International Journal of Natural and Engineering Sciences
E-ISSN: 2146-0086 19(1): 20-32, 2025
Research Article

Adsorption and Corrosion Inhibition Behavior of Vitamin B1 and Ascorbic Acid on Iron B500 In Hydrochloric Acid

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(Received: 18 May 2026 / Accepted: 17 July 2026)

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Abstract

This study evaluates the inhibition efficiency of vitamin B1 and ascorbic acid as environmentally friendly corrosion inhibitors for B500 steel in a 1 M HCl solution. The corrosion rate, inhibition efficiency, and surface coverage were determined using the gravimetric (weight loss) method. Based on the experimental data, the Langmuir adsorption isotherm was constructed, and the adsorption equilibrium constant (K_ads) and the standard Gibbs free energy of adsorption (ΔG_ads) were calculated. The results showed that increasing the inhibitor concentration significantly reduced the corrosion rate. In the presence of ascorbic acid, the corrosion rate decreased from 0.00608 mm/year in the uninhibited acidic solution to 0.00184 mm/year at a concentration of 1 g/L. However, the inhibition effect reached a plateau at concentrations above 0.5 g/L. In contrast, vitamin B1 exhibited a gradual reduction in the corrosion rate, reaching 0.00133 mm/year at 1 g/L. At the same concentration, the inhibition efficiency reached 69.79% for ascorbic acid and 78.09% for vitamin B1, while the corresponding surface coverage values (θ) were 0.689 and 0.781, respectively. The Langmuir adsorption isotherm, together with the calculated K_ads and ΔG_ads values, confirmed the adsorption of both inhibitors onto the B500 steel surface. Overall, vitamin B1 exhibited superior corrosion inhibition performance compared with ascorbic acid, indicating that it is a promising environmentally friendly corrosion inhibitor for B500 steel in acidic media.

Keywords: weight loss method, acidic medium HCl 1 M, vitamin B1, ascorbic acid

Introduction

Motion planning is a well-established field within robotics, with extensive research aimed at improving efficiency, robustness, and adaptability in various environments. Over the years, numerous approaches have been proposed to tackle path planning challenges, particularly for robots operating in complex terrains. Classical algorithms such as A*, Dijkstra's algorithm, and Rapidly-exploring Random Trees (RRT) have long been foundational in motion planning. A* algorithm [1], remains one of the most widely used methods for finding optimal paths in grid-based environments, guaranteeing the shortest path. However, it suffers from efficiency problems in large, complex terrains. Similarly, Dijkstra's algorithm [2] finds the shortest path between nodes but is computationally expensive when applied to large-scale grids due to its exhaustive nature. For dynamic and uncertain environments, RRT and its variants, such as RRT* [3], have become popular due to their ability to handle high-dimensional spaces, although they remain computationally intensive when dealing with terrain features such as slopes.

Corrosion is generally defined as the deterioration of a metallic material resulting from its interaction with the surrounding environment. It represents one of the most significant challenges in engineering and industry, leading not only to substantial economic losses but also to serious safety hazards and environmental concerns.

The annual cost of corrosion in industrialized countries is estimated to account for approximately 3–4% of the gross domestic product (GDP) [1]. Therefore, the development of effective, economical, and environmentally sustainable corrosion protection strategies has become an important research topic.

Among the available corrosion protection methods, the use of environmentally friendly (green) corrosion inhibitors has attracted considerable attention. Numerous studies have demonstrated that organic compounds containing heteroatoms such as oxygen, nitrogen, and sulfur, as well as aromatic and heterocyclic rings, exhibit excellent corrosion inhibition properties. These compounds adsorb onto the metal surface, forming a protective film that effectively isolates the substrate from the aggressive environment. In addition to their high inhibition performance, green inhibitors are generally inexpensive, non-toxic, biodegradable, and environmentally benign, as they do not contain heavy metals or hazardous substances. [2-4].

Organic compounds such as vitamins have recently emerged as promising green corrosion inhibitors in acidic media due to their eco-friendly nature, low toxicity, and high adsorption capability on metal surfaces. Several studies have reported the successful application of different vitamins as corrosion inhibitors for steel in acidic solutions [5].

The aim of the present study is to evaluate the corrosion inhibition performance of vitamin B1 and ascorbic acid for B500 reinforcing steel in 1 M HCl solution using the gravimetric (weight loss) method. The corrosion rate, inhibition efficiency, and surface coverage were determined at different inhibitor concentrations. Furthermore, the adsorption behavior of both inhibitors was investigated through the Langmuir adsorption isotherm, and the corresponding adsorption equilibrium constant (K_ads) and standard Gibbs free energy of adsorption (ΔG_ads) were evaluated.

