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Original article

Corrosion Inhibition of Carbon Steel Using (Arginine–Levofloxacin–Metal) Complexes in Acidic Media

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Abstract
This work investigates the inhibition efficiency of carbon steel corrosion in 1 M hydrochloric acid using synthesized complexes of levofloxacin, arginine, and metal ions Cu^{2+}, Mn^{2+}, Cd^{2+}. The study relies solely on weight loss measurements to evaluate corrosion rates at different concentrations and temperatures (25–45 °C). The results revealed that the Cu–levofloxacin–arginine complex provided the highest inhibition efficiency of 97.3% at 298 ^{0}K, significantly outperforming the Mn and Cd analogs. The inhibition mechanism was attributed to surface adsorption, which followed the Langmuir isotherm model, indicating monolayer coverage. These findings suggest that the copper-based complex is a promising, eco-friendly inhibitor for carbon steel in acidic environments.
Keywords. Corrosion Inhibition, Carbon Steel, Levofloxacin, Arginine, Copper Complex.

Introduction
Carbon steel corrosion under acidic conditions remains a significant problem in numerous industrial fields, as it causes material deterioration and financial waste. The widespread use of corrosion inhibitors includes organic compounds that develop protective coatings on metal surfaces. Pharmaceutical-based inhibitors have become popular because they offer both environmental benefits and diverse structural applications [1]. The standard isotherm is shown in Table 1.

Table 1: Different standard isotherms express

Expression	Name
β_c^n=θ (0<n<1)	Freundlish
$\beta_c = \theta$	Henry
$\beta_c = \theta/(1-\theta)$	Langmuir
$\beta_c = \theta/((1-\theta)xe^{(-2a\theta)}$	Frumkin
$\beta_c = (e^{(a\theta)}-1)/(1-e^{(-a(1-\theta))})$	Temkin
β = exp(-ΔGads)/RT	

The fluoroquinolone antibiotic levofloxacin possesses functional groups (–COOH, C=O, and fluorinated aromatic systems) that enable strong metal surface adsorption. The mixture of levofloxacin with arginine, which features various donor atoms, leads to enhanced metal surface chelation and better surface protection Figure 1. The systems demonstrate enhanced inhibition performance after forming complexes with Cu^{2+}, Mn^{2+}, and Cd^{2+} because of their synergistic effects [2].

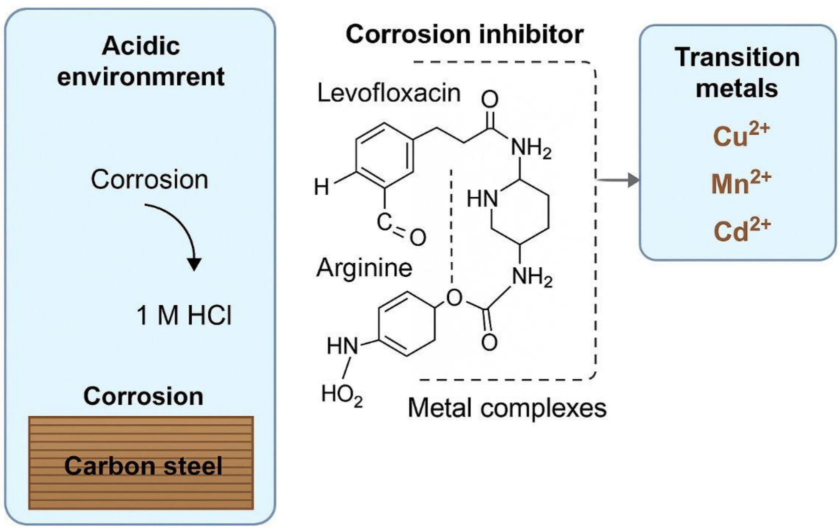

Figure 1. The metals and the Ligand corrosion inhibitor of this study

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The metal complexes were widely used for many applications as antibacterial and fungi, and others [3 -7]. Many chemical phenomena were studied as potentiometric, corrosion, stability constants, and others [8-15]. The aim of this is to investigate the efficiency of levofloxacin–arginine–metal complexes as corrosion inhibitors on carbon steel through weight loss measurements in (1 M HCl) solutions. The copper-based complex demonstrated the best performance among all tested complexes, which indicates its suitability as an environmentally friendly corrosion inhibitor for acidic applications.

