



# Corrosion Investigation of Mild Steel in Aqueous Hydrochloric Acid Environment Using N-(Naphthalen-1-yl)-1-(4-Pyridinyl)Methanimine Complemented with Antibacterial Studies

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Received: 22.08.2020; Revised: 12.09.2020; Accepted: 14.09.2020; Published: 16.09.2020

**Abstract:** The inhibitive performance of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine Schiff base on mild steel corrosion in one molar hydrochloric acid environment was investigated by utilizing weight loss techniques. N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine has significant inhibitive performance on the mild steel corrosion in the corrosive medium. The effect of immersion time (1-24 h) and temperature (303 to 333 K) on the behavior of mild steel corrosion in the absence and presence of the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine have also been investigated. The adsorption of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules on the surface of mild steel follows Langmuir adsorption isotherm. The surface morphology of the mild steel coupon was investigated by scanning electron microscopy. The antibacterial efficiencies of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine for gram-negative bacteria, namely *Escherichia coli*, and gram-positive bacteria, namely *Staphylococcus aureus* was studied. The antibacterial activity findings exhibited that the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine has significant antibacterial efficiencies against tested microorganisms.

**Keywords:** naphthalene; corrosion inhibition; methanimine; microorganisms.

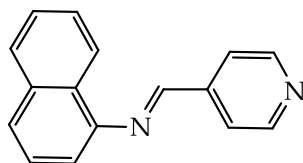
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## 1. Introduction

Natural and organic molecules having phosphorus, sulfur, oxygen, and nitrogen as hetero-atoms in addition to double and triple bonds, which are being as adsorption sites, are efficient as corrosion inhibitors [1-9]. Schiff bases were examined as corrosion inhibitors where exhibited significant inhibition efficiencies at lower and high concentrations [10-14]. In the last years, Schiff bases have been attention due to having effective inhibitors that have considerable inhibition compared to parent carbonyls and primary-amines [15-18]. Schiff base molecules have an imine group, which has the ability to be adsorbed on the surface of tested alloys [19,22].

Due to the significant characteristics of Schiff base derivatives, this work represents the behavior of Schiff base, namely N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine (Scheme 1)

as a corrosion inhibitor for mild steel in a corrosive environment. For the present objective, gravimetric techniques (weight loss methods) and scanning electron microscopy (SEM) have been utilized. Also, the antibacterial activities were achieved out against selected types of gram-negative and gram-positive bacteria, namely bacteria (*Escherichia coli*) (*Staphylococcus aureus*), respectively.



**Scheme 1.** Structure of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine.

## 2. Materials and Methods

### 2.1. Solutions.

The acidic environments were made of 37.0 % hydrochloric acid. The inhibitor concentrations ranged from 0.001 to 0.005 M in 1 M hydrochloric acid. Double distilled water was used to prepare the solutions.

### 2.2. Mild steel sample.

The tested mild steel coupons as working electrodes have the dimensions  $2.5 \times 1.0 \times 0.1 \text{ cm}^3$  and have chemical compositions, as follows (wt %): Fe, 99.21; C, 0.21; Mn, 0.35; Si, 0.05; Al, 0.01; S, 0.38 and P, 0.09. The emery papers were used for mechanically ground the tested coupons and washed distilled water, acetone, and dried [23-25].

### 2.3. Weight loss techniques.

In the weight loss methods, coupons of mild steel were completely immersed in 100 mL 1 M HCl solution in the absence and presence of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine as a corrosion inhibitor in an aerated beaker. After the period of time (1, 5, 10, and 24 h), the coupons were removed and washed with double distilled water, rinsed with acetone, dried, and reweighing [26-28]. The corrosion rate (CR) and inhibition efficiency (IE%) of the inhibitor were evaluated from the mean of three replicates analysis and using equations 1 and 2.

$$C_R(\text{mmpy}) = \frac{87.6 \times W}{atd} \quad (1)$$

where W is the loss of weight (mg), d is the density, A is immersion area ( $\text{cm}^2$ ), and t is the time (h).

$$IE = W_o - \frac{W_i}{W_o} \times 100 \quad (2)$$

$W_o$  and  $W_i$  are weight loss in the presence-absence of corrosion inhibitor, respectively.

The effects of temperature on the inhibition efficiency for the different concentrations of tested inhibitor have been investigated at (303, 313, 323, and 333 K).

### 2.4. Scanning electron microscopy.

The mild steel coupons were an immersion in 1 M hydrochloric acid in the absence and presence of 0.005 M of the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine at 303 K for 5 h,

mild steel coupons were washed with distilled water, dried, and the surface was studied by scanning electron microscope.

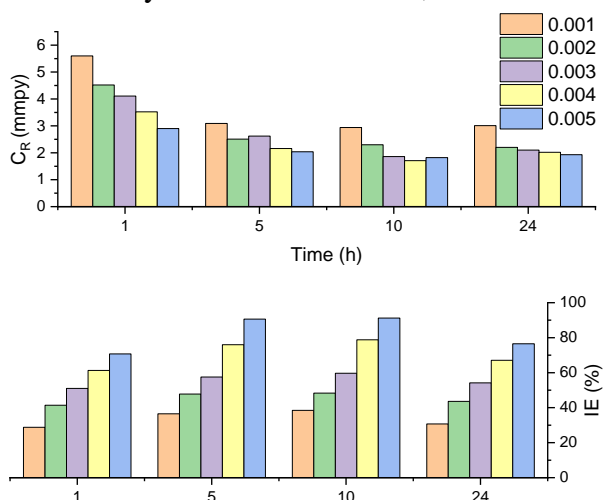
### 2.5. Antibacterial activities.

Antibacterial performance of the target compound, namely “N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine” was evaluated against *Staphylococcus aureus* and *Escherichia coli* by disc diffusion techniques using nutrient agar. The incubation for tested bacteria in agar medium was done for 24 h., at 37 °C. The 5.0 mm diameter discs were soaked in the tested solution with the investigated concentrations (0.1, 0.2, 0.3, 0.4, and 0.5 mM) of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine, which was dissolved in dimethylsulfoxide (DMSO) and put it in Petri dishes on a suitable medium previously seeded with investigated bacteria and occupied for 24 h. The inhibition zone, which was appeared around the tested discs, was calculated in mm. To determine the inhibition performance of DMSO on the selected bacteria, additionally, examine were done using DMSO as control. The DMSO exhibited no activity toward the tested organism [29,30].

## 3. Results and Discussion

### 3.1. Effect of concentrations.

The mild steel corrosion of in 1 M hydrochloric acid medium without and with the addition of different concentrations (0.001, 0.002, 0.003, 0.004, and 0.005 M) of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine was studied at various Temperature 303-333 K for 1, 5, 10 and hour immersion time utilizing gravimetical techniques. From the results of weight loss techniques, the corrosion rate and inhibition efficiency versus concentration at various immersion time was an exhibit in Figure 1. Figure 1 confirms that the corrosion rate of the investigated inhibitor decreases with an increase in the concentration of the studied inhibitor. The observed trend can be explained by the reaction of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules with the mild steel surface through coordination bonds which formed by the reaction of free electrons of nitrogen atoms of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine with the d-orbital of iron atoms of the surface of mild steel. The inhibition efficiency increases with an increase in inhibitor concentration and also increases with time. The inhibition efficiency decreases after 24 h, of immersion time [31].

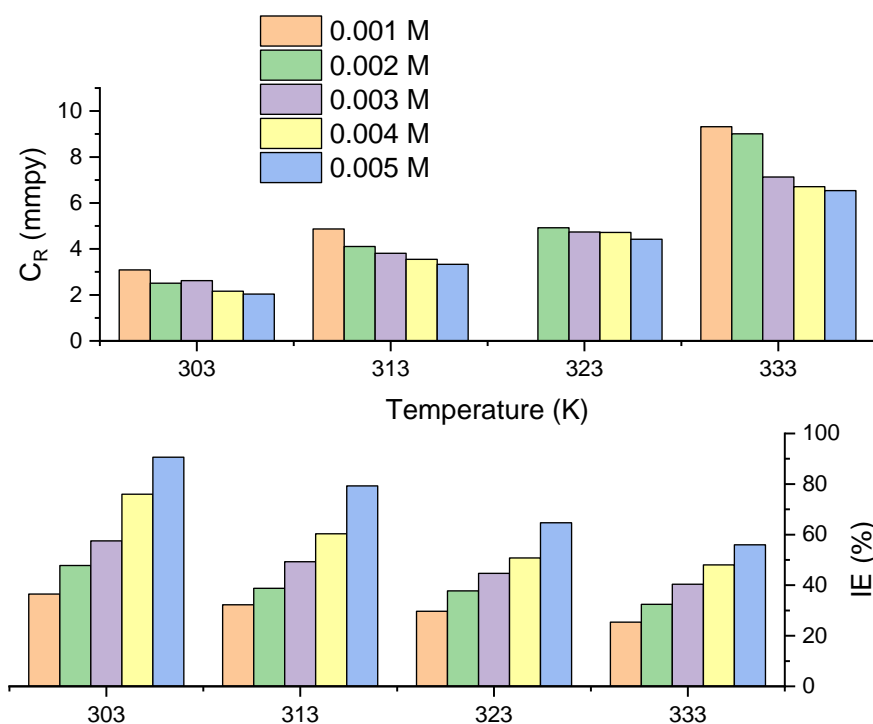


**Figure 1.** The corrosion rate and inhibition efficiency versus various inhibitor concentrations at different immersion time for mild steel in 1 M hydrochloric acid solution.

