

## Synthesis New Triethylammonium Salts as Corrosion Inhibitors for Mild Steel in 1 M H<sub>2</sub>SO<sub>4</sub>

Mariam S. Muhsin\* and Mehdi S. Shihab

Department of Chemistry, College of Science, Al-Nahrain University, Jadriya, Baghdad-Iraq

### Article's Information

Received:  
09.02.2023  
Accepted:  
07.05.2023  
Published:  
30.06.2023

#### Keywords:

Triethylammonium salts  
Corrosion reaction  
Surface of mild steel  
Adsorption process

### Abstract

Some new triethylammonium salts, namely triethylammonium 4-(cyclohexylamino)-4-oxobut-2-enoate(B1), triethylammonium 5-(cyclohexylamino)-5-oxopentanoate (B2), triethylammonium 4-(cyclohexylamino)-4-oxobutanoate (B3) were synthesized as a corrosion inhibitor for mild steel. These salts could test in one molarity sulfuric acid at room temperature for 24 hours by using weight of losing method. The results revealed that the efficiency of inhibition of all triethylammonium salts were high at the maximum concentration of triethylammonium salt. The increase concentration of inhibitors is associated with decreasing the rate of corrosion, but the increasing of efficiencies of inhibition, and a greater degree of surface covering. Adsorption values of the free energy were used to illustrate the effects of physisorption for (B1, B2, and B3), which was helpful in forecasting the natural interaction between organic corrosion inhibitor molecules and the metal surface of steel.

DOI: 10.22401/ANJS.26.2.02

\*Corresponding author: [sadoonmaryam@gmail.com](mailto:sadoonmaryam@gmail.com)



This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

### 1. Introduction

Corrosion inhibitors have been thoroughly researched in a range of industries to reduce the rate of corrosion of metal surfaces in contact with hostile environments [1-3]. Acidic solutions are often applied in a variety of sectors, including petrochemical operations, oil-well acidification, industrial cleaning, acid rescaling, and acid pickling [4].

One of the most effective ways to prevent corrosion, particularly in acid solutions to stop metal evaporation and acid consumption, is to use inhibitors [5].

Many industrial processes employ mild steel in acid solutions, and corrosion of mild steel is known to happen in this setting.

The use of organic inhibitors is one of the most efficient ways to stop corrosion [6].

The topic of mild steel corrosion inhibitors in acidic environments has been the focus of several scientific investigations [7-12].

Surfactant efficiency as corrosion inhibitors has recently been extensively researched in various media and for the protection of multiple metals, leading to studies on organic-based corrosion inhibitors [13-15]. Gemini surfactants, which are new generation quaternized salt surfactants composed of two surfactant monomers joined together by a spacer group, have been thoroughly investigated in corrosion investigations [16,17]. For instance, innovative cationic Gemini surfactants produced for C-steel pipeline corrosion inhibition in 1 M HCl media [18] shown a potent

inhibition effectiveness. Additionally, the impact of a long spacer chain on enhancing surface coverage was demonstrated by three cationic Gemini surfactants with different spacer lengths, namely G-12, G-6, and G-2 [19]. Additionally, in oil well formation water with existing sulfide ions, additional cationic Gemini surfactant compounds demonstrated corrosion inhibition efficiency between 76 to 81% at 300 ppm [20]. Inhibition of mild steel corrosion by new green surfactants made from erucic acid was examined in a 15% HCl solution [21]. At 90 °C, they had a 98% inhibitory efficiency. In a solution containing 3.5% NaCl and 0.5 M HCl at temperatures between 30 and 60 °C, cationic surfactants produced with a Schiff base group achieved 95% protection efficacy for C-steel [22]. The goal of the current investigation was to determine the effectiveness of certain triethylammonium salts (see Figure 1) as corrosion inhibitors for mild steel that would be tested in 1M sulfuric acid at room temperature for 24 hours.

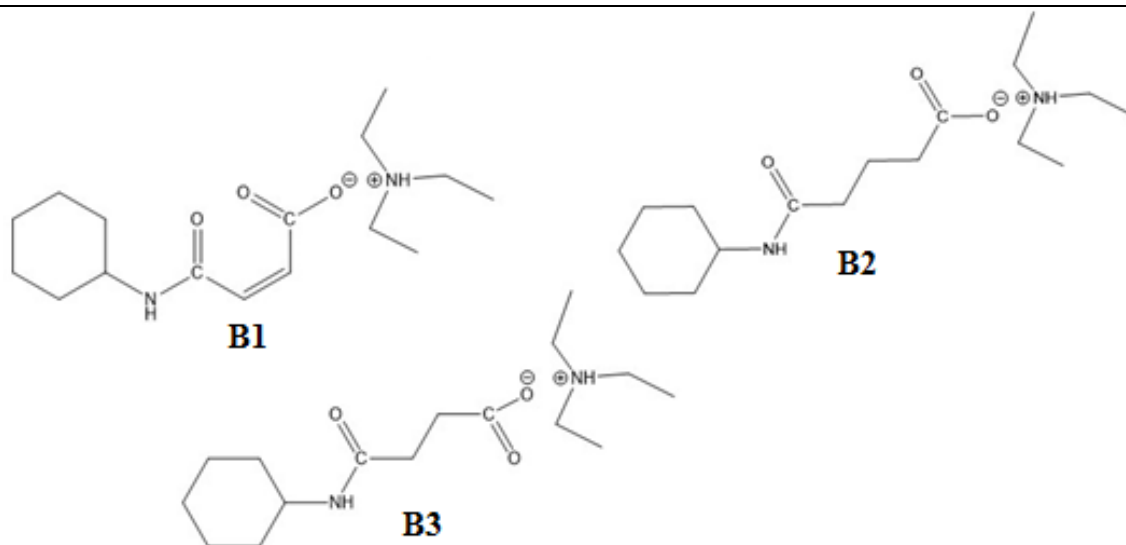


Figure 1. The formula of prepared inhibitor molecules.

## 2. Experimental

### 2.1 Materials:

Reagents and solvents were both utilized in their identical original form.

### 2.2 Instrumentation:

All there were prepared organic compounds measured by Bruker Company FTIR spectrophotometry with range of the wave number ( $4000\text{--}400\text{ cm}^{-1}$ ) and  $^1\text{H-NMR}$  was applied by using (DMSO- $d_6$ ) as a solvent. The melting points were calculated using the open capillary technique employing apparatus of Gallenkamp hot stage, but all the measurements were usually uncorrected. The mild steel specimen's composition was determined by SPECTROMAX device (2009, Germany) in Ministry Industry and Materials/State Company for Inspections and Rehabilitation.