Methods

Chemicals and Reagents

All chemicals utilized in this study were of analytical grade and used without further purification. Levofloxacin is one of the Fluoroquinolone antibiotics, its Molecular Formula $C_{18}H_{20}FN_3O_4$. Some of the metal chlorides included $CuCl_2{\cdot}2H_2O$, $MnCl_2{\cdot}4H_2O$, $CdCl_2$,$CdCl_2$, $MnCl_2{\cdot}4H_2O$ and $CdCl_2$ were used in this study. The main amino acid selected in this study was Arginine. Also, ethanol and potassium hydroxide were used.

Synthesis of Complexes

The complexes were prepared by dissolving levofloxacin (0.946 g) and arginine (1.31 g) in 50 mL of absolute ethanol, followed by the addition of potassium hydroxide (0.112 g). After adjusting the pH to approximately 7.5, equimolar amounts of metal salts ($CuCl_2{\cdot}2H_2O$ – 1.68 g, $MnCl_2{\cdot}4H_2O$ – 1.79 g, or $CdCl_2$ – 2.38 g) were added with continuous stirring. The mixtures were left at room temperature for 24 hours. The precipitated solids were filtered, washed with cold ethanol, and dried.

Weight Loss Measurements (WL)

Pre-weighed carbon steel specimens were immersed in 1 M HCl solutions containing different concentrations ($3 - 9 \times 10^{-6}$ M) of each inhibitor complex at three temperatures: 25 °C, 35 °C, and 45 °C. After a fixed immersion time, the specimens were removed, cleaned, dried, and reweighed. The corrosion rate (CR) and inhibition efficiency (% IE) were calculated using standard equations. The curves in the presence of inhibitors are lower than those in the absence of inhibitors [1]. For a specified dipping period, the WL of the samples was measured. This method involves dipping the sample in an acid solution for a certain period, after which the sample's level of corrosion is determined [2].

Results

Weight loss

The samples were analyzed for WL over a predetermined dipping duration. This technique determines the sample's degree of corrosion by immersing it in an acidic solution for a predetermined amount of time, 180 minutes. During the studies, the samples were exposed to different temperatures and doses in 1.0 molar hydrochloric acid. (Table 1) shows the findings of a 120-minute investigation [3]. The results were given in the (Figures 2-4) for Cu complexes, the (Figures 5-7) for the Mn, and the (Figures 8-10) for the Cd complexes, for the applied temperature values 25, 35, and 45.

Inhibition Efficiency at 25 °C

The inhibition efficiencies increased with the inhibitor concentration for all complexes. At 25 °C and 9×10^{-6} M, the Cu complex showed the highest inhibition efficiency of 97.3%, followed by Cd (92.4%) and Mn (56.4%).

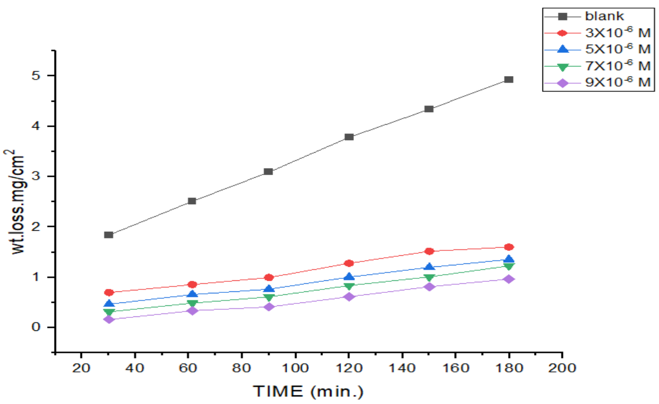

Figure 2. Weight loss-time with and without various concentrations of Levo+ argn+ Cu at 250 °C

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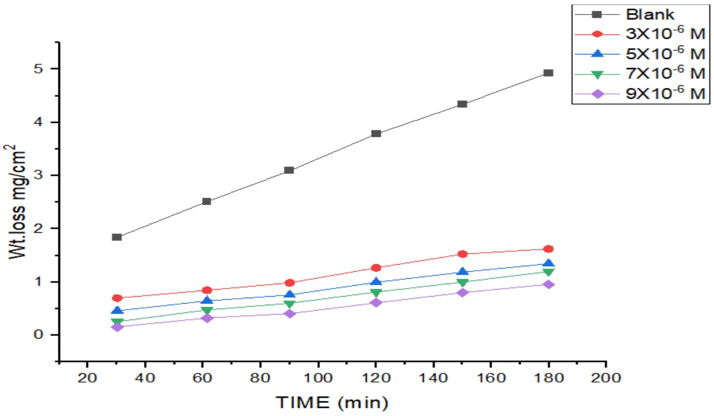

Figure 3. Weight loss-time with and without various concentrations of Levo+argn+Cu at 35 °C.
Weight loss-time with and without various concentrations of Levo+argn+Cu at 35 °C.

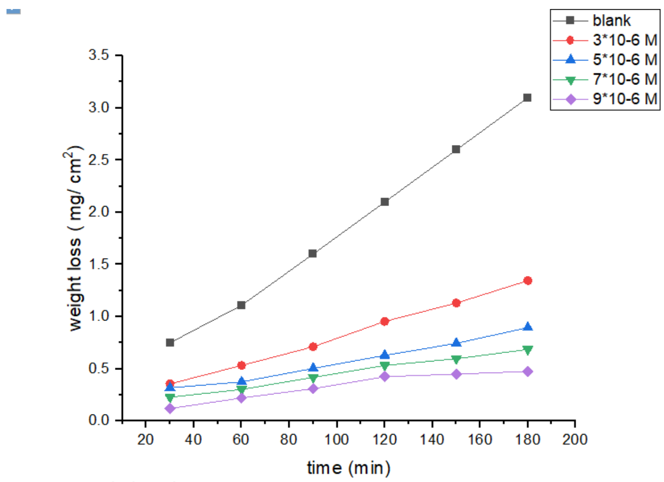

Figure 4: Weight loss-time with and without various concentrations of Levo +argn + Cu at 45 °C .

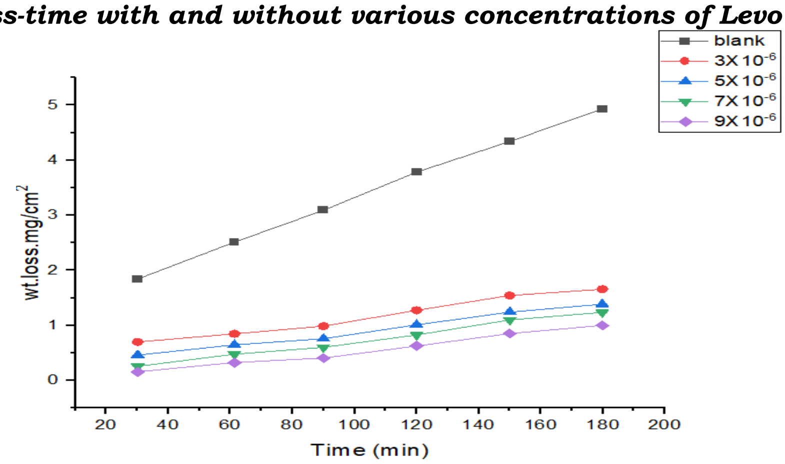

Figure 5: Weight loss-time with and without various concentrations of Levo +argn + Mn at 25 ^{0}C.

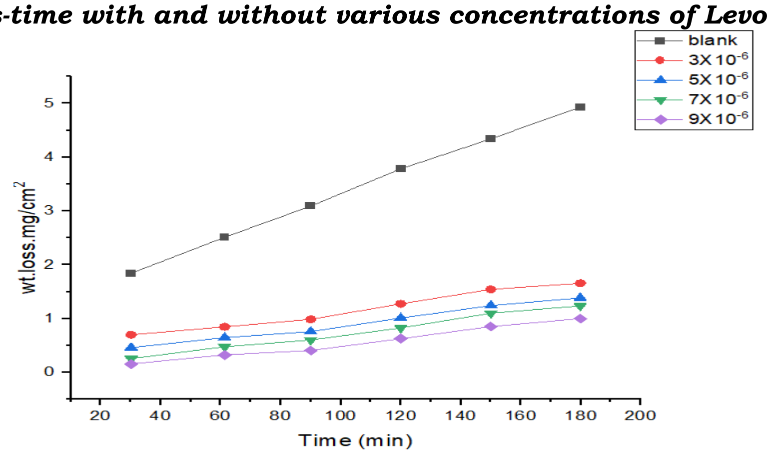

Figure 6: Weight loss-time with and without various concentrations of Levo +argn + Mn at 35 °C.

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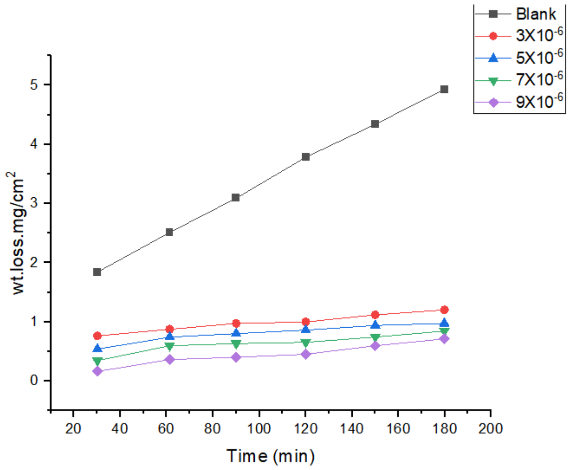

Figure 7: Weight loss-time with and without various concentrations of Levo +argn + Mn at 45⁰C.

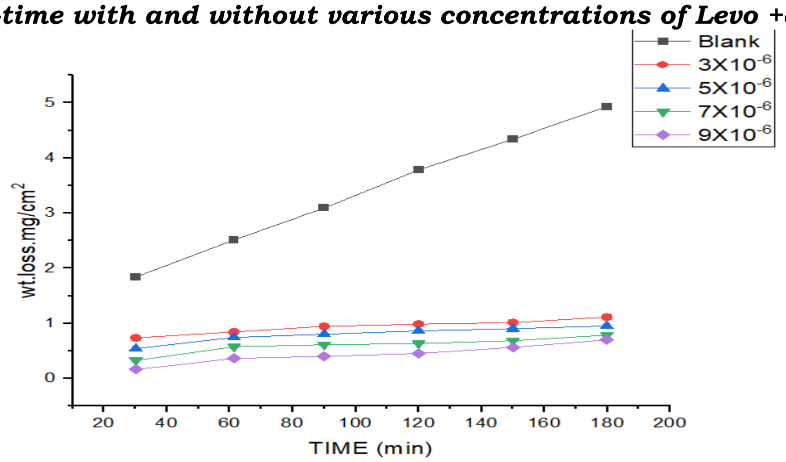

Figure 8: Weight loss-time with and without various concentrations of Levo +argn + Cd at 25⁰C.

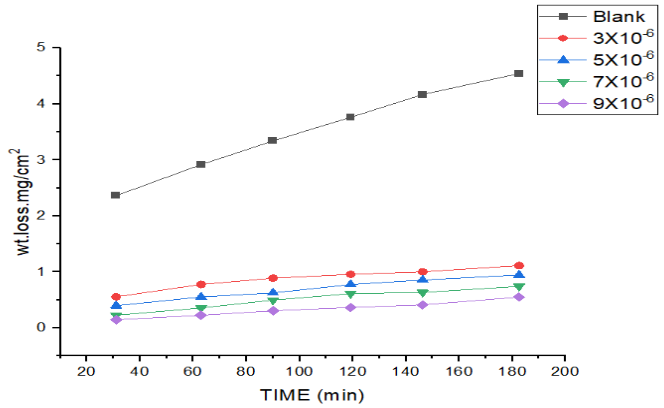

Figure 9: Weight loss-time with and without various concentrations of Levo +argn + Cd at 35 °C.

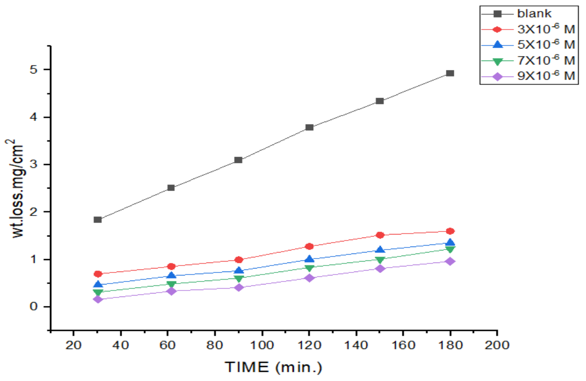

Figure 10: Weight loss-time with and without various concentrations of Levo +argn + Cd at 45 °C.

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Table 2 shows the inhibition efficiency of the used complexes on the weight loss during 120 minutes.

Table 2. Variations in the corrosion rate (kcorr) and inhibition efficiency (%IE) of Inhibitors Based on weight loss Measurements during a 120-minute immersion in 1M HCl at 25°C.

	Levo+argn+Cu		**Levo+argn+Mn**		**Levo+argn+Cd**	
	CRx102 mg cm-2 min-1	%IE	CRx102 mg cm-2 min-1	%IE	CRx102 mg cm-2 min-1	%IE
Blank	0.1526	--	0.1526	--	0.1526	--
3 x10-6	0.0216	85.8	0.0314	79.4	0.0378	75.2
5 x10-6	0.0183	88.0	0.0296	80.6	0.0325	78.7
7x10-6	0.0165	89.2	0.0223	85.4	0.0237	84.5
9 x10-6	0.0138	91.0	0.0181	88.1	0.0199	87.0

Effect of Temperature

At elevated temperatures of (35 and 45 °C), a slight reduction in inhibition efficiency was observed for all complexes. This reduction indicates partial desorption of the inhibitor from the steel surface due to increased thermal agitation. Despite this, the Cu complex maintained superior performance, indicating better thermal stability compared to the Mn and Cd complexes (Tables 3 - 5).

Table 3. Variations in inhibitory efficiency (%IE) and surface coverage (θ) for Levo+argn+Cu concentrations at varying temperatures.

Temp. °C	**Conc. M**	**Levo+argn+Cu**	
		θ	%IE
35	Blank	--	--
	3×10^{-6}	0.845	84.5
	5×10^{-6}	0.865	86.5
	7×10^{-6}	0.869	86.9
	9×10^{-6}	0.871	87.1
45	Blank	--	--
	3×10^{-6}	0.801	80.1
	5×10^{-6}	0.798	79.8
	7×10^{-6}	0.781	78.1
	9×10^{-6}	0.772	77.2

Table 4. Variations in inhibitory efficiency (%IE) and surface coverage (θ) for levo+argm+Mn, varying concentrations at varying temperatures.

Temp. °C	**Conc. M**	**levo+argm+Mn**	
		θ	%IE
35	Blank	--	--
	3×10^{-6}	0.766	76.6
	5×10^{-6}	0.791	79.1
	7×10^{-6}	0.825	82.5
	9×10^{-6}	0.858	85.8
45	Blank	--	--
	3×10^{-6}	0.743	74.3
	5×10^{-6}	0.738	73.8
	7×10^{-6}	0.729	72.9
	9×10^{-6}	0.709	70.9

Table 5. Variations in inhibitory efficiency (%IE) and surface coverage (θ) for varying levo+argn+Cd concentrations at varying temperatures

Temp. °C	**Conc. M**	**levo+argn+Cd**	
		θ	%IE
35	Blank	--	--
	3×10^{-6}	0.744	74.4
	5×10^{-6}	0.739	73.9
	7×10^{-6}	0.728	72.8
	9×10^{-6}	0.719	71.9
45	Blank	--	--

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	3×10^{-6}	0.664	66.4
	5×10^{-6}	0.659	65.9
	7×10^{-6}	0.648	64.8
	9×10^{-6}	0.639	63.9

Adsorption Isotherm

The adsorption isotherm of the inhibition of corrosion steel was conducted by the use of complexes in the study, the results were given in the (Figures 11 – 13) for the complexes of Cu, Mn, and Cd, respectively.

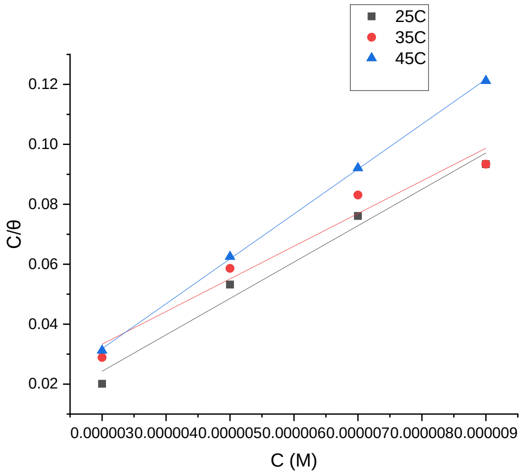

Figure 11: Langmuir isotherm model for levofloxacin + arginine with Cu for dissolution of CS in 1 M HCl