Experimental

The material selected for this study was B500 steel produced in Elbasan. Its chemical composition is presented below.

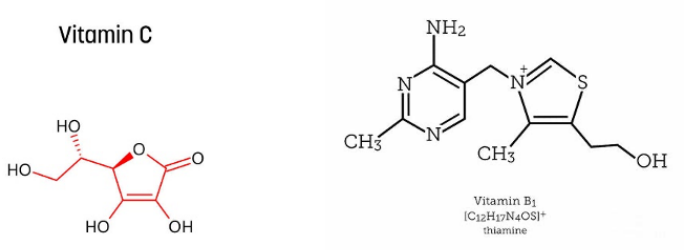
Table 1. *Composition of the tested low alloy carbon steel*

Elements %	C	Si	Mn	Cr	Ni	Cu	P	S
Iron B500	0.224	0.152	0.68	0.110	0.102	0.318	0.021	0.027

The Environment

The corrosion inhibition performance of vitamin B1 (thiamine) and ascorbic acid was investigated for B500 reinforcing steel in a 1.0 M hydrochloric acid (HCl) solution. The aggressive solution was prepared by diluting analytical-grade hydrochloric acid with distilled water to obtain a concentration of 1.0 M, which is commonly employed for evaluating the corrosion behavior of steel and the performance of corrosion inhibitors under acidic conditions.

The inhibitors were tested at four different concentrations: 0.25, 0.50, 0.75, and 1.00 g/L. Corrosion tests were carried out in the absence (blank solution) and in the presence of each inhibitor concentration.



Ascorbic acid **Vitamin B1**

Figure 1. *The structure of ascorbic acid and vitamin B1*

Weight loss measurements

For the weight loss measurements, the specimens were prepared by cutting them from B500 reinforcing steel bars. Cylindrical samples were machined on a lathe to dimensions of 38 ± 4 mm in length and 7 ± 1 mm in diameter. A 3 mm diameter hole was drilled at the top of each specimen to facilitate suspension during immersion, as shown in Figure 2.

Figure 2. *Preparation of the sample for the weight loss measurements*

Prior to testing, the specimens were mechanically polished using silicon carbide abrasive papers with grit sizes ranging from 200 to 1200, rinsed with distilled water, degreased with acetone, and dried in air.

The weight loss experiments were performed in closed glass vessels under a continuous flow of high-purity nitrogen to minimize the influence of dissolved oxygen. The specimens were immersed for 24 h at room temperature in 1.0 M HCl solutions in the absence (blank solution) and presence of different concentrations (0.25, 0.50, 0.75, and 1.00 g/L) of vitamin B1 and ascorbic acid.

After the immersion period, the specimens were removed, rinsed with distilled water, washed with acetone, dried, and weighed. Corrosion products were subsequently removed in an ultrasonic bath using a cleaning solution consisting of a 1:1 (v/v) mixture of hydrochloric acid and distilled water containing 1 g of hexamethylenetetramine (urotropine) as a corrosion inhibitor during the cleaning procedure. The cleaned specimens were then rinsed thoroughly with distilled water and acetone for 5 min, dried, and weighed again. To improve measurement accuracy, each specimen was weighed twice, and the average value was used for subsequent calculations.

The corrosion rate (CR), expressed in mm year^{-1}, was calculated using Equation (1) [6-7]:

$$V_{(mm/vit)} = \frac{87.6 \cdot \Delta m}{d \cdot A \cdot t}$$

Equation 1

Where: Δm - the difference of weight in mg;

d- the density in g/cm3;

A - the surface of sample in cm2;

t - the time of exposure of the sample in hours

The inhibition efficiency (IE%) was calculated using the following equation [8]:

Inhibitor Efficiency (%) = [(CR uninhibited – CR inhibited)/ CR uninhibited] x 100

Equation 2

The adsorption equilibrium constant (K_ads) and the standard Gibbs free energy of adsorption (ΔG_ads) were calculated from the Langmuir adsorption isotherm using the following equations [9]:

$$K\_ads = 1/\ intercept$$

Equation 3

$$\Delta G\_ads = -\ RT\ \ln (55.5K\_ads)$$

Equation 4

where T is the temperature, R is the universal gas constant and 55.5 is the molar concentration of water.

