Corrosion Inhibition Study Using Ofloxacin (Antibiotics) As Corrosion Inhibitor for Mild Steel in Hci Medium

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ABSTRACT

This study explores the corrosion inhibition performance of ofloxacin for mild steel in 0.1 M and 0.5 M hydrochloric acid solutions and was investigated using the gravimetric (weight loss) method at 298 K. Different concentrations of ofloxacin (0.1–0.5 g/L) were employed to evaluate its effect on corrosion rate, inhibition efficiency and surface coverage. The results revealed that ofloxacin significantly reduced the corrosion rate of mild steel in both acidic media. Maximum inhibition efficiencies of 78.86% in 0.5 M HCl and 70.86% in 0.1 M HCl were achieved at 0.5 g/L inhibitor concentration. The inhibition efficiency increased with increasing inhibitor concentration, indicating adsorption-controlled inhibition. Adsorption of ofloxacin on the mild steel surface followed the Langmuir adsorption isotherm, suggesting monolayer adsorption. The study confirms that ofloxacin is an effective corrosion inhibitor for mild steel in hydrochloric acid environments.

Keywords: Corrosion, Corrosion rate, Mild steel, Organic coating, Inhibitor, Ofloxacin.

INTRODUCTION AND LITERATURE REVIEW

Corrosion of mild steel in acidic environments remains a major industrial challenge, particularly in pickling, acid cleaning, oil well acidification and descaling operations. Hydrochloric acid is widely used in these applications due to its high efficiency. However, it aggressively attacks steel surfaces which results in severe metal loss, equipment failure and increased maintenance costs.

The use of organic corrosion inhibitors is one of the most effective approaches for mitigating acid-induced corrosion of steel. Organic inhibitors typically function through adsorption on the metal surface via heteroatoms such as nitrogen, oxygen, sulfur and π-electron systems, forming a protective barrier that suppresses anodic metal dissolution and cathodic hydrogen evolution reactions.

In recent years, pharmaceutical compounds have gained attention as corrosion inhibitors owing to their environmentally friendly nature, well defined molecular structures, availability and high electron density. Antibiotics, in particular, contain several adsorption centres that can enhance interaction with metal surfaces, making them suitable candidates for corrosion inhibition applications.

Ofloxacin is a fluoroquinolone antibiotic containing multiple heteroatoms (N, O, and F) as well as conjugated aromatic systems, which can promote strong adsorption on metal surfaces. Despite increasing interest in drug-based inhibitors, detailed investigations on the corrosion inhibition behavior of ofloxacin for mild steel in hydrochloric acid solutions are still limited.

This study investigates the corrosion inhibition performance of ofloxacin on mild steel in 0.1 M and 0.5 M HCl solutions using the weight loss method at 298 K. The effects of inhibitor concentration and acid strength on corrosion rate and inhibition efficiency were examined. The adsorption behavior of the inhibitor was evaluated using the Langmuir adsorption isotherm to elucidate the inhibition mechanism.

Al-Moubaraki et al. (2022), due to the diversity of their structures, have used many common plant extracts as corrosion inhibitors for materials in pickling and cleaning processes. Plant materials contain proteins,

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polysaccharides, polycarboxylic acids, tannins, alkaloids, etc. These compounds are potential acid corrosion inhibitors for many metals.

Okeke et al. (2023), have confirmed that plant-derived extracts act as effective and eco-friendly corrosion inhibitors for aluminium and other metals in acidic media. Their inhibition performance generally increases with concentration and exposure time due to adsorption of phytochemical constituents onto the metal surface, forming a protective barrier against corrosion.

Recent investigations by Jero et al. (2024) and Chudakova (2025), have shown that organic corrosion inhibitors containing functional groups such as amines, amides, imidazolines, and fatty acid derivatives are effective in controlling corrosion in aggressive environments. These inhibitors demonstrate good performance over a wide concentration range and remain effective under both static and dynamic conditions, including systems containing CO_2 and H_2S. Their compatibility with other chemical additives further supports their applicability in industrial corrosion control.

Recent studies confirm that nitrogen containing triazole derivatives and long-chain/surfactant organic inhibitors remain effective corrosion inhibitors for steels and other metals in acidic media (HCl), achieving high inhibition efficiencies often greater than 90% via adsorption or film forming mechanisms (Al-Ahmed et al., 2025).