The extent of inhibitive performance depends on the functional group of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine, which were the C=N groups. At the lowest tested inhibitor concentration (0.001 M), the inhibitive performance increases progressively until the highest tested concentration (0.005 M). The results of weight loss methods reveal that the inhibition efficiency decreases when the immersion time reach to 24 h.

### 3.2. Effect of temperature.

The temperature effect on the inhibition activity on tested coupons in 1 M hydrochloric acid solution is studied by gravimetric techniques in the temperature extend 303-333 K without and with the addition of tested inhibitor at various inhibitor concentrations (0.001-0.005 M). Figure 2 exhibits the inhibition efficiency versus different solution temperatures, from figure 2. The tested inhibitor molecules are adsorbed on the coupon surface at the temperature 303 and 313 k, but the inhibition efficiency decreases at the Temperature 323 and 333 K. This may be attributed to increase in the protective film solubility on the mild steel surface. The increases in solution temperature leading to decreases in the number of inhibitor molecules that were adsorbed on the mild steel surface, leading to inhibition efficiency decreases [32].



**Figure 2.** Corrosion rate and inhibition efficiency versus various inhibitor concentrations at different temperatures for mild steel in 1 M hydrochloric acid solution.

### 3.3. Adsorption isotherm.

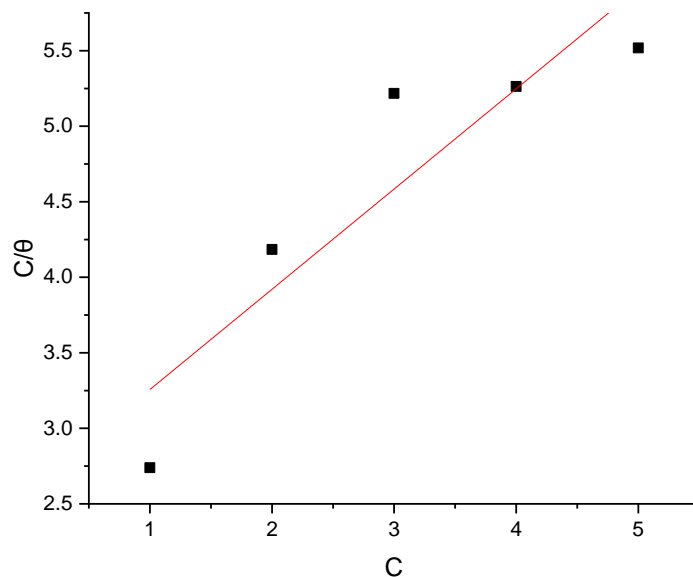
Natural and organic compounds are utilized to control corrosion through adsorb these molecules on the mild steel surface/acidic environment interface. The most significant factor that the adsorption process depends on is the nature of the inhibitor molecules and the chemical structure of these molecules. Another factor is the nature of the corrosive solution, temperature, and potential mild steel surface/ solution interface. Freundlich, Langmuir, Frumkin, and Temkin as adsorption isotherms were investigated for the tested inhibitor on the tested coupon surface

in hydrochloric acid solution at 303 K. R2 as correlation coefficient was employed to evaluate the fit adsorption isotherm. For the investigated inhibitor fit adsorption isotherm was Langmuir adsorption isotherm. Equation 3 represents the Langmuir isotherm.

$$\frac{C}{\theta} = \frac{1}{K} + C \quad (3)$$

Where K is the equilibrium constant, C is the concentration of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine.