Table 2. *Composition of solution for weight loss method*

No.	Blank	Concentration of vitamin B1 (g/L) and ascorbic acid			
		0.25	0.5	0.75	1
1	+				
2	+	+			
3	+		+		
4	+			+	
5	+				+

Results and discussion

The corrosion inhibition performance of vitamin B1 and ascorbic acid for B500 reinforcing steel in 1.0 M HCl solution was evaluated using the gravimetric (weight loss) method. The corrosion rate (CR), inhibition efficiency (IE%), and surface coverage (θ) obtained in the absence and presence of different inhibitor concentrations are summarized in Table 3.

Table 3. *Corrosion rate, inhibition efficiency, surface coverage of vitamin B1 and ascorbic acid in HCl 1 M*

Sample	Medium	Corrosion rate (mm/year)		Inhibition Efficiency (%)		Surface coverage	
1	Blank (1 M HCl)	Vitamin B1	Ascorbic acid	Vitamin B1	Ascorbic acid	Vitamin B1	Ascorbic acid
		0.00608	0.00608	0	0	0	0
2	0.25 g/L	0.00227	0.00194	62.672	68.04	0.627	0.68
3	0.5 g/L	0.00206	0.00187	66.167	69.29	0.662	0.693
4	0.75 g/L	0.00187	0.00186	69.226	69.48	0.692	0.695
5	1 g/L	0.00133	0.00184	78.09	69.79	0.781	0.698

For vitamin B1, increasing the inhibitor concentration from 0 to 1.0 g/L progressively decreased the corrosion rate from 0.00608 to 0.00133 mm year^{-1}. Simultaneously, the inhibition efficiency increased to 78.09%, while the surface coverage reached 0.781. This continuous improvement suggests that vitamin B1 adsorbs progressively onto the steel surface, producing a compact and stable protective film. The superior inhibition

performance of vitamin B1 can be attributed to the presence of nitrogen and sulfur heteroatoms together with electron-rich π-electrons, which facilitate adsorption through electron donation to the vacant d-orbitals of iron atoms. Consequently, a larger fraction of the steel surface becomes covered, effectively reducing the interaction between the metal and the acidic solution.

In contrast, ascorbic acid also reduced the corrosion rate, although to a lesser extent. At 1.0 g/L, the corrosion rate decreased from 0.00608 to 0.00184 mm year^{-1}, with an inhibition efficiency of 69.79% and a surface coverage of approximately 0.69. Unlike vitamin B1, the inhibition performance of ascorbic acid reached a plateau at concentrations above 0.5 g/L, indicating that increasing the inhibitor concentration produced only a marginal improvement in corrosion protection. This behavior suggests that adsorption of ascorbic acid rapidly approaches saturation, leaving a portion of the steel surface insufficiently protected. Although ascorbic acid contains several hydroxyl (-OH) groups capable of interacting with the metal surface, its molecular structure appears to produce a less compact protective layer than vitamin B1.

Langmuir Adsorption Isotherm

The adsorption behavior of both inhibitors was further evaluated using the Langmuir adsorption isotherm.

Table 4. *Intercept, Adsorption Constant, and Gibbs Free Energy Values*

	Vitamin B1	**Ascorbic acid**
Intercept	0.1362	0.0121
R^2	0.985	0.999
ΔG_ads	-14.9 kJ/mol	-20.9 kJ/mol
K_ads	7.34	82.9

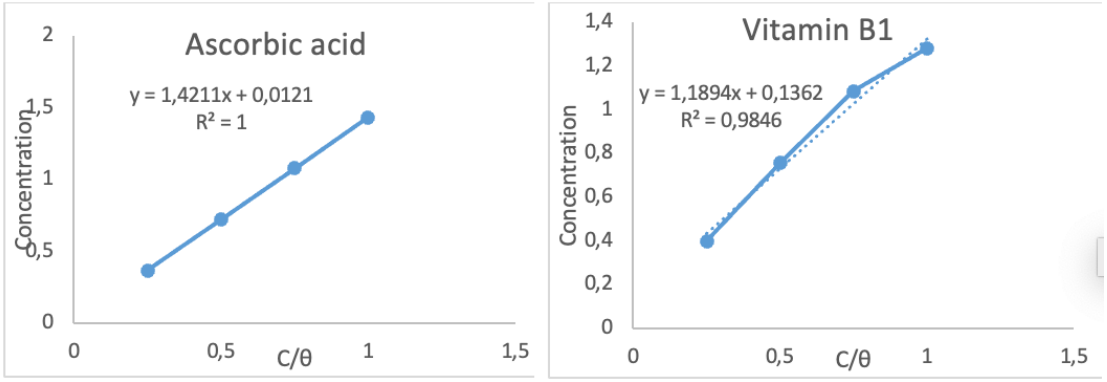


Figure 3. *The Langmuir adsorption isotherm for ascorbic acid and vitamin B1*

For vitamin B1, the Langmuir plot exhibited an approximately linear relationship with only a slight deviation at the highest concentration, indicating that the adsorption process generally follows the Langmuir model. The gradual increase in surface coverage (θ) with increasing inhibitor concentration confirms continuous adsorption and progressive occupation of the available active sites on the steel surface.