Table 1.1: Summary of selected corrosion inhibitors for mild steel in acidic media

Inhibitor type	metal	medium	Method	Maximum inhibition efficiency (%)	Reference
Plant extract (Chrysophyllum albidum)	Mild Steel	HCl	Weight loss	~85	Okeke et al. (2023)
Triazole derivative	Low carbon steel	HCl	Electrochemical	>90	Al-Ahmed et al. (2025)
Film-forming amines	Carbon steel	CO_2/H_2S systems	Electrochemical	>90	Jero et al. (2024)
Ofloxacin (this study)	Mild steel	0.1 & 0.5 M HCl	Weight loss	78.86	Present study

Table 1.1 is a comparative summary of selected organic and green corrosion inhibitors reported for mild steel and related substrates in acidic environments, highlighting inhibition efficiency, evaluation methods and adsorption behavior.

Literature Selection Methodology

The literature reviewed in this study was selected through systematic searches of major scientific databases including Scopus, Web of Science, ScienceDirect, SpringerLink, MDPI, Google Scholar and the likes. Keywords such as “corrosion inhibition”, “ofloxacin”, “drug-based inhibitors”, “organic corrosion inhibitors”, and “mild steel in HCl” were used. Only peer-reviewed journal articles published between 2022 and 2025 were considered. Studies that focus on acidic medium, adsorption mechanisms and gravimetric evaluation methods were also prioritized to ensure relevance and reliability of the study.

MATERIALS AND METHOD

Materials

Reagents and materials used

Reagents: Acetone, ethanol, hydrochloric acid (HCl), sodium hydroxide (NaOH), and zinc dust.

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Materials: Conical flask, beaker, volumetric flask, spatula, mortar and pestle, brush, hand gloves, funnel, aluminium foil, and measuring cylinder.

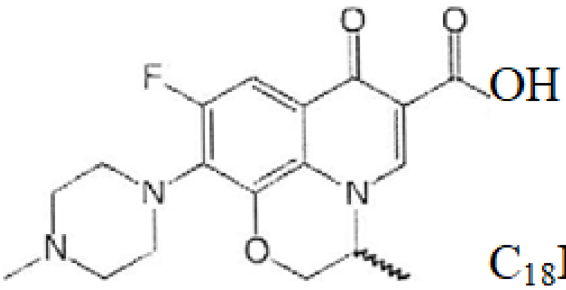
Preparation of mild steel

The mild steel strips used in the study were mechanically pressed-cut into coupons of size 4.5cm x 2cm x 0.2cm with the following composition: 0.14% C, 0.35% Mn, 0.17% Si, 0.025% S, 0.03% P, and the rest Fe. The coupons were degreased by washing them in ethanol and dried in acetone. The dried coupons were then stored in a moisture-free desiccator. The reagents used in this study were of annular grade, and double distilled water was used to prepare them (Ojong et al., 2023).

Preparation of the antibiotics

Sachets of Ofloxacin Comprimes U.S.P (200mg) were purchased in a pharmacy and crushed well into fine powder. Different grams of the ofloxacin powder were weighed, the grams that were weighed included 0.1, 0.2, 0.3, 0.4, and 0.5. The structure of ofloxacin goes thus:

Figure 2.1: Structure of Ofloxacin



$C_{18}H_{20}FN_3O_4$

Method

Gravimetric method

The sample coupon of mild steel was weighed using an electrical weighing balance, labelled and immersed in the test solutions with and without inhibitor for as long as 24 hrs at a temperature of 298k after immersion. The coupon pieces were removed, washed with NaOH and zinc dust, degreased in ethanol, dried with acetone, and re-weighed. The duration of the process was 168 hours. The weight loss of the metal in the corrosive solution, the inhibition efficiency (%) of the inhibitor, the degree of surface coverage and the corrosion rate of the mild steel (CR) were calculated using equations 1, 2, 3, and 4respectively (Pantazopoulou et al., 2022).

$$\Delta W = W_1 - W_2 \qquad (2.1)$$

$$\%I = (1 - W_1/W_2) \times 100 \qquad (2.2)$$

$$\theta = 1 - W_1/W_2 \qquad (2.3)$$

$$CR = DW/AT \qquad (2.4)$$

WI and W2 are metal weights before and after exposure to the corrosive solution respectively.

θ = Degree of surface coverage

ΔW = Weight loss of the mild steel in 'g' after time ct'

W = Weight loss in 'g'

T = Exposure time in hours.

A = Exposed area of coupon in cm^2

RESULTS AND DISCUSSION

Results

Table 3.1: corrosion parameters for mild steel in 0.5M HCI in the presence and absence of different concentrations of the inhibitors

Concentrations (g/l)	inhibition efficiency (%I)	surface coverage (θ)	corrosion rate (g/cm^2h)
Blank			$4.49x10^{-3}$
0.1	46.14	0.4614	$2.37x10^{-3}$
0.2	55.71	0.5571	$1.92x10^{-3}$
0.3	69.29	0.6929	$1.39x10^{-3}$
0.4	74.00	0.7400	$1.19x10^{-3}$
0.5	78.86	0.7886	$9.26x10^{-4}$

Discussion

The weight loss method was employed to evaluate the corrosion behavior of mild steel in 0.1 M and 0.5 M HCl solutions in the presence and absence of various concentrations of ofloxacin ranging from 0.1 to 0.5 g/L. The calculated corrosion rate, inhibition efficiency, and surface coverage values are presented in Tables 3.1 and 3.2.

From Table 3.1, it is evident that the corrosion rate of mild steel in 0.5 M HCl significantly decreased in the presence of ofloxacin when compared to the uninhibited solution. This reduction became more pronounced with increasing inhibitor concentration, indicating that ofloxacin effectively retards the corrosion process by adsorbing onto the metal surface. The inhibition efficiency increased from 46.14% at 0.1 g/L to 78.86% at 0.5 g/L, confirming a strong concentration-dependent inhibition behavior.

Table 3.2: Corrosion parameters for mild steel in 0.1M HCI in the presence and absence of different concentrations of the inhibitors

Concentrations (g/l)	inhibition efficiency (%I)	surface coverage (θ)	corrosion rate (g/cm^2h)
Blank			$3.04x10^{-3}$
0.1	21.71	0.2171	$2.18x10^{-3}$
0.2	57.00	0.5700	$1.32x10^{-3}$
0.3	57.86	0.5786	$1.32x10^{-3}$
0.4	61.43	0.6143	$1.12x10^{-3}$
0.5	70.86	0.7086	$7.92x10^{-4}$

Discussion

Table 3.2, similarly shows that ofloxacin reduced the corrosion rate of mild steel in 0.1 M HCl. Although the inhibition efficiency values were generally lower than those observed in 0.5 M HCl at corresponding concentrations, a consistent increase in inhibition efficiency with increasing inhibitor concentration was observed, reaching a maximum value of 70.86% at 0.5 g/L. This trend suggests that adsorption of ofloxacin molecules improves surface coverage and forms a protective barrier against acid attack.

Table 3.3: Langmuir adsorption isotherm parameters for 0.5 M HCl

Concentrations (g/l)	**log C**	θ	**log (C/** θ **)**
0.1	-1.00	0.4614	-0.66
0.2	-0,69	0.5571	-0.44
0.3	-0.52	0,6929	-0.36
0.4	-0.39	0.7400	-0.26
0.5	-0.30	0.7886	-0.19

Discussion

The Langmuir adsorption parameters presented in Table 3.3 show a consistent variation of log(C/θ) with log C for ofloxacin in 0.5 M HCl. The gradual increase in surface coverage (θ) with inhibitor concentration indicates effective occupation of active sites on the mild steel surface. The near-linear relationship expected from the Langmuir model suggests that adsorption occurs through the formation of a uniform monolayer of inhibitor molecules, with minimal interaction between adjacent adsorbed species.

The relatively higher surface coverage values obtained in 0.5 M HCl imply that ofloxacin molecules possess sufficient affinity for the steel surface even in a highly aggressive acidic environment. This behavior supports strong inhibitor–metal interaction, which is responsible for the high inhibition efficiencies recorded at higher concentrations. The validity of the Langmuir isotherm further confirms that inhibition efficiency is primarily controlled by adsorption equilibrium rather than bulk solution effects.

Table 3.4: Langmuir adsorption isotherm parameters for 0.1M HCI

Concentrations (g/l)	**log C**	θ	**log (C/** θ **)**
0.1	-1.00	0.2171	-0.33
0.2	-0.69	0.5700	-0.45
0.3	-0.52	0.5786	-0.28
0.4	-0.39	0.6143	-0.18
0.5	-0.30	0.7086	-0.15

Discussion

Table 3.4 presents the Langmuir adsorption parameters for mild steel in 0.1 M HCl. As observed, surface coverage increases with increasing inhibitor concentration, although the increments are slightly less regular than those observed in 0.5 M HCl. This may be attributed to differences in metal surface charge distribution and inhibitor–acid interactions at lower acid concentration.

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Nevertheless, the linear relationship obtained from the log(C/θ) versus log C plot (Figure 3.6) confirms that adsorption of ofloxacin in 0.1 M HCl also obeys the Langmuir adsorption isotherm. This indicates monolayer adsorption with no significant lateral interaction between adsorbed inhibitor molecules. The results suggest that although the acid medium is less aggressive, adsorption remains the dominant inhibition mechanism, accounting for the steady increase in inhibition efficiency with inhibitor concentration.

Fig. 3.1: Weight loss of mild steel in 0.5M HCI solution with inhibitor

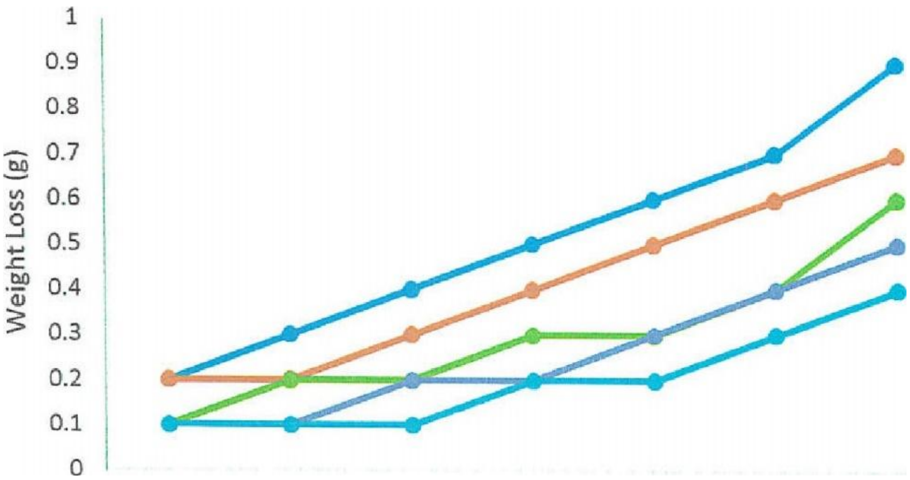
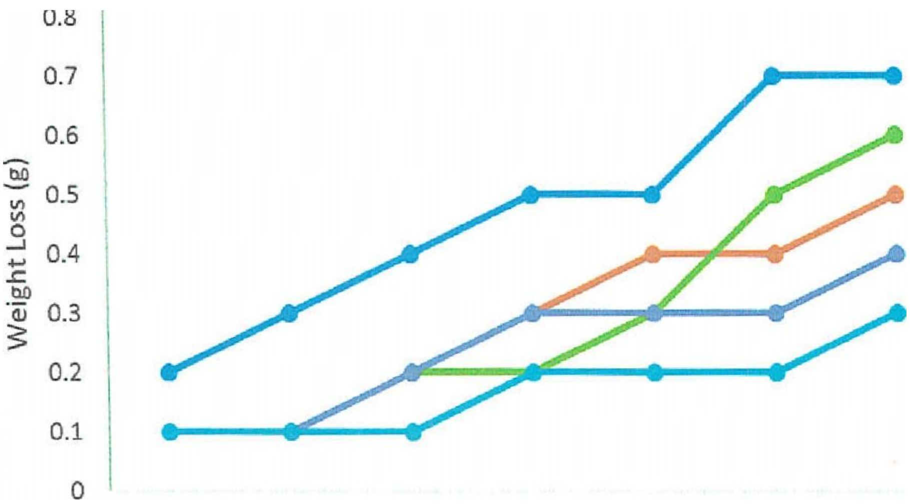


Figure 3.1 shows the variation of weight loss with immersion time for mild steel in 0.5 M HCl in the presence of different concentrations of ofloxacin. The blank solution exhibits the highest weight loss throughout the exposure period, indicating severe corrosion in the absence of inhibitor. In contrast, inhibited solutions show a marked reduction in weight loss, with progressively flatter curves observed as the inhibitor concentration increases.

This behavior suggests that ofloxacin is adsorbed rapidly onto the steel surface, forming a protective layer that limits metal dissolution even at longer immersion times. The significant divergence between the blank curve and the inhibited curves at higher concentrations further confirms the strong inhibitive action of ofloxacin in highly acidic environments.

Fig. 3.2: Weight loss of mild steel in 0.1M HCI solution with inhibitor



Discussion

Figure 3.2 illustrates the variation of weight loss with time for mild steel in 0.1 M HCl containing various concentrations of ofloxacin. Although weight loss increases with immersion time for all systems, the rate of increase is lower than that observed in 0.5 M HCl, reflecting the reduced aggressiveness of the acid medium.

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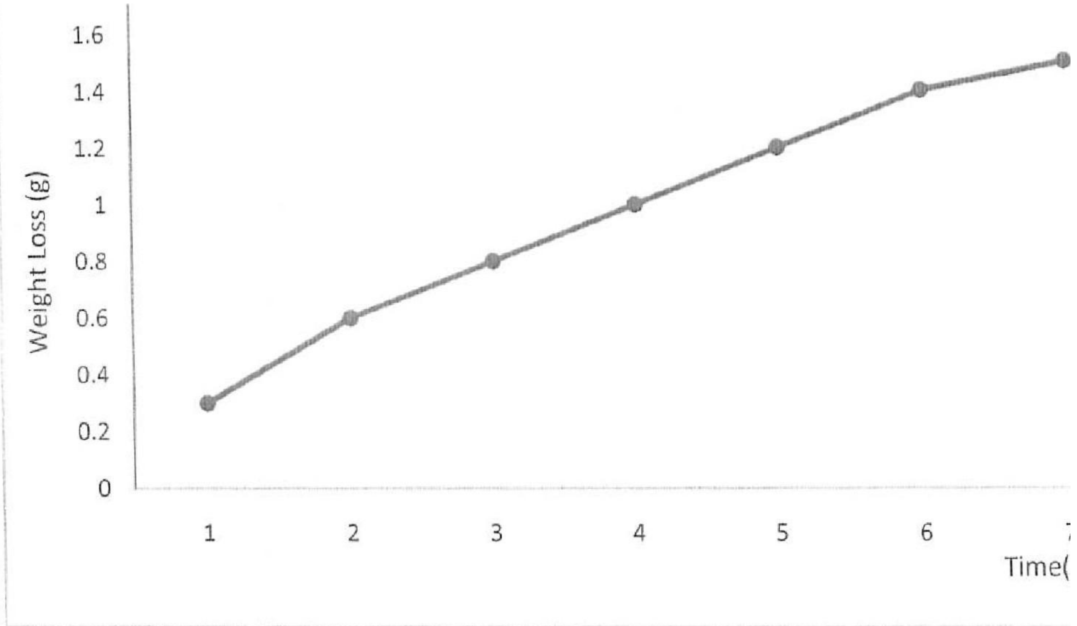
The inhibited curves display noticeable reductions in weight loss compared to the blank, with higher inhibitor concentrations producing better protection. The relatively closer spacing of curves at intermediate concentrations suggests partial surface coverage at lower inhibitor dosages, which improves significantly as the concentration approaches 0.5 g/L. This trend supports the concentration-dependent adsorption of ofloxacin on the mild steel surface.

Fig. 3.3: Weight loss of mild steel in 0.5M HCI solution without inhibitor



Discussion

Figure 3.3 represents the weight loss behavior of mild steel in 0.5 M HCl in the absence of inhibitor. The steep, nearly linear increase in weight loss with time reflects rapid and continuous metal dissolution in the strongly acidic environment. This figure serves as the reference baseline for assessing the effectiveness of ofloxacin, highlighting the severity of corrosion when no protective barrier is present.

Fig. 3.4: Weight loss of mild steel in 0.1M HCI solution without inhibitor

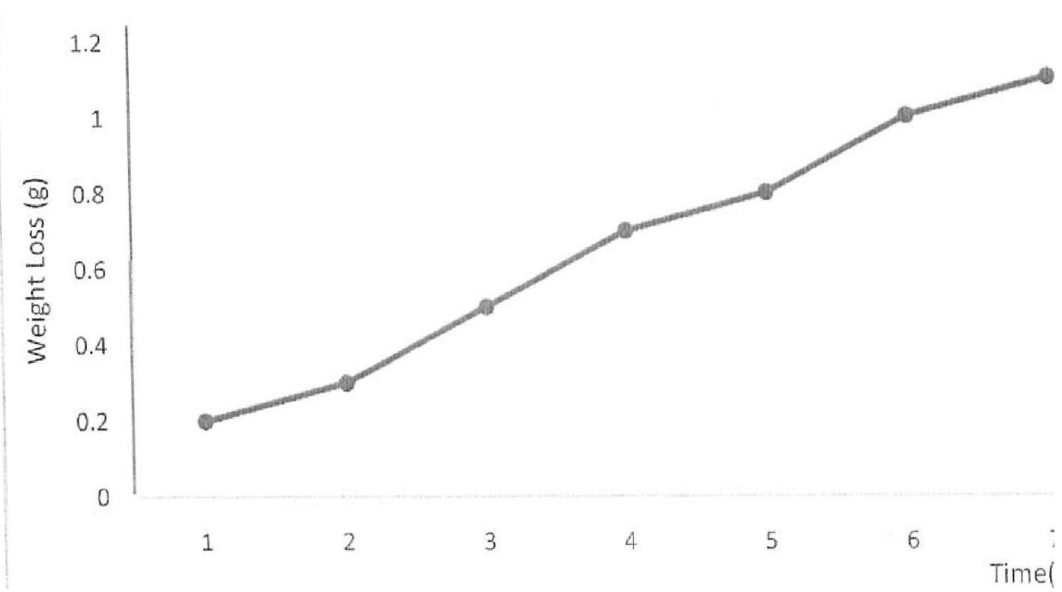


Figure 3.4 shows the weight loss profile of mild steel in 0.1 M HCl without inhibitor. Compared to Figure 3.3, the slope of the curve is less steep, confirming that corrosion severity decreases with lower acid concentration. Nonetheless, the continuous increase in weight loss with time indicates that corrosion proceeds steadily in the absence of inhibitor, reinforcing the necessity of corrosion control even in moderately acidic environments.

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Fig.3.5: Langmuir isotherm for the adsorption of ofloxacin on the surface of mild steel for 0.5 HCI

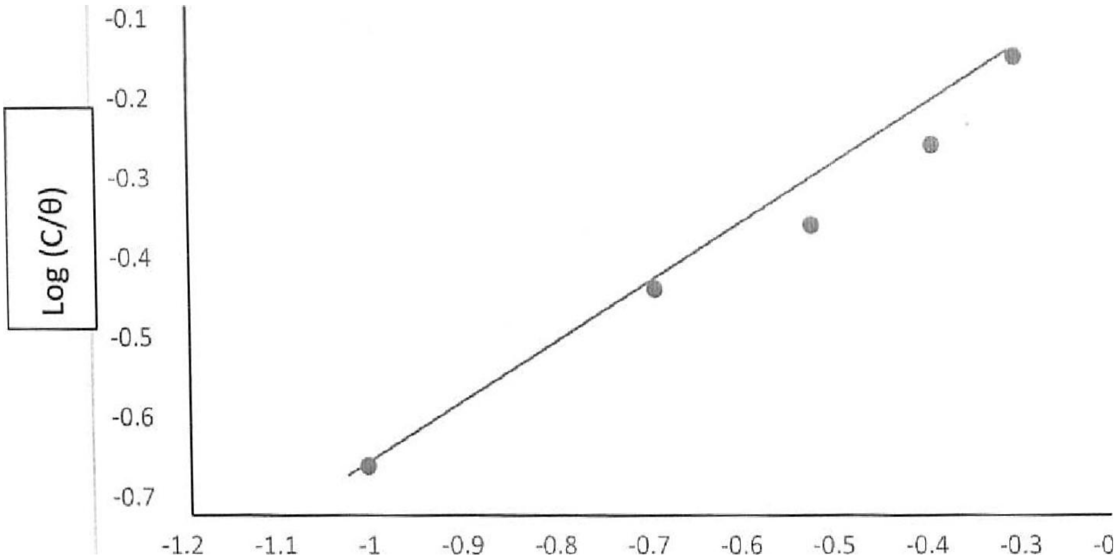
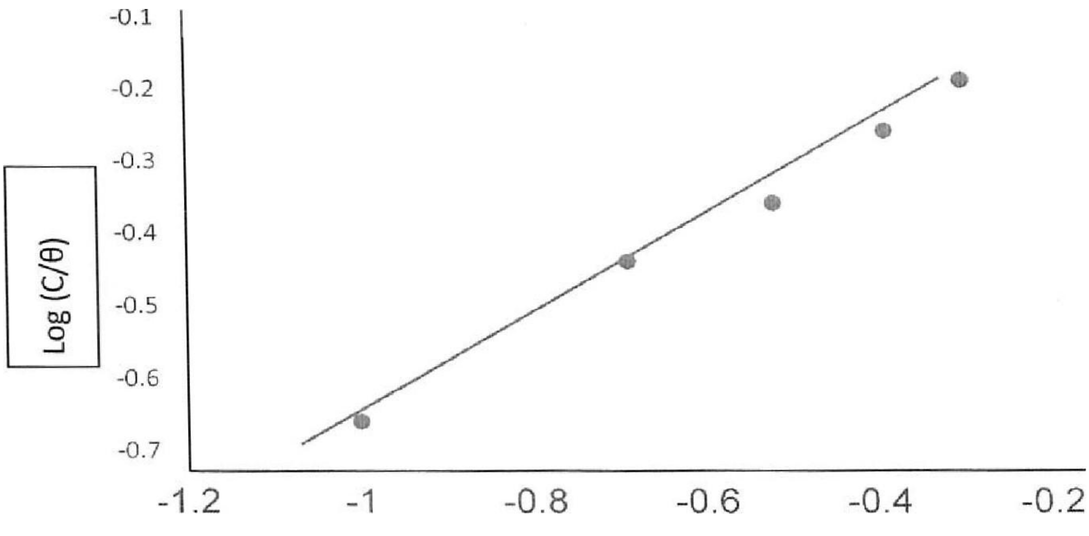