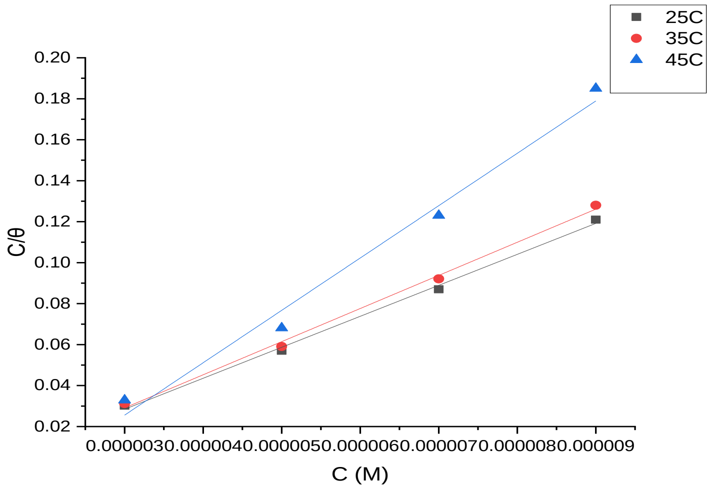

Figure 12: Langmuir isotherm model for levofloxacin + arginine with Mn for dissolution of CS in 1 M HCl

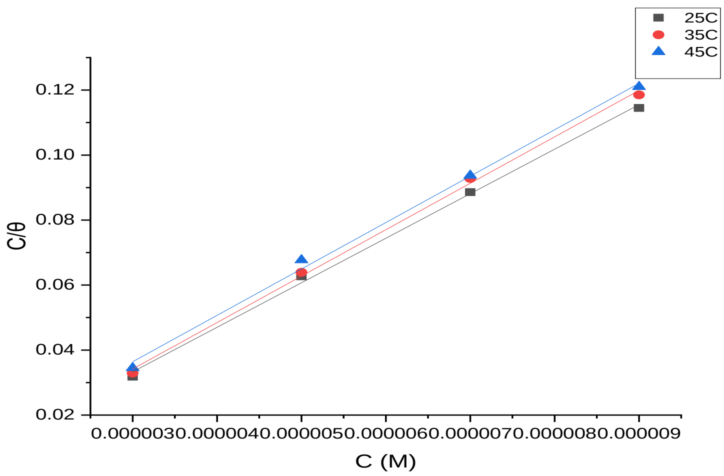

Figure 13: Langmuir isotherm model for levofloxacin + arginine with cd for dissolution of CS in 1 M HCl

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Discussion

In this study the complexes obtained from linkage between arginine and levofloxacin with some heavy metals used in this study Cu, Mn and Cd showed inhibition of corrosion carbon steel, this is mainly attributed to the complexes used in this study contain functional groups such as carboxylic acid (-COOH) and keto (C=O) groups, which facilitate adsorption on metal surfaces. Fluorine atom and heterocyclic rings enhance interaction with metal surfaces [2&3]. Can form coordinate bonds with metal ions. As a Corrosion Inhibitor: Acts as a mixed-type inhibitor (affects both anodic and cathodic reactions). Adsorbs onto metal surfaces, forming a protective barrier against corrosive agents. Chemical Properties: Also contains carboxylic and keto groups, enabling strong interaction with metal surfaces. Features a piperazine ring, increasing its binding affinity. Fluorine enhances its electronic activity and adsorption capability. As a Corrosion Inhibitor: Forms a protective film on the metal through physical and chemical adsorption. Shows good inhibition efficiency, especially in acidic environments (e.g., HCl) [16].
The study demonstrates the effectiveness of arginine–levofloxacin–metal complexes as corrosion inhibitors for carbon steel in acidic environments. Among the three tested systems, the Cu–levofloxacin–arginine complex showed the highest inhibition efficiency, reaching 97.3% at room temperature. Its superior performance is attributed to enhanced adsorption and stronger metal–ligand interactions. These green inhibitors are promising candidates for application in acidic industrial environments where corrosion control is essential. Adsorption isotherms, which describe the framework comprising metal, inhibitor, and environment, are frequently derived to express the quantification of adsorption. Surface coverage (θ) characteristics were used to examine the inhibitor's adsorption and interaction behavior on the metal's surface. We used modified adsorption isotherms such as Langmuir, Frumkin, Henry, and Temkin to explain how Complexes stick to the CS surface in HCl solution [17]. When metals come in close contact with aggressive media, their surfaces corrode. The speed and extent of the corrosion process depend on several factors, like the concentration of the aggressive medium and temperature [18]. The adsorption of the complexes obeyed the Langmuir adsorption isotherm, suggesting monolayer adsorption on the steel surface [19]. The calculated thermodynamic parameters ($\Delta G°_{ads}$ values between –40 and –43 kJ/mol) suggest that the inhibition mechanism involves both physisorption and chemisorption [20].

Conclusion

According to the results obtained in this study, the use of complexes containing functional groups mainly shows inhibitors of corrosion of carbon steel, as well as the adsorption processes for the Langmuir isotherm.

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Conflict of interest. Nil

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