### 2.3 General procedure for synthesized triethylammonium salts:

The synthesis of triethylammonium salts were consisted two steps: namely triethylammonium 4-(cyclohexylamino)-4-oxobut-2-enoate (B1), triethylammonium 5-(cyclohexylamino)-5-oxopentanoate (B2), triethylammonium 4-(cyclohexylamino)-4-oxobutanoate (B3), were synthesized as follow:

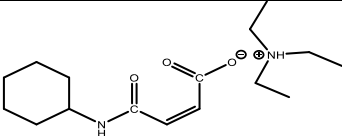
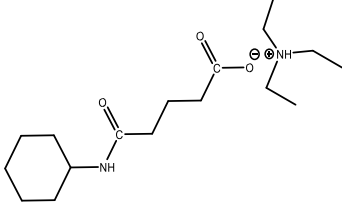
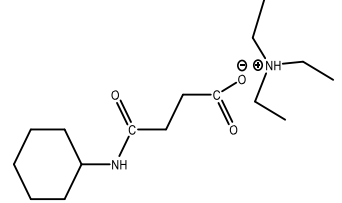
A mixture of each compound cyclohexyl amine (0.01 mol) with (0.01 mol) of each (maleic anhydride, glutaric anhydride, succinic anhydride) in 10 mL of THF at room temperature was stirred for four hours to formation amic acids (A1-A3). Then left the mixture 24 hours at  $25\text{ }^\circ\text{C}$ . The sold compound was filtered, precipitated, and cleaned with 5 mL of THF two times. In the next step, (0.01 mol) of each amic acid and triethylamine in 15 mL methanol was stirred 1 hour at room temperature. Then left the mixture 24 hours at room temperature. The sold salt was precipitated, filtered,

and washed with 5 mL of methanol two times. Tables 1 and 2 show structural data of prepared compounds.

Table 1. Structural data of prepared compounds.

Compounds	Name	MW, (g/mol)	Color	M.P. °C	Yield %	FTIR data, $\nu$ , $\text{cm}^{-1}$
A1	4-((4-aminocyclohexyl) amino)-4-oxobut-2-enoic acid	212.25	Yellow	158-160	92	C-H aliphatic 2925,2850 C-H olefinic 3050 C=O carboxylic 1664 C=O amide 1637 N-H amide 3249
A2	5-((4-aminocyclohexyl) amino)-5-oxopentanoic acid	286.13	White	145-147	74	C-H aliphatic 2925,2853 C=O carboxylic 1700 C=O amide 1635 N-H amide 3330
A3	4-oxo-4-(phenylamino) butanoic acid	193.20	Off-white	159-161	70	C-H aliphatic 2925,2855 C=O carboxylic 1690 C=O amide 1636 N-H amide 3242
B1	triethylammonium 4-((4-aminocyclohexyl) amino)-4oxobut-2-enoate	313.44	Brown	179-181	87	C-H aliphatic 2929,2855 C-H olefinic 3050 C=O carboxylic 1660 C=O amide 1631 N-H amide 3296 3400 for $-\text{N}^+-\text{H}$
B2	triethylammonium 5-((4-aminocyclohexyl) amino)-5oxopentanoate	329.48	Yellow	219-221	65	C-H aliphatic 2930,2854 C=O carboxylic 1738 C=O amide 1626 N-H amide 3278 3437 for $-\text{N}^+-\text{H}$
B3	triethylammonium 4-((4-aminocyclohexyl) amino)-4oxobutanoate	315.46	White	220-218	84	C-H aliphatic 2930,2854 C=O carboxylic 1704 C=O amide 1634 N-H amide 3289 3436 for $-\text{N}^+-\text{H}$

Table 2. The  $^1\text{H-NMR}$  spectral structural data in ppm for compounds (B1 to B3).

B1		1H of N-H (-CO-NH-) (s, 8.1); 2H of H-N <sup>+</sup> - (s, 10.9); 2H of CO -CH=CH-CO (d, 5.8, 6.1); 1H of -NH-CH- (m, 3.5); 6H of -N <sup>+</sup> -CH <sub>2</sub> (m, 3.0); 9H of CH <sub>3</sub> (m, 1.5); 10H of CH <sub>2</sub> (m, 1.0-1.7);
B2		1H of N-H (-CO-NH-) (s, 7.7); 1H of H-N <sup>+</sup> - (s, 7.4); 6H of CO-CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CO (m, 2.2-2.7); 1H of -NH-CH- (m, 3.9); 6H of -N <sup>+</sup> -CH <sub>2</sub> (m, 3.5); 9H of CH <sub>3</sub> (m, 1.5); 10H of CH <sub>2</sub> (m, 1.0-1.7);
B3		1H of N-H (-CO-NH-) (s, 7.7); 1H of H-N <sup>+</sup> - (s, 7.2); 4H of CO-CH <sub>2</sub> -CH <sub>2</sub> -CO (m, 2.2); 1H of -NH-CH- (m, 3.9); 6H of -N <sup>+</sup> -CH <sub>2</sub> (m, 3.5); 9H of CH <sub>3</sub> (m, 1.5); 10H of CH <sub>2</sub> (m, 1.01-1.7);

#### 2.4. Preparation of aggressive solution:

Dilution of analytical grade (98%) H<sub>2</sub>SO<sub>4</sub> with distilled water yielded an aggressive solution of 1M H<sub>2</sub>SO<sub>4</sub>. The inhibitor concentrations ranging between (0.0005-0.01 M) were achieved with 1M H<sub>2</sub>SO<sub>4</sub> aqueous solution.

#### 2.5 Weight loss measurements:

Composition: 0.288% Mn, 0.0154 % S, 0.03 % C, 0.0199 % Cr, 0.065 % Cu, 0.002 % P, 0.0005 % V, 0.002 % Mo. The mild steel sheet was being formed into a disk (2.5 cm as diameter). These disc forms were polished using energy paper of a grade 2000 to obtain a flawless surface. They then disinfected with distilled water, alcohol and acetone. The treated specimens were dried out in a desiccator before being utilized in corrosion testing. The mild steel disc is initially weighted using an electronic balance. In both the absence and presence of the known concentration of produced organic inhibitor, the mild steel disc was then fully submerged in a suitable beaker containing 1 M sulfuric acid. After 24 hours at room temperature, the specimens were removed and cleaned with a mixture of water and acetone. The specimens were dried and maintained in a desiccator before being reweighted. The weight reduction

technique was used in accordance with ASTM test results [23,24]. To guarantee the validity of the results, the tests were repeated twice. The average value of the weight loss allowed for the calculation of the average rate of corrosion (mgcm<sup>-2</sup>h<sup>-1</sup>). Using formula (1), the rate of corrosion of mild steel test was determined as follows [25]:

$$W = \frac{\Delta m}{S.t} \quad \dots(1)$$

where:

*m*: a weight loss (grams),  
*S*: area (squaremeters), and  
*t*: immersing time (hours).

The efficiency of inhibition (IE%) was calculated by using the equation (2) as a following [25]:

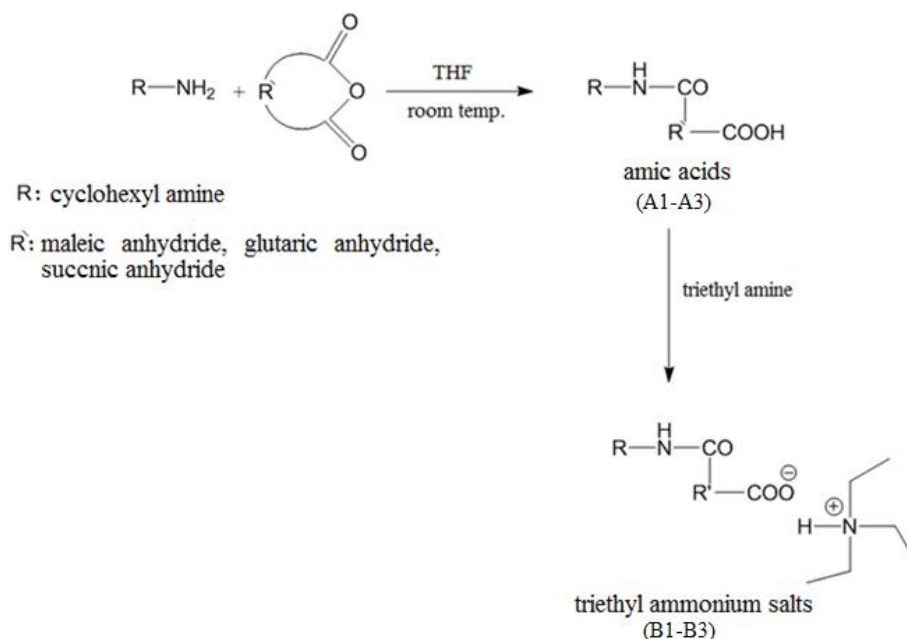
$$IE\% = \frac{W_{corr} - W_{corr(inh)}}{W_{corr}} \times 100 \quad \dots(2)$$

where:

*W<sub>corr</sub>*: corrosion rates in absence of the inhibitor, and  
*W<sub>corr(inh)</sub>*: corrosion rates in the presence of the inhibitor.

### 3. Results and Discussion

Scheme 1 shows the preparation of synthesized triethylammonium salts (B1-B3) of the present work.



**Scheme 1.** Synthesis steps of the triethylammonium salts (B1, B2 and B3).

The reactions above are included preparation of the amic acids (A1, A2 and A3) by using cyclohexylamine to react with an acid anhydride. Then the reaction followed by the acid-base reaction with triethylamine to prepare triethylammonium salts (B1, B2 and B3).

The FT-IR spectral data and physical properties of the prepared compounds are summarized in the Table (1, see Fig. (2-7)) and the <sup>1</sup>H-NMR spectral data of compounds (B1, B2, and B3) in ppm listed in Table 2 (see Figures 8-10).

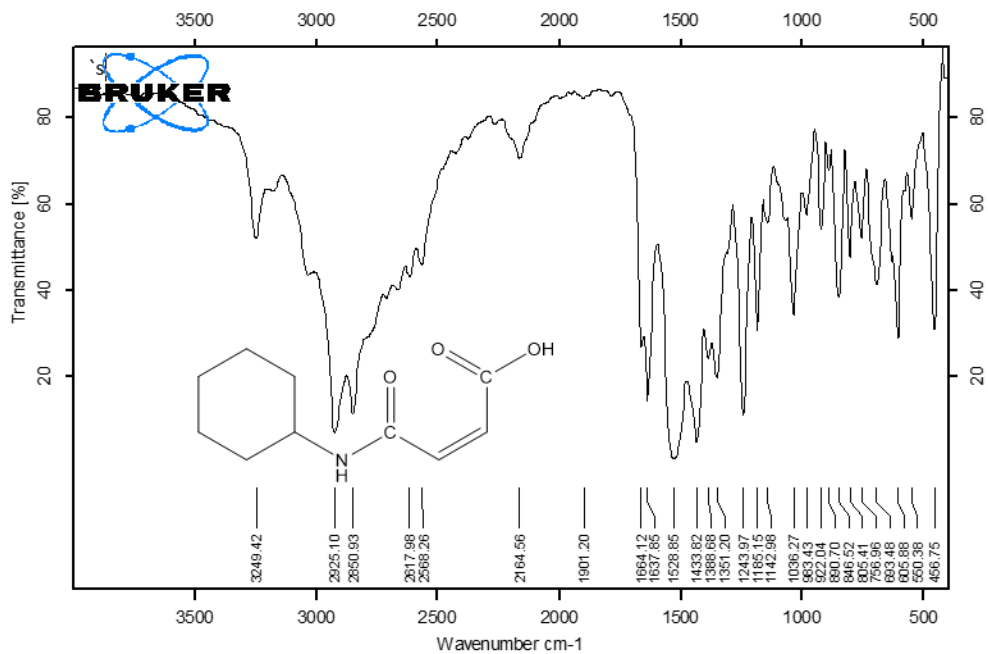


Figure 2. FT-IR of compound (A1).

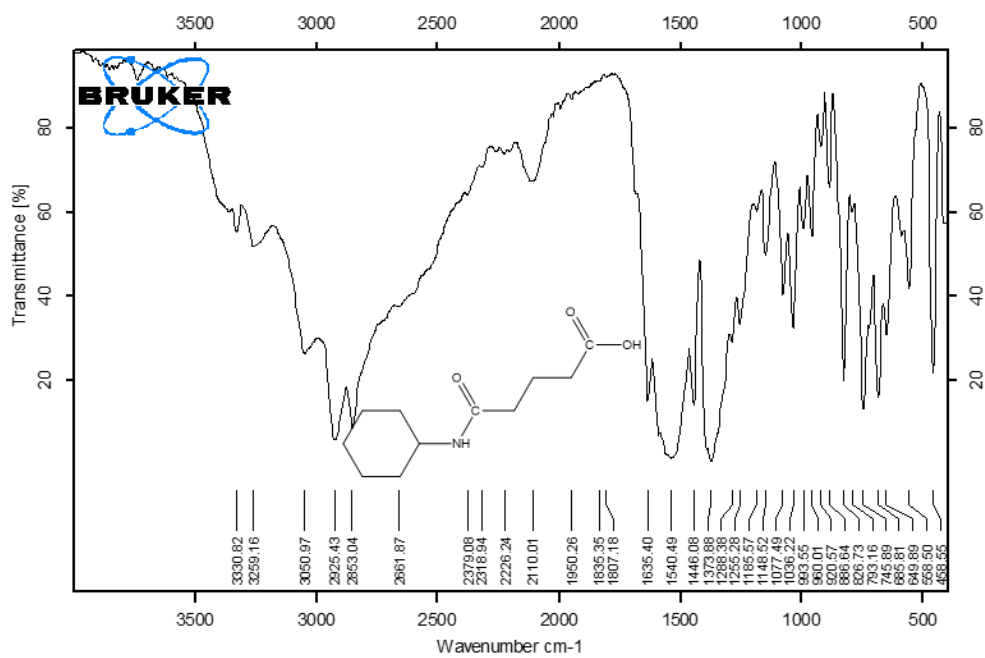


Figure 3. FT-IR of compound (A2).

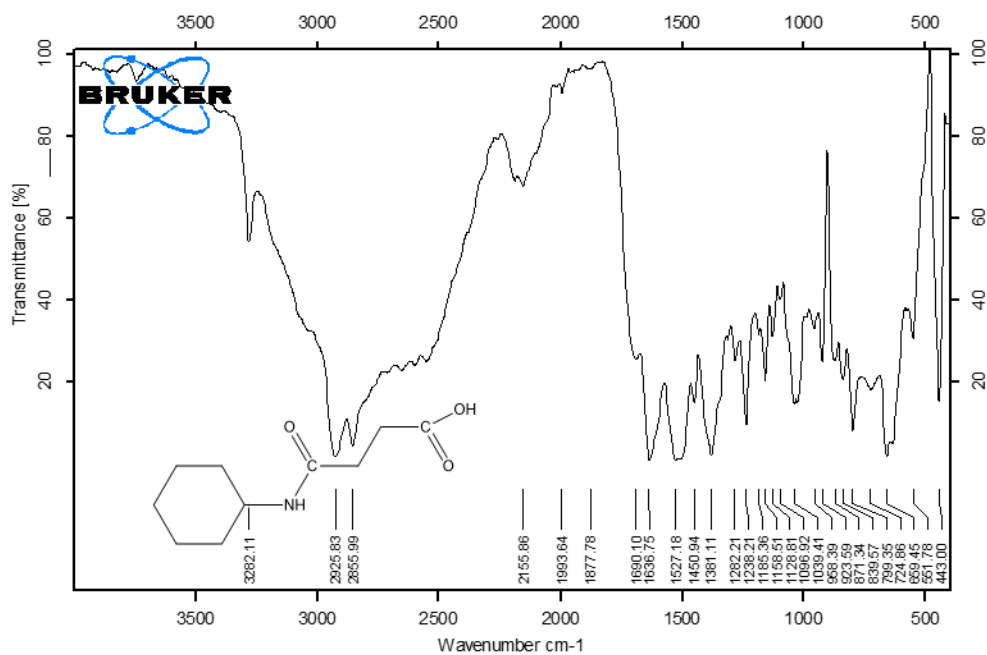


Figure 4. FT-IR of compound (A3).

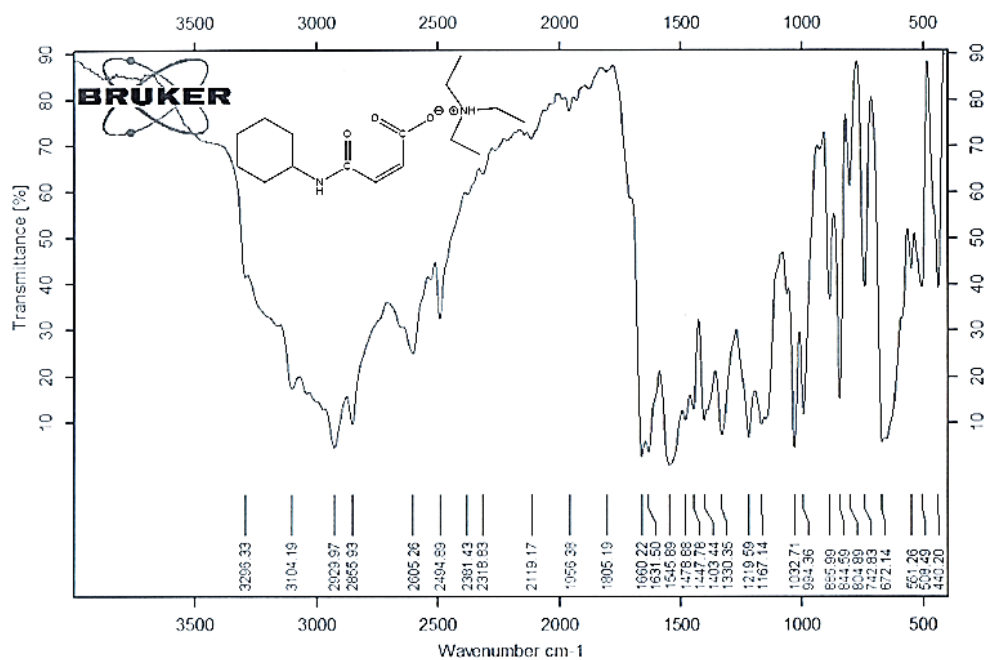


Figure 5. FTIR of compound (B1).

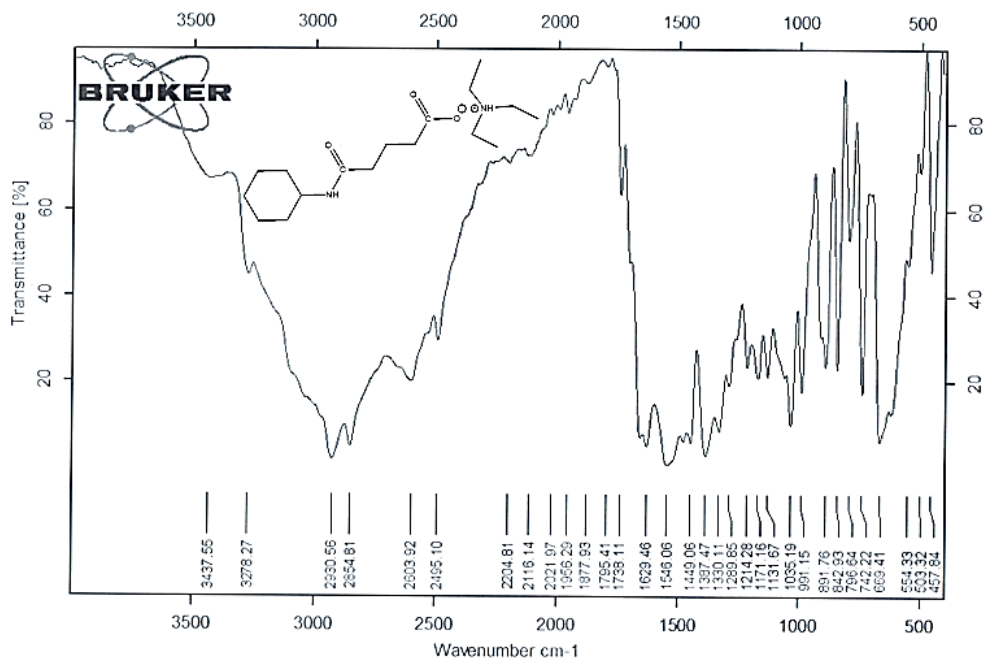


Figure 6. FT-IR of compound (B2).

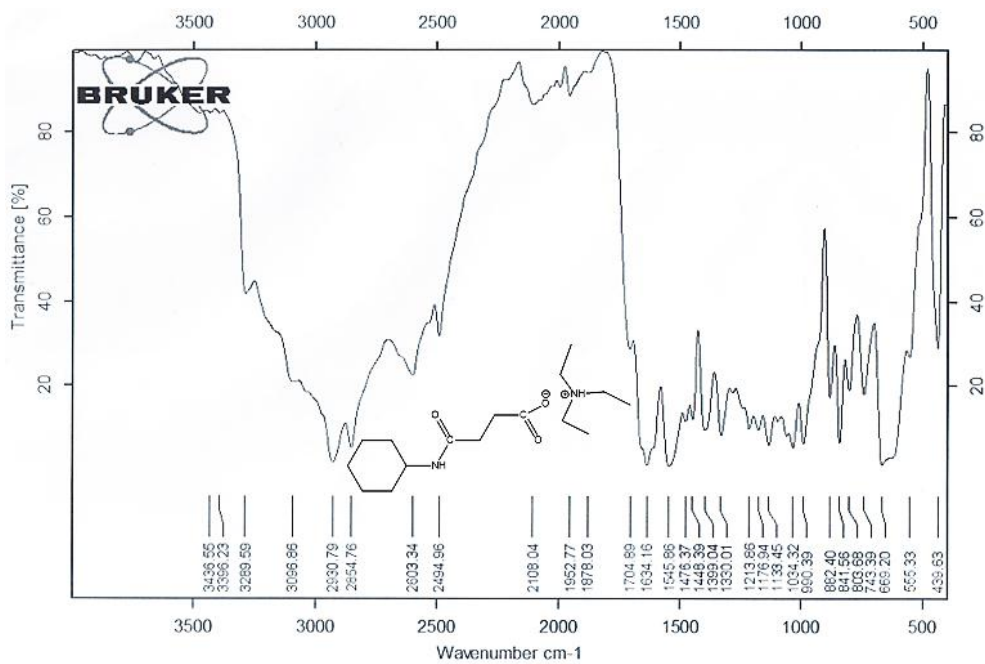
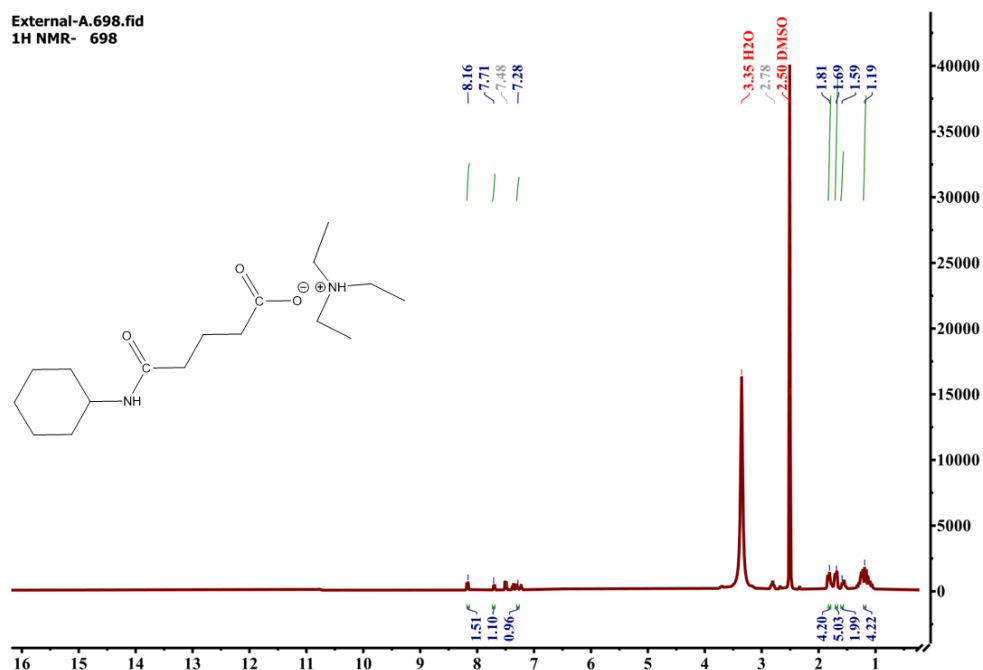
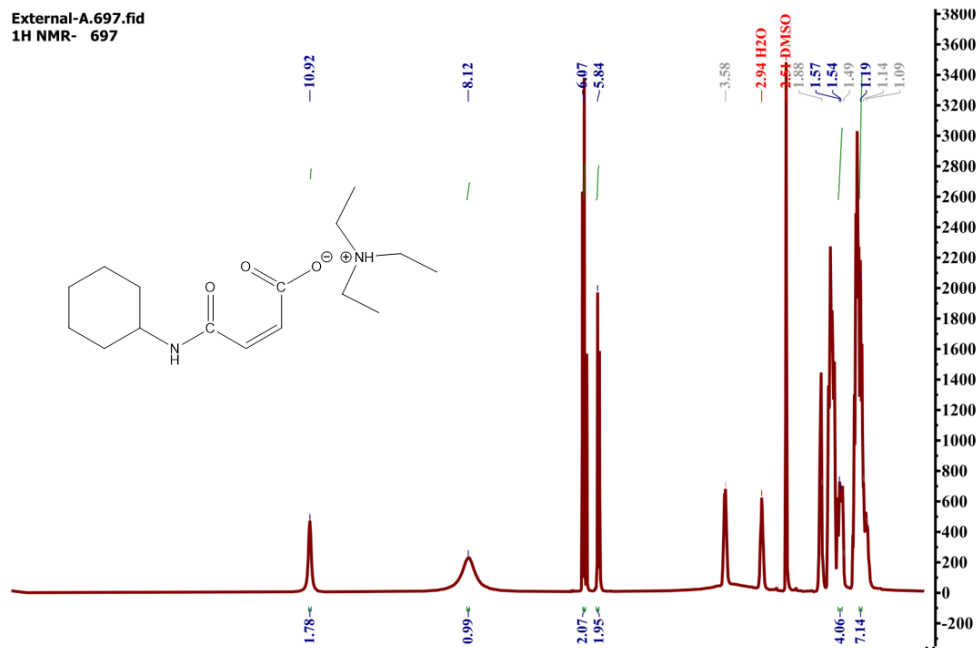


Figure 7. FT-IR of compound (B3).





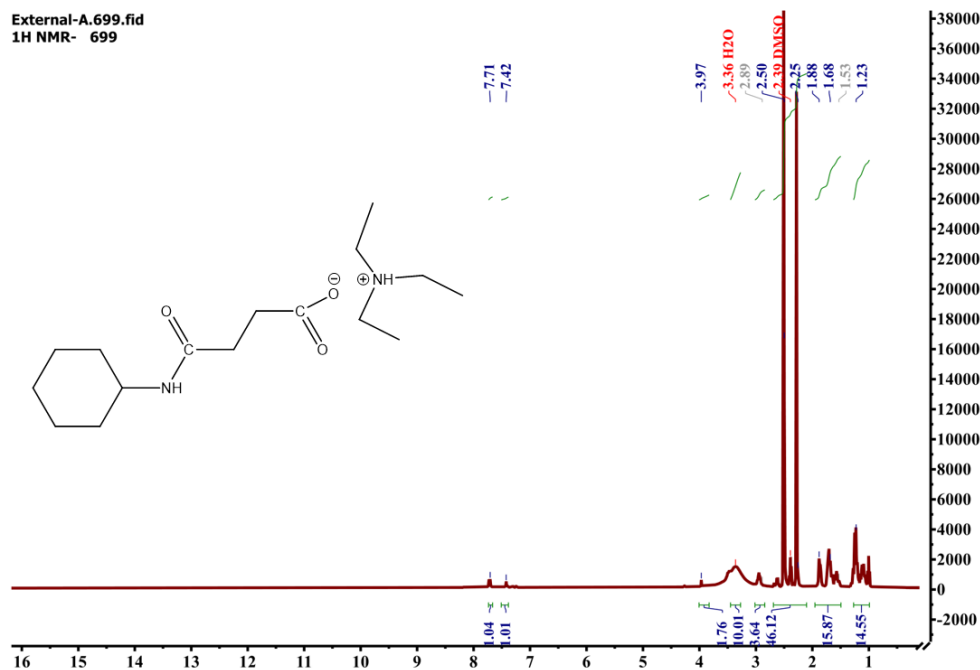


Figure 10. HNMR of compound (B3).

After 24 hours and at room temperature the immersing, the rate of corrosion results and efficiency of inhibition has obtained using measurements of weight loss with

concentrations in different of organic inhibitor molecules (B1-B3) are listed within Table 3 and showed in Figures 11 and 12.

**Table 3.** Corrosion rate, efficiency of inhibition (E %), coverage of surface ( $\theta$ ) and  $\Delta G^{\circ}_{ads}$  for mild steel test by 1 M H<sub>2</sub>SO<sub>4</sub> with measurements of weight loss at room temperature in 24 hours.