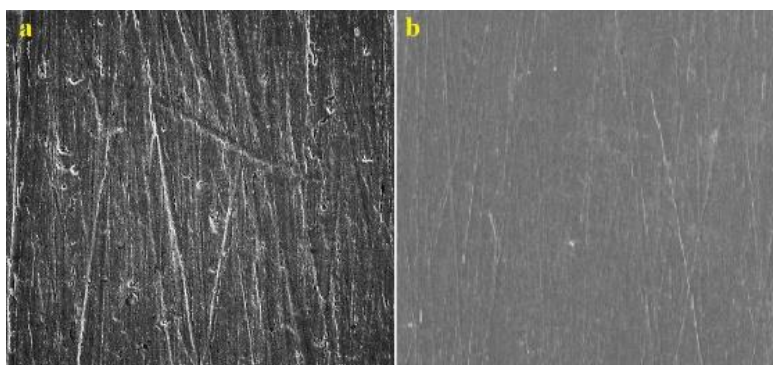
From Figure 3, the straight line was obtained from the plot of C/θ versus C. The value of R2 of the straight line is almost equal to one. The slope deviation was imputed to the interaction of the adsorbed molecules and ions on the coupon surface.



**Figure 3.** Langmuir adsorption isotherm for tested inhibitor on the mild steel in 1 M HCl solution.

#### 3.4. Scanning electron microscopy (SEM).

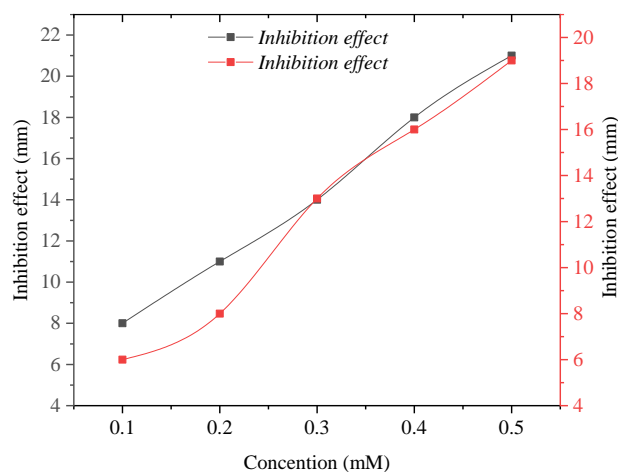
It is clear from the weight loss results that the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine is confirmed to be a significant corrosion inhibitor for the surface of tested alloy in 1 M hydrochloric acid and in order to prove these findings, SEM images of tested coupons have been taken in the absence (Figure 4a) and presence (Figure 4b) of tested inhibitor with the concentration 0.005 M for 5 h at 303 K in hydrochloric acid solution. The SEM images are demonstrated in Figure 4. It is clear from figure 4b; there was almost no damage on the coupon surface comparing to Figure 4a.



**Figure 4.** SEM images of coupon surface of (a) uninhibited surface, (b) inhibited surface of mild steel in 1 M hydrochloric acid environment.

### 3.5. The antimicrobial activities.

The antimicrobial testing findings exhibit that the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine has significant antibacterial efficiency. The inhibition activity of the target compound is better than the parent compounds, namely isonicotinaldehyde or naphthalen-1-amine. The excellent inhibitive efficiency of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules was imputed to the presence of the imine (C=N) group. The tendency of the imine group to increase the inhibition activities of the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules toward investigated microbial is expected and N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules may be considered as a bactericidal agent, due to killing bacteria better than the parent compounds which form the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine. In N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules, the nitrogen electron pairs are shared with the  $\pi$ -bonds of the aromatic rings present in the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules, and there may be delocalization of  $\pi$ -electrons over all the molecule (N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecule). This will increase the lipophilicity of the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules and prefer its permeation by the lipid layer of the membrane of the studied microbes. The increasing of lipophilicity seems to be responsible for increasing the inhibition efficiency toward studied bacteria. We can propose that N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules able to inhibit different cellular enzymes, that play a vital role in different metabolic pathways of investigated microbes. As seen from Figure 5, the N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules show inhibitive efficiency toward *E. coli* was better than the inhibitive efficiency toward *Staphylococcus aureus* [33].



**Figure 5.** Effect of N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine against selected bacteria.

At any time, over 1.4 billion people worldwide suffer from infectious complications acquired in hospital. Microorganisms often implicated in these infections include *E. coli* and *S. aureus* [34,35].

## 4. Conclusions

In the present investigation, N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine has been successfully synthesized and fully characterized by different spectroscopic techniques. The N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine was studied for corrosive inhibitive efficiency

and antimicrobial activates. N-(naphthalen-1-yl)-1-(4-pyridinyl)methanimine molecules have significant corrosion inhibitive characteristics and excellent antibacterial effects.

## Funding

This research received no external funding.

## Acknowledgments

This study was supported by the University of Technology, Baghdad, Iraq.

## Conflicts of Interest

The authors declare no conflict of interest.

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