Synthesis and characterization of triazol derivative as new corrosion inhibitor for mild steel in 1M HCl solution complemented with antibacterial studies

Abdulhadi Kadhim¹, Ghassan Sulaiman², Ahmed E. Abdel Moneim², Rahimi M. Yusop³ and Ahmed Al-Amiery⁴

¹ Laser and Optoelectronics Department, University of Technology, Baghdad 10001, Iraq.
² Applied Science Department, University of Technology, Baghdad 10001, Iraq.
³ Department of Zoology and Entomology, Faculty of Science, Helwan University, Cairo, Egypt.
⁴ School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Malaysia.

Abstract: One of the most serious problems in the industry in which mild steel is used is corrosion. Billions of dollars are lost every year due to corrosion problems, especially in industries that use acids, especially hydrochloric acid, where hydrochloric acid has an important role in industrial processes, in refining crude oil, pickling acid, industrial cleaning, acid sizing, and in petrochemical processes. New inhibitor derived from triazole namely “methyl 2-(1-(5-methyl-1-(p-toly)-1H-1,2,3-triazol-4-yl)ethylidene)hydrazinecarbodithioate” (MTH) has been synthesized and fully characterized by Fourier transformer infra-red (FT-IR) and Nuclear Magnetic Resonance (NMR) spectroscopically techniques in addition to CHN analysis. The new compound has been tested as new corrosion inhibitor for mild steel in hydrochloric acid solution. The inhibition performance of new corrosion inhibitor was investigated by weight loss method. Results demonstrate that the corrosion rate (CR) decreased significantly in the presence MTH. On the other hand, the inhibition efficiency, increased with the increase of the concentration of MTH up to 95.1% achieved at 303 K for a 0.5mM concentration. The inhibition efficiency decreases with temperature increase. The antimicrobial activities of MTH for Escherichia coli and Staphylococcus aureus have been investigated. The results revealed that the MTH has satisfactory activities against the tested bacteria. The corrosion of mild steel is one of the most serious problems in the industry. Billions of dollars are lost every year due to the corrosion problems, especially in industries that use acids such as especially hydrochloric acid, where it has an important role in industrial processes, in refining crude oil, pickling acid, industrial cleaning, acid sizing, and in petrochemical processes. New inhibitor derived from triazole namely “methyl 2-(1-(5-methyl-1-(p-toly)-1H-1,2,3-triazol-4-yl) ethylidene) hydrazinecarbodithioate” (MTH) has been synthesized and fully characterized by Fourier Transformer Infra-Red (FT-IR) and Nuclear Magnetic Resonance (NMR) as a spectroscopic technique. In addition to CHN analysis. The new compound has been tested as a new corrosion inhibitor for mild steel in hydrochloric acid solution. The performance of new corrosion inhibitor was studied by weight loss method. The results demonstrates that the corrosion rate (CR) decreased significantly in the presence of an MTH. On the other hand, the inhibition efficiency was increased with the increase in the concentration of MTH up to 95.1% achieved at a temperature of 303 °K for a concentration of 0.5mM. The inhibition efficiency was decreases with increasing temperature. The
antimicrobial activities of MTH for *E. coli* and *S. aureus* have been investigated. The results revealed that the MTH has satisfactory activities against the tested bacteria.

**Keywords:** Corrosion inhibitor, Triazol derivative, Antibacterial

**Introduction**

Plain-carbon steel, also known as mild steel, is now the most common form of steel due to its cheapness, as it possesses important and beneficial properties in petroleum, industrial and medical applications [1]. Moreover, the mild steel having a low resistance to corrosion, especially in acidic and basic solutions, is in itself a challenge for scientists and researchers in the field of corrosion [2]. Cleaning operations using acids, pickling, and descaling, which occur in industries as well as oil and gas exploration and drilling operations, in which acidic environments are widely used, lead to corrosion of iron and steel pipes or surfaces, which were used in these industries and processes [3]. Many inorganic inhibitors that mostly contain phosphates, chromates and other heavy metals were previously used, but because of their toxicity and the difficulties they face in getting rid of them from the soil or from water, especially in the marine industry where they cause danger to aquatic life and life in water bodies in general. These types of inhibitors were restricted or prohibited by different environmental regulations [4]. Synthetic organic inhibitors are widely used, although many are very expensive and toxic. This made the researchers ‘orientation to synthesis of novel environmentally friendly (or non-toxic) corrosion inhibitors as well as being cheap and biodegradable, and thus considered the most important alternative to replace toxic and inorganic inhibitors. It has been reported that some synthesized organic molecules were non-toxic and/or environmentally friendly and can be used as effective corrosion inhibitors [5-7]. For instance, Researchers, [8] were investigated the corrosion inhibition of aluminum alloys by using synergies between coumarins (which are natural products that can be easily synthesized) with iodine salt. Another instance, researchers [9] studied the corrosive inhibiting characteristics of thiadiazoles and the effect of high temperature on mild steel in solutions of hydrochloric acid. Habib et al. [10], in another study, were investigated the effect of temperature on a new synthesized organic compound on the inhibition of corrosion of mild steel in a solution in hydrochloric acid. Al-Amiery et al. [11] were synthesized a new organic compound from curcumin, which was synthesized and the inhibitory potentials at different temperatures were evaluated on the corrosion of mild steel in HCl solutions. In continuation of our previous studies on the synthesis of new anti-corrosion, we present our updated study [12-21] which focuses on assessing the anti-corrosion efficacy of methyl 2-(1-(5-methyl-1-(p-tolyl)-1H-1,2,3-triazol-4-yl)ethylidene)hydrazinecarbodithioate” (MTH) on corrosion of mild steel under different temperatures and inhibitor concentrations. Also, the antibacterial studies were performed on two types of gram-negative bacteria (*Escherichia coli*) and gram-positive bacteria (*Staphylococcus aureus*).

Plain-carbon steel is also known as mild steel. It is now considered as the most common form of steel due to its cheapness, as it possesses important and beneficial properties in petroleum, industrial and medical applications [1]. Moreover, the mild steel having a low resistance to corrosion, especially in acidic and basic solutions. This is represented as a challenge for scientists and researchers in the field of corrosion [2]. Cleaning operations using acids, pickling, and descaling, which occur in industries as well as oil and gas exploration and drilling operations, in which acidic environments are widely used, lead to corrosion of iron and steel pipes or surfaces, which were used in these industries and processes [3]. Many inorganic inhibitors that mostly contain phosphates, chromates and other heavy metals were previously used, but because of their toxicity and the difficulties they face in getting rid of them from the soil or from water, especially in the marine industry where they cause danger to aquatic life and life in water bodies in general. These types of inhibitors where restricted or prohibited by different environmental regulations [4]. Synthetic organic inhibitors are widely used, although many are very expensive and toxic. This made the researchers ‘orientation to the synthesis of novel environmentally friendly (or non-toxic) corrosion inhibitors as well as being cheap and biodegradable, and thus considered the most important alternative to replace toxic and inorganic
1. Experimental

1.1 Synthesis of corrosion inhibitor

Alcoholic solution of 1-(p-toly)-5-methyl-4-acetyl-1,2,3-triazol (10.0 mmol) and hydrazinecarbodithioate (10.0 mmol) was refluxed for 3.0 h. The mixture was cooled, filtered, and crystallized from the ethyl alcohol. The yield was 61% and the melting point was 185-187 °C. Fourier transformer infra-red (FT-IR): 3495.6 cm⁻¹ (amino group), 3059.2 cm⁻¹ (C-H aromatic), 2941.8 cm⁻¹ (C-H aliphatic), 1611 cm⁻¹ (C=N), 1556.1 cm⁻¹ (C=C). Nuclear Magnetic Resonance (NMR) in DMSO-d6: δ = 2.35 ppm (3H, singlet, CH₃ aromatic), 2.48 ppm (3H, singlet, S-CH₃), 2.56 ppm (3H, singlet, allylic CH₃), 3.14 ppm (3H, singlet, triazol-CH₃), 7.41–7.53 ppm (4H, aromatic) and 10.24 ppm (1H, singlet, amine). CHN anal. Calculated (Found). For C₁₂H₁₇N₅S₂: C, 52.64 (53.11); H, 5.36 (5.83); N, 21.92 (22.15).

Alcoholic solution of 1-(p-toly)-5-methyl-4-acetyl-1,2,3-triazol (10.0 mmol) and hydrazinecarbodithioate (10.0 mmol) was refluxed for 3.0 h. The mixture was then cooled, filtered, and crystallized from the ethyl alcohol. The yield and the melting point were 61% and 185-187 °C, respectively. The observed peaks of Fourier transformer infra-red (FT-IR) were recorded at 3495.6 cm⁻¹ (amino group), 3059.2 cm⁻¹ (C-H aromatic), 2941.8 cm⁻¹ (C-H aliphatic), 1611 cm⁻¹ (C=N), 1556.1 cm⁻¹ (C=C). Nuclear Magnetic Resonance (NMR) in DMSO-d6: δ = 2.35 ppm (3H, singlet, CH₃ aromatic), 2.48 ppm (3H, singlet, S-CH₃), 2.56 ppm (3H, singlet, allylic CH₃), 3.14 ppm (3H, singlet, triazol-CH₃), 7.41–7.53 ppm (4H, aromatic) and 10.24 ppm (1H, singlet, amine). CHN anal. Found, %: 53.11; H; 5.83; N; 22.15. C₁₂H₁₇N₅S₂. Calculated, %: C, 52.64; H, 5.36; N, 21.92.

1.1. Materials and solutions

Mild steel coupons of size 4.0×2.5×0.05 cm³ were applied for weight loss measurements. The synthesized corrosion inhibitor was initially examined by weight loss techniques. The mild steel coupons were firstly weighed before exposure to the corrosive solution of 1 N of hydrochloric acid. After immersion time (1, 5, 10 and 24 hour), the mild steel coupons were taken out, washed with double distilled water and acetone then dried and weighed [22, 23]. The weight loss was determined before and after exposure of mild steel coupons to corrosive environments. The methods were repeated for different concentrations (0.1, 0.2, 0.3, 0.4 and 0.5mM) of inhibitor in 1N hydrochloric acid solution. To investigate the temperature, impact the same techniques were performed at various temperature extents 303-333 K [24, 25].

Mild steel coupons of sizes 4.0×2.5×0.05 cm³ were applied to weight loss measurements. The synthesized corrosion inhibitor was initially examined by weight loss techniques. The mild steel coupons were firstly weighed before the exposure to the corrosive solution of 1 N of hydrochloric acid.
acid. After an immersion time (1, 5, 10, and 24 hours), the mild steