an acidic environment and delays the process of iron breakdown in this environment, according to findings from different electrochemical techniques that are in good agreement with one another and with (±2). As a result, old Lactulose drugs operate as a corrosion inhibitor for the environment.

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References

1. R.S. Abdelhameed, *Al-Azhar Bull. Sci.,* 10 (2009) 151.
2. R.S. Abdelhameed, *Port. Electrochim. Acta.,* 29 (2011) 273.
3. R.S. Abdel Hameed, *Phys. Chem.: Indian J.,* 8 (2013) 146.
4. R. S. Abdel Hameed, M. M. Aljohani, A. Essa, A. Khald, A. M. Nasar, M. M. Badr, S. R. AlMhyawii, M.S. Suliman, *Int. J. Electrochem. Sci.*, 16 (2021) 210446.
5. R.S. Abdel Hameed, H. Alshafey, A.H. Abunawas, *Int. J. Electrochem. Sci.,* 9 (2014) 6006.
6. R.S. Abdel Hameed, H. Alshfey, A.H. Abunawas, *Int. J. Electrochem. Sci.,* 10 (2015) 2098.
7. N. Vaszilcsin, D.A. Duc, A. FLURAŞ, M.L. DANa, *Stud. Univ. Babes-Bolyai, Chem.,* 64 (2019) 17.
8. N.K. Gupta, C.S.A. Gopal, V. Srivastava, M.A. Quraishi, *Int. J. Pharm. Chem. Anal.,* 4,8(2017)4.
9. M. Abdallah, H. Hawsawi, A. S. Al-Gorair , M. T. .Alotaibi , S. S. Al-Juaid , R.S. Abdel Hameed, *Int. J. Electrochem. Sci*., 17 (2022) 220462.
10. Reda S. AbdelHameed, SofianObeidat, M.T.Qureshi, S.R.Al-Mhyawi, Enas H.Aljuhani, M.Abdallahd,, *J. Mater. Res. Technol.*, 21, (2022) 2743.

11. R. S. AbdelHameed, Gh. M. S. Aleid , A. Khaleed , D. Mohamaad , E. H. Aljuhanyi , S. R. Al-Mhyawii ,F. Alshammarey, , M. Abdallah, *Int. J. Electrochem. Sci.*, 17 (2022) 220655.
12. R. S. Abdel Hameed, A. M. Al-bonayan, *Journal of Optoelectronic and Biomedical Materials,* 13 (2021)45.
13. Reda S. Abdel Hameed, Enas H. Aljuhani, Rasha Felaly & Alaa M. Munshi , *J. Adhes. Sci. Technol.,* 34 (2020)1-27. DOI: 10.1080/01694243.2020.1826801.
14. R. S. Abdel Hameed, M.T. Qureshi , D. Mohamed, M. Abdallah, M. M. Aljohani, S. R. Al-Mhyawi, E. H. Aljuhani, M. S. Soliman, *Int. J. Corros. Scale Inhib.*, 10 (2021) 1748.
15. M. M. Ibrahim, R.S. Abdel Hameed, Abd-Alhakeem H.Abu-Nawwas, Sawsan E Mohamad. *Journal of Organic Chemistry,* 10 (2014)271.
16. M. M. Ibrahim, R. S. Abdel Hameed, A. H. Abu-Nawwas, *Journal of Organic Chemistry,* 9 (2013)493.
17. R.S. Abdel Hameed, E.H. Aljuhani, A.H. Al-Bagawi, A.H. Shamroukh and M. Abdallah, *Int. J. Corros. Scale Inhib.,* 9 (2020) 623.
18. R. S. Abdel Hameed, M.Abdallah, *Surf. Eng. Appl. Electrochem,* 54 (2018) 599.
19. R.S. Abdel Hameed, M.abdallah, *Prot. Met. Phys. Chem,* 54 (2018) 113.
20. R.S. Abdel Hameed, and A.H. Shamroukh, *J. Corros. Scale Inhib.*, 6 (2017) 333.
21. R. S. Abdel Hameed, M. T. Qureshi, M. Abdallah, *J. Corros. Scale Inhib.,* 10 (2021) 68.
22. M. Abdallah, A. S. Al-Gorair, A. Fawzy, H. Hawsawi & Reda S. Abdel Hameed, *J. Adhes. Sci. Technol.,* 36 (2021) 35.
23. A. S. Al-Gorair , H. Hawsawi , A. Fawzy , M. Sobhi , A. Alharbi , R. S. Abdel Hameed, S. Abd El Wanees , M. Abdallah, *Int. J. Electrochem. Sci.,* 16 (2021)211119.
24. R. S. Abdel Hameed ; A. Essa; D. Mohamed; M. Abdallah; M. Aljohani ; S. Al-Mhyawi; M. Souluman; E. I. Arafa, *Egypt. J. Chem.*, 64 (2021)53.
25. R. S. Abdel Hameed, *J. New Mater. Electrochem. Syst.*, 20 (2017) 141.
26. R.S. Abdel Hameed, *Materials Science Journal,* 14 (2016)503.
27. R. S. AbdelHameed, M. T. Qureshi, A. M. Al-Boniayan, S. R. Al-Mhyawi, M. F. H. Abdelkader, *Journal of Optoelectronic and Biomedical Materials* 13 (2021)1.
28. R.S. Abdel Hameed, Abd-Alhakeem H Abu-Nawwas, HA Shehata. *Adv. Appl. Sci. Res.,* 4 (2013)126.
29. A. M. Atta, Hamad A. Al-Hodan, R. S. Abdel Hameed, *Prog. Org. Coat.*, 111 (2017)283.
30. RJ. Rathish, R. Dorothy, RM. Joany, *Eur Chem Bull.,* 2 (2013) 965.
31. P. Jain, B. Patidar, J. Bhawsar, *J. Bio- Tribo-Corros.* 6 (2020) 43.
32. ZT. Khodair, A. A. Khadom, H. A. Jasim, *J. Mater. Res. Technol.*, 8 (2019)424.
33. S. Mandal, S. Marpu, R. Hughes, M. Omary, and S. Shi, *Green Sustainable Chem.,* 11 (2021) 38.
34. J. Das, M. Paul Das, and P. Velusamy, *Spectrochim. Acta, Part A.,* 104 (2013)265.
35. H. F. Aritonang, H. Koleangan , and A. D. Wuntu, *Int. J. Microbiology* 2019 (2019)8642303.
36. P. Singh, S. Pandit, , J. Garnæs, S. Tunjic, V. R. Mokkapati, A. Sultan, A. Baun, , et al., *Int. J. Nanomed.,*13 (2018)3571.
37. R.S. Abdel Hameed, *Tenside, Surfactants, Deterg.,* 56 (2019) 209.
38. R.S. Abdel Hameed, *Port. Electrochim. Acta,* 36 (2018) 271.
39. R.S. Abdel Hameed, *Adv. Appl. Sci. Res.,* 2 (2011) 483.
40. R.S. Abdel Hameed, *Adv. Appl. Sci. Res.,* 7 (2016) 92.
41. R.S. Abdel Hameed, M. Abdallah, *Prot. Met. Phys. Chem. Surf.*, 54 (2018) 113.
42. R.S. Abdel Hameed, M. Abdallah, *Surf. Eng. Appl. Electrochem.,* 54 (2018) 599.
43. M. Abdalla, A. Fwzy, H. Hwsawi, R.S. Abdel Hameed, S.S. Al-Juid, *Int. J. Electrochem. Sci.,* 15 (2020) 8129.
44. M. Alfakeer, M. Abdallah, R. S. Abdel Hameed, *Prot. Met. Phys. Chem. Surf.,* 56 (2020) 225.
45. M. Abdallah, F. Alabdali, E. Kamr, R. S. Abdel Hameed, *Chem. Data Collect.,* 28 (2020) 100407.
46. R.S. Abdel Hameed, E. Ismil, H. Alshafe, M. Abas, *J. Bio-Tribo-Corros.,* 6 (2020) 124.

47. M. Abdallah, A. Fwzy, A. Albhir, *Int. J. Electrochem. Sci.,* 15 (2020) 4739.
48. A.S. Fuda, F.M. Eltawel, N.H. Mohammed, *Int. J. Electrochem. Sci.,* 15 (2020) 188.
49. H. A. Alrafai, *Int. J. Electrochem. Sci.,* 17 (2022) 220216.
50. Sh. Singh , R. Singh , N. R. Sharma, A. Singh, *Int. J. Electrochem. Sci.*, 17 (2022) 220341.
51. A.F. Shoair, M. A. H. Shanab , M. H. H. Mahmoud , Z. I. Zaki, H. M. Abdel-Ghafar, M. M. Motawea, *Int. J. Electrochem. Sci.,* 17 (2022) 220642.
52. Reda Abdel Hameed, Mohamad Faride, Mohamad Othman, Bader Huwaimel, Saedah Al-Mhyawi, Ahmed Shamroukh, Freah Alshammary, Enas Aljuhani & Metwally Abdallah, Green synthesis of zinc sulfide nanoparticlesorganic heterocyclic polyol system as eco-friendly anti corrosion and anti-bacterial corrosion inhibitor for steel in acidic environment, *Green Chem. Lett. Rev.,* 15,3(2022)847.
53. R.S . Abdel Hameed, Gh. M. S. Aleid , D. Mohammad , Magd M. Badr , Bader Huwaimel , M. Sh. Suliman, Freah Alshammary, M. Abdallah, Spinacia oleracea Extract as Green Corrosion Inhibitor for Carbon Steel in Hydrochloric Acid Solution, *Int. J. Electrochem. Sci.,* 17 (2022) 221017
54. R. S. Abdel Hameed, Gh. M. S. Aleid1 , A. Khaled , D. Mohammad , Enas H. Aljuhani , Saedah R. Al-Mhyawi ,Freah Alshammary, , M. Abdallah, Expired Dulcolax Drug as Corrosion Inhibitor for Low Carbon Steel in Acidic Environment, *Int. J. Electrochem. Sci.,* 17, 5 (2022) 220655.
55. M. Abdallah , M. Alfakeer , Mubark Alshareef , H. Hawsawi , Salih S. Al-Juaid , R.S. Abdel Hameed, M.Sobhi, Natural Sweet Almond Oil as an Effective Green Inhibitor for Aluminum Corrosion in Sulfuric Acid Medium, *Int. J. Electrochem. Sci.,* 17 (2022) 220949.