Concentration (M)	Corrosion rate (mg.cm <sup>-2</sup> .h <sup>-1</sup> )	IE %	$\theta$	$\Delta G^{\circ}_{ads}$ (kJ. mol <sup>-1</sup> )
Blank	0.1225			
<b>B1</b>				
5×10 <sup>-4</sup>	0.0233	80.97	0.8097	-33.74 (R <sup>2</sup> = 0.9999)
1×10 <sup>-3</sup>	0.0133	89.14	0.8914	
5×10 <sup>-3</sup>	0.0095	92.24	0.9224	
1×10 <sup>-2</sup>	0.0072	94.14	0.9414	
<b>B2</b>				
5×10 <sup>-4</sup>	0.0157	87.18	0.8718	-34.53 (R <sup>2</sup> = 0.9999)
1×10 <sup>-3</sup>	0.0038	96.90	0.9690	
5×10 <sup>-3</sup>	0.0028	97.71	0.9771	
1×10 <sup>-2</sup>	0.0010	99.18	0.9918	
<b>B3</b>				
5×10 <sup>-4</sup>	0.0049	96.00	0.9600	-38.79 (R <sup>2</sup> = 0.9999)
1×10 <sup>-3</sup>	0.0031	97.46	0.9746	
5×10 <sup>-3</sup>	0.0024	98.04	0.9804	
1×10 <sup>-2</sup>	0.0022	98.20	0.9820	

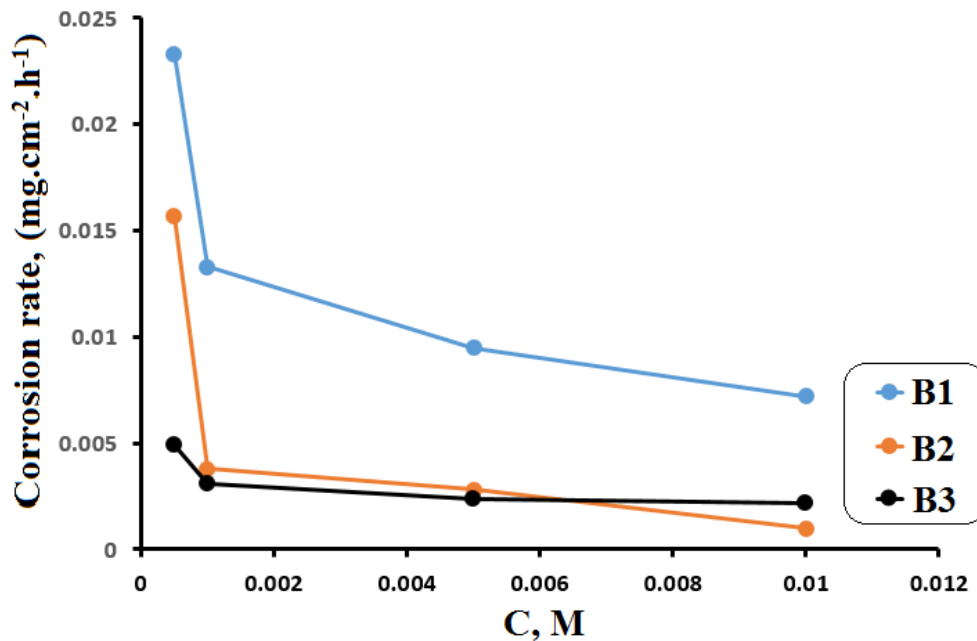


Figure 11. Effect of inhibitor concentrations on the corrosion rate for mild steel  $1\text{M}\text{H}_2\text{SO}_4$  at room temperature for suggested inhibitors (B1-B3).

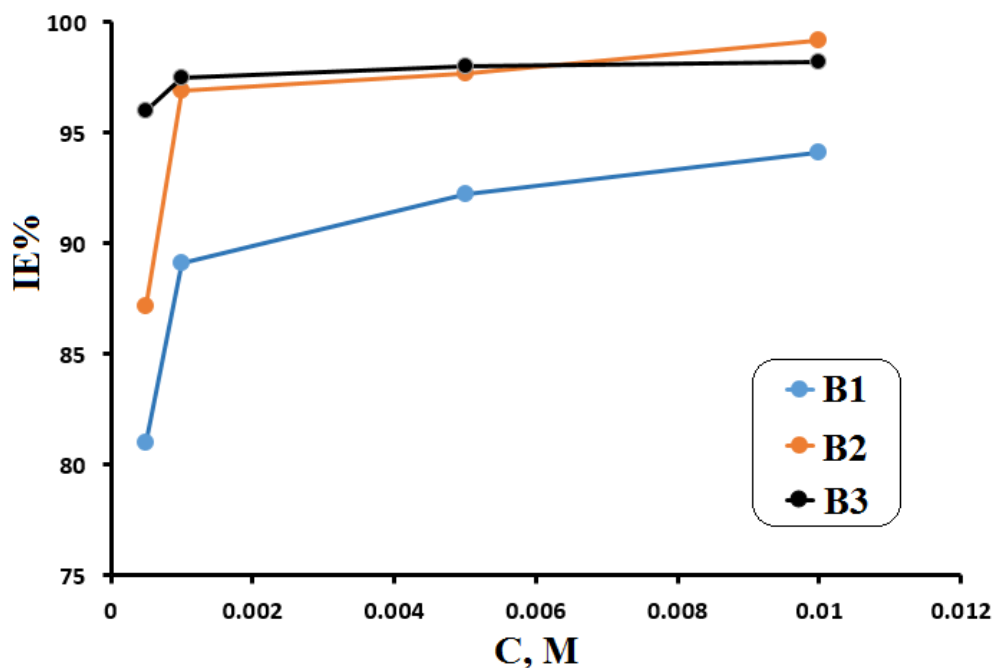
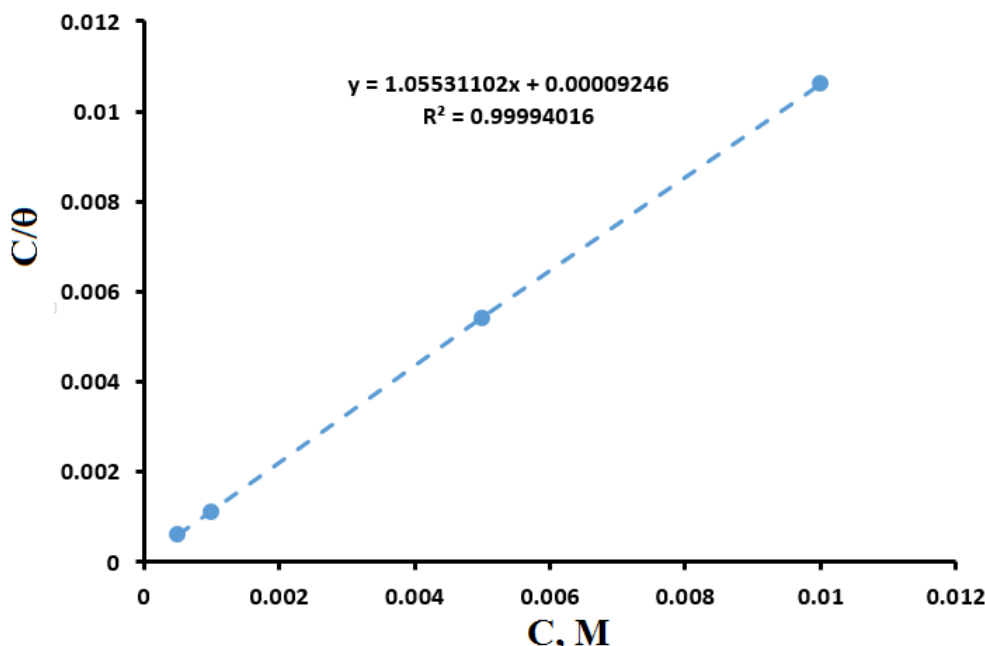


Figure 12. Effect of concentrations inhibitor on mild steel  $1\text{M}\text{H}_2\text{SO}_4$  inhibition efficiency at room temperature for organic inhibitor molecules (B1-B3).



**Figure 13.** Langmuir adsorption isotherm plot for mild steel in 1M<sub>H<sub>2</sub>SO<sub>4</sub></sub> solution in the presence of various concentrations of inhibitor (B1).

The corrosion effectiveness increases with increasing inhibitor concentrations, as shown in Table 3, with 10-2 M having the highest inhibition efficiencies. The analysis reveals that the effectiveness of inhibition (C1 to C3) is roughly equivalent. The values of efficiency inhibition and the process adsorption may be used to describe how molecular organic structures (flexible structures with B2 and B3) affect efficiency inhibition. Basic knowledge about the adsorption process may be used to remove the organic molecule compound's natural contact with the metal surface. In order to acquire the values of surface covering degree, with various doses of inhibitor, weight loss experiments using 1M sulfuric acid were conducted  $\theta = E(\%)/100$  (see Table 3) at room temperature and determined by relationship Langmuir isothermal, (3) [26]:

$$\frac{C}{\theta} = \frac{1}{K_{ads}} + C \quad \dots(3)$$

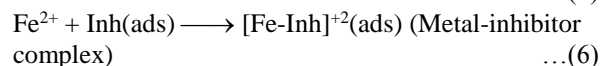
where  $C$  is concentration, (M),  $K_{ads}$ , adsorption process of equilibrium constant.

The Langmuir isotherm states that values for  $K_{ads}$  are determined by intersections between a straight line and  $C$ , (see Figure 13),  $\Delta G^{\circ}_{ads}$ , is calculated by equation (4): (55.5 value: water molar concentrations, M).

$$K_{ads} = \frac{1}{55.5} \exp\left(\frac{-\Delta G^{\circ}_{ads}}{R}\right) \quad \dots(4)$$

Table 3 displays the free energy values of the process adsorption with a negative sign to demonstrate that the adsorption of (B1-B3) is occurring spontaneously over the surface of mild steel after 24 hours of immersion at room temperature. This is done to explain the interaction between the metal surface and the substance being adsorbed (B1-B3). With this point, organic molecules are moving nearby metal surface causing interfering electrons of organic

molecules with the empty orbitals of metal surface atoms [27-30]. With this idea, the organic inhibitor adsorption on metal by donor atoms leads to formation kind of complexation between the metal and organic inhibitor as showing in (5, 6) [31]:

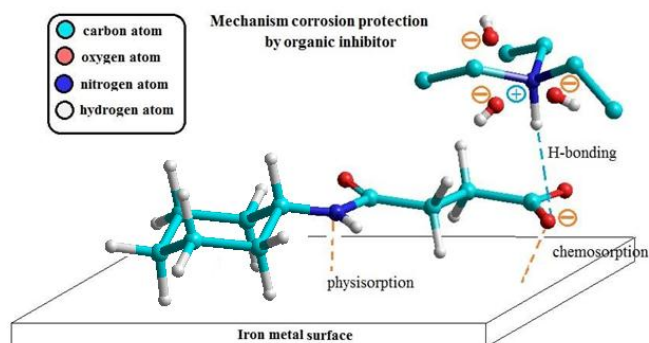


In order to stop the formation of  $Fe^{2+}$  ions, the mineral inhibitor complex will act as a thin film layer on anode sites. As a result, it's probable that with decreasing concentrations of the suggested inhibitor, metal inhibitor complexes are lower. The interaction of organic molecular adsorption molecules with N or O atoms controls the process of adsorption of a specific inhibitor. It has been documented that functional groups within molecule is causing to change molecule electrons density, which can be affected adsorption process [32]. The proposed inhibitors (B1-B3) that adsorbing with metal surface through thin film complex can be allocated on the site's anode, that to reduce or prevent to losing metal atoms of surface via the reaction of electrochemical dissolutions.

physical adsorption, as shown in Table 3, was discovered [32]. As indicated in Table, the suggested inhibitor (B3) displayed a value of  $G_{ads} = 38.79$  kJ/mol, which was confirmed by IE% values (96-99) for the same dosages (3). E% is greater than E% values for (B1) and (B2) despite the low concentration of (B3) (0.0005M) (B2). The amide group and acetate group have a greater electron density because of the chemical structure of B3. By evenly distributing the electron density on the surface metal with organic molecules (B3) as well as for B1 and B2, the

interaction between the organic molecule (B3) and the surface metal will be improved.

Last but not least, Figure 14 illustrates the reaction mechanism of the interaction between the organic molecule (B3) and the surface metal. This figure also depicts the aromatic groups of the suggested inhibitor molecules on the iron surfaces as well as a modeling representation of the process of nitrogen and oxygen atoms adsorption.



**Figure 14.** Suggested interaction mechanism of inhibitor molecules on the mild steel surface.

#### 4. Conclusion

Triethylammonium salts (B1-B3) were successful using like, corrosion organic inhibitors for surface of iron metal within solution of 1 M sulfuric acid within room temperature. The efficacy inhibitory, IE %, results were showed considerable effects inhibitory of the prepared inhibitor molecules. The free energy adsorption values were showing effect within physical process adsorption (B1-B3) and obtained important informations to elucidate the natural interactions between the molecules of biological matter and the metal surface.

#### References

- [1] Christov M. and Popova A.; "Adsorption characteristics of corrosion inhibitors from corrosion rate measurements". *Corrosion Science*, 46(7): 1613-1620, 2004.
- [2] Okafor P. C.; Liu X. and Zheng Y. G.; "Corrosion inhibition of mild steel by ethylamino imidazoline derivative in CO<sub>2</sub>-saturated solution". *Corrosion Science*, 51(4): 761-768, 2009.
- [3] Herrag L.; Hammouti B.; Elkadiri S. et al.; "Adsorption properties and inhibition of mild steel corrosion in hydrochloric solution by some newly synthesized diamine derivatives: experimental and theoretical investigations". *Corrosion Science*, 52(9): 3042-3051, 2010.
- [4] Cheng S.; Chen S.; Liu T.; Chang X. and Yin Y.; "Carboxymethylchitosan + Cu<sup>2+</sup> mixture as an inhibitor used for mild steel in 1 M HCl". *Electrochimica Acta*, 52(19): 5932-5938, 2007.
- [5] Chauhan L. R. and Gunasekaran G.; "Corrosion inhibition of mild steel by plant extract in dilute HCl medium". *Corrosion Science*, 49(3): 1143-1161, 2007.
- [6] Bayol E.; Gürten T.; Gürten A. A. and Erbil M.; "Interactions of some Schiff base compounds with mild steel surface in hydrochloric acid solution". *Materials Chemistry and Physics*, 112(2): 624-630, 2008.
- [7] Tahseen R. A.; Taghried A. S. and Mehdi S. S.; "Pomelo leaves extract as a green corrosion inhibitor for carbon steel in 0.5 M HCl". *Int. J. Corros. Scale Inhib.*; 10(4), 1729-1747, 2021.
- [8] Rania K. H. and Mehdi S. S.; "Study new pyridine derivatives as corrosion inhibitors for mild steel in an acidic media". *Al-Nahrain Journal of Science*, 24 (3): 1-8, 2021
- [9] Rania K. H. and Mehdi S. S.; "Synthesis new pyridinium salts as corrosion inhibitors for mild steel in 1 M H<sub>2</sub>SO<sub>4</sub>". *Al-Nahrain Journal of Science*, 24, 14-20, 2021
- [10] Mehdi H. N. Mehdi S. S.; Eden A. H. and Xianming S.; "Mechanism of corrosion protection in chloride solution by an apple-based green inhibitor: experimental and theoretical studies". *Journal of Infrastructure Preservation and Resilience*, 1: 7, 2020
- [11] Zahraa T. K. and Mehdi S. S.; "Study synergistic effect of some pyrazole derivatives as corrosion inhibitors for mild steel in 1M H<sub>2</sub>SO<sub>4</sub>". *Surface Engineering and Applied Electrochemistry*, 56(5): 601-609 2020
- [12] Mehdi S. and Atheer M. F.; "Approach for Synthesis of N-pyridinium Derivatives using Schiff's Base Compounds". *KKU Journal of Basic and Applied Sciences*, 3(2): 36-38, 2017.
- [13] Bianchetti, G.O.; Devlin, C.L. and Seddon, K.R.; "Bleaching systems in domestic laundry detergents: A review". *RSC Adv.*; 5: 65365-65384, 2015.
- [14] Arthur, T.; Harjani, J.R.; Phan, L.; Jessop, P.G. and Hodson, P.V.; "Effects-driven chemical design: The acute toxicity of CO<sub>2</sub>-triggered switchable surfactants to rainbow trout can be predicted from octanol-water partition coefficients. *Green Chem.*; 14, 357-362, 2012.
- [15] Obot, I.B.; Solomon, M.M.; Umoren, S.A.; Suleiman, R.; Elanany, M.; Alanazi, N.M. and Sorour, A.A.; "Progress in the development of sour corrosion inhibitors: Past, present, and future perspectives. *J. Ind. Eng. Chem.*; 79, 118, 2019
- [16] Hamed, I.; Osman, M.M.; Abdelraheem, O.H.; Nessim, M.I. and El Mahgary, M.G.; "Inhibition of API 5L X52 Pipeline Steel Corrosion in Acidic Medium by Gemini Surfactants: Electrochemical Evaluation and Computational Study. *Int. J. Corros.*; 2019, 4857181, 2019.
- [17] Brycki, B. and Szulc, A.; "Gemini surfactants as corrosion inhibitors". A review. *J. Mol. Liq.*; 344, 117686, 2021.
- [18] Hegazy, M.A.; Abdallah, M. and Ahmed, H.; "Novel cationic gemini surfactants as corrosion inhibitors for carbon steel pipelines". *Corros. Sci.*; 52, 2897-2904, 2010.
- [19] Migahed, M.A.; Shaban, M.M.; Fadda, A.A.; Ali, T.A. and Negm, N.A.; "Synthesis of some quaternary

- ammonium gemini surfactants and evaluation of their performance as corrosion inhibitors for carbon steel in oil well formation water containing sulfide ions". *RSC Adv.*; 5, 104480-104492, 2015.
- [20] Allah, M.D.; Abdelhamed, S.; Soliman, K.A. and Mona, A.; "The performance of three novel Gemini surfactants as inhibitors for acid steel corrosion: Experimental and theoretical studies". *RSC Adv.*; 11, 37482-37497, 2021.
- [21] Wang, D.; Li, Y.; Chen, B. and Zhang, L.; "Novel surfactants as green corrosion inhibitors for mild steel in 15% HCl: Experimental and theoretical studies". *Chem. Eng. J.*; 402, 126219, 2020.
- [22] Abd El-Lateef, H.M. and Tantawy, A.H.; "Synthesis and evaluation of novel series of Schiff base cationic surfactants as corrosion inhibitors for carbon steel in acidic/chloride media: Experimental and theoretical investigations". *RSC Adv.*; 6, 8681-8700, 2016.
- [23] ASTM G.; "Standard practice for laboratory immersion corrosion testing of metals". West Conshohocken, PA; ASTM, 31-72, 1990.
- [24] Ajmal M.; Mideen A. S. and Quraishi M. A.; "2-hydrazino-6-methyl-benzothiazole as an effective inhibitor for the corrosion of mild steel in acidic solutions". *Corros. Sci.*; 36, 79, 1994.
- [25] Scendo M. and Hepel M.; "Inhibiting properties of benzimidazole films for Cu(II)/Cu(I) reduction in chloride media studied by RDE and EQCN techniques". *Journal of Electroanalytical Chemistry*. 613(1), 35-50, 2008.
- [26] Ullah S.; Azmi M.S.; Nadeem M.; Bustam M.A.; Shahid S.A.; Murshid G.; et al.; "Synergistic Effect of Thiourea and Surfactants on Corrosion Inhibition of Stainless Steel-410 in Presence of Sulfuric Acid". *AMM*; 699: 186-91, 2014.
- [27] Maayta A. K. and Al-Rewashed N. A. F.; "Inhibition of acidic Corrosion of Pure Aluminum by Some Organic Compounds". *Corros. Sci.*; 46, 1129, 2004.
- [28] Chaouiki, A.; Chafiq, M.; Ko, Y.G.; Al-Moubaraki, A.H.; Thari, F.Z.; Salghi, R.; Karrouchi, K.; Bougrin, K.; Ali, I.H. and Lgaz, H.; "Adsorption Mechanism of Eco-Friendly Corrosion Inhibitors for Exceptional Corrosion Protection of Carbon Steel: Electrochemical and First-Principles DFT Evaluations". *Metals*, 12, 1598, 2022.
- [29] Manssouri M.; El Ouadi Y.; Chraka A.; Khaddor M.; Znini M. and Majidi L.; "Aqueous extracts of *Aaronsohnia pubescens* subsp. *pubescens* aerial parts as Green Corrosion Inhibitor for Mild Steel in hydrochloric acid solution". *Journal of the Turkish Chemical Society Section A: Chemistry*. 8(3): 953-968, 2021.
- [30] Bentis F.; Lebrini M. and Lagrenée M.; "Thermodynamic characterization of metal dissolution and inhibitor adsorption processes in mildsteel /2,5-bis(n-thienyl)-1,3,4-thiadiazoles/hydrochloricacid system". *Corros. Sci.*; 47: 2915-2931, 2005.
- [31] Li E. E.; Oguzie Y. and. Wang H.; "Corrosion inhibition and adsorption behavior of methionine on mild steel in sulfuric acid and synergistic effect of iodide ion". *Journal of Colloid and Interface Science*, 310: 90-98, 2007.
- [32] Chen L.; Lu D. and Zhang Y.; "Organic Compounds as Corrosion Inhibitors for Carbon Steel in HCl Solution: A Comprehensive Review". *Materials* 15(2023): 1-59, 2022.