Figure 3.5 presents the Langmuir adsorption isotherm plot for ofloxacin on mild steel in 0.5 M hydrochloric acid. The linear relationship obtained between log(C/θ) and log C confirms that the adsorption of ofloxacin follows the Langmuir adsorption model. This suggests that the inhibitor molecules form a uniform monolayer on the steel surface, with each adsorption site accommodating one inhibitor molecule and without significant interaction between adsorbed species.

The good linearity of the plot indicates that adsorption equilibrium is established between ofloxacin molecules in the solution and those adsorbed on the mild steel surface. Despite the high aggressiveness of the 0.5 M HCl medium, the inhibitor demonstrates strong affinity for the metal surface, which accounts for the high inhibition efficiencies observed at higher inhibitor concentrations. This behavior reflects stable inhibitor–metal interactions and supports adsorption as the dominant corrosion inhibition mechanism in this medium.

Fig. 3.6: Langmuir isotherm for the adsorption of ofloxacin on the surface of mild steel for 0.1M HCI



DISCUSSION

Figure 3.6 illustrates the Langmuir adsorption isotherm for ofloxacin on mild steel in 0.1 M hydrochloric acid. The linear trend observed in the plot of log(C/θ) versus log C indicates that the adsorption process also obeys the Langmuir isotherm in the less concentrated acidic medium. This confirms monolayer adsorption of ofloxacin molecules on the mild steel surface.

Compared to the 0.5 M HCl system, the adsorption behavior in 0.1 M HCl occurs in a less aggressive environment, which may allow more stable surface–inhibitor interactions at lower concentrations. The

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consistency of Langmuir behavior in both acid concentrations suggests that the adsorption mechanism of ofloxacin is largely independent of acid strength and is governed primarily by the molecular structure of the inhibitor. These findings further support that adsorption is the key factor responsible for the corrosion inhibition of mild steel by ofloxacin.

It is worth noting that recent studies show substantial progress in developing efficient and environmentally friendly corrosion inhibitors for metals in acidic environments, with growing emphasis on bio-based and organic compounds due to their high inhibition efficiencies and low environmental impact. For example, Aslam et al. (2024) reported that a bio-based ionic liquid achieved inhibition efficiencies above 98% for mild steel in 5% HCl, with adsorption behavior following the Langmuir isotherm and attributed to strong surface adsorption and protective film formation by heteroatom-rich structures. Furthermore, recent reviews highlight the increasing use of green and heterocyclic inhibitors, such as triazole-based and phytochemical compounds, for protecting mild steel and aluminium in acidic media, where inhibition efficiency depends on molecular structure, concentration, temperature, and exposure time, and is predominantly governed by adsorption-controlled mechanisms (Iorhuna et al., 2024). These findings underscore the continued evolution of corrosion inhibition research toward high-efficiency, sustainable, adsorption-based approaches, consistent with the present study.

In line with these recent developments, pharmaceutical compounds containing heteroatoms and conjugated π-electron systems have also been explored as effective corrosion inhibitors. Ofloxacin, a fluoroquinolone antibiotic, possesses multiple adsorption-active sites including nitrogen, oxygen and aromatic rings, which favors strong interaction with metal surfaces in acidic environments. Similar to bio-based ionic liquids and triazole-based inhibitors, the inhibition performance of ofloxacin is governed primarily by adsorption and protective film formation, often conforming to Langmuir adsorption behavior. These characteristics position ofloxacin within the broader class of modern organic inhibitors that combine high inhibition efficiency with adsorption-controlled mechanisms, as reported in recent corrosion inhibition studies.

Adsorption and Thermodynamic Considerations

The adsorption behavior of ofloxacin on the mild steel surface was evaluated using the Langmuir adsorption isotherm. The degree of surface coverage (θ) obtained from weight loss data was used to test the applicability of the Langmuir model according to the relationship (Abdou, 2023):

$$C/\theta = 1/K + C$$

where C is the inhibitor concentration and K is the adsorption equilibrium constant.

Plots of log(C/θ) against log C, shown in Figures 3.5 and 3.6, produced straight lines with good linear correlation coefficients for both 0.1 M and 0.5 M HCl solutions. This result indicates that adsorption of ofloxacin on the mild steel surface follows the Langmuir adsorption isotherm, suggesting monolayer adsorption without significant interaction between adsorbed molecules.

The good agreement between experimental data and the Langmuir model confirms that inhibition efficiency is directly related to the extent of surface coverage achieved by ofloxacin molecules.

Mechanism of Inhibition

The corrosion inhibition behavior of ofloxacin for mild steel in hydrochloric acid solutions can be explained based on adsorption mechanisms. In acidic media, ofloxacin molecules exist partly in protonated form, which facilitates electrostatic interaction with the negatively charged metal surface.

Adsorption occurs through lone pairs of electrons on nitrogen and oxygen atoms, as well as π-electrons present in the aromatic rings of the ofloxacin molecule (Hao et al. 2023). These interactions result in the formation of a protective adsorbed layer that blocks both anodic sites (reducing metal dissolution) and cathodic sites (suppressing hydrogen evolution). Consequently, ofloxacin acts as a mixed-type corrosion inhibitor.

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The inhibition efficiency is influenced by molecular size, number of adsorption centers, electron density, and surface coverage, all of which favor strong and stable adsorption of ofloxacin on the mild steel surface.

Limitations

Thermodynamic parameters such as activation energy and free energy of adsorption could not be evaluated due to the use of a single experimental temperature (298 K). Further studies involving multiple temperatures would allow comprehensive thermodynamic analysis and deeper understanding of the adsorption mechanism.

Critical Appraisal of Existing Literature

Many studies report high inhibition efficiencies for organic and drug-based inhibitors, but still, discrepancies exist due to differences in experimental methods, metal composition, inhibitor purity and test conditions. Some studies report higher efficiencies using electrochemical techniques compared to gravimetric methods, which may overestimate short-term inhibition performance. In addition, variations in acid concentration, temperature and immersion time contribute to inconsistent results across the literature. These differences highlight the need for standardized testing conditions and complementary techniques when evaluating corrosion inhibitors.

CONCLUSION AND RECOMMENDATION

Conclusion

Ofloxacin demonstrated effective corrosion inhibition for mild steel in both 0.1 M and 0.5 M hydrochloric acid solutions. Maximum inhibition efficiencies of 78.86% in 0.5 M HCl and 70.86% in 0.1 M HCl were achieved at an inhibitor concentration of 0.5 g/L. The inhibition efficiency increased consistently with increasing inhibitor concentration, confirming adsorption-controlled inhibition. Adsorption of ofloxacin followed the Langmuir adsorption isotherm, indicating monolayer adsorption on the mild steel surface. The findings establish ofloxacin as a promising inhibitor for protecting mild steel in acidic environments.

Recommendation

Further studies should investigate the effect of temperature on the inhibition performance of ofloxacin in order to evaluate thermodynamic parameters and adsorption energy. In addition, electrochemical techniques such as potentiodynamic polarization and electrochemical impedance spectroscopy are recommended to complement gravimetric findings and provide deeper mechanistic insight.

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