A different behavior was observed for ascorbic acid. Although the Langmuir plot also appeared approximately linear, the surface coverage values changed only slightly above 0.5 g/L, remaining between approximately 0.68 and 0.70. This indicates that adsorption equilibrium was reached rapidly and that most of the available active sites became occupied at relatively low inhibitor concentrations. Consequently, further increases in inhibitor concentration produced little additional surface coverage, suggesting an adsorption process with limited surface capacity. Similar adsorption behavior has been reported for other environmentally friendly corrosion inhibitors exhibiting predominantly physical adsorption mechanisms.

Thermodynamic Analysis of Adsorption

The thermodynamic parameters of adsorption were determined from the Langmuir isotherm by calculating the adsorption equilibrium constant (K_ads) and the standard Gibbs free energy of adsorption (ΔG_ads). The negative ΔG_ads values obtained for both inhibitors confirm that adsorption occurs spontaneously on the steel surface. Vitamin B1 exhibited a ΔG_ads value of −14.9 kJ mol^{-1}, whereas ascorbic acid showed a value of −20.9 kJ mol^{-1}. These values indicate that the adsorption process is predominantly governed by physical interactions, including electrostatic forces, hydrogen bonding, and van der Waals interactions [10-11].

The calculated adsorption equilibrium constants were 7.34 for vitamin B1 and 82.9 for ascorbic acid. Although the higher K_ads value of ascorbic acid indicates a stronger adsorption affinity toward individual active sites, this did not result in superior corrosion protection. Instead, vitamin B1 provided higher inhibition efficiency and greater surface coverage, demonstrating that corrosion inhibition depends not only on adsorption strength but also on the ability of inhibitor molecules to form a continuous and compact protective film over the metal surface. The early saturation observed for ascorbic acid suggests localized adsorption with limited lateral surface coverage, whereas vitamin B1 promotes a more homogeneous distribution across the steel surface.

Overall, the gravimetric measurements, Langmuir adsorption analysis, and thermodynamic parameters consistently demonstrate that both compounds act as environmentally friendly corrosion inhibitors for B500 steel in 1.0 M HCl solution. Nevertheless, vitamin B1 provides superior corrosion protection owing to its progressive adsorption behavior, higher inhibition efficiency, and more effective surface coverage, making it the more promising inhibitor under the investigated experimental conditions [12].

Conclusions

Both vitamin B1 and ascorbic acid act as effective environmentally friendly corrosion inhibitors for B500 steel in 1.0 M HCl, significantly reducing the corrosion rate compared with the uninhibited solution.

Corrosion inhibition occurs through the adsorption of inhibitor molecules onto the steel surface, leading to the formation of a protective layer that decreases the active sites available for the anodic and cathodic corrosion reactions.

Vitamin B1 exhibited superior corrosion inhibition performance, achieving the highest inhibition efficiency (78.09%) and surface coverage ($\theta = 0.781$). Its inhibition efficiency increased progressively with concentration, indicating continuous adsorption and the formation of a more uniform and compact protective film.

Ascorbic acid also reduced the corrosion rate effectively; however, its inhibition efficiency reached a plateau at concentrations above 0.5 g/L, suggesting early saturation of the steel surface and a more limited increase in surface coverage with increasing inhibitor concentration.

The adsorption behavior of both inhibitors approximately followed the Langmuir adsorption isotherm. The calculated negative values of the standard Gibbs free energy of adsorption (ΔG_ads = −14.9 kJ mol^{-1} for vitamin B1 and −20.9 kJ mol^{-1} for ascorbic acid) indicate that the adsorption process is spontaneous and predominantly governed by physical adsorption.

Overall, the experimental results demonstrate that the corrosion inhibition efficiency is influenced not only by the adsorption affinity of the inhibitor molecules but also by their ability to produce continuous and effective surface coverage. Under the investigated experimental conditions, vitamin B1 provided more effective and stable corrosion protection than ascorbic acid, making it the more promising green corrosion inhibitor for B500 reinforcing steel in acidic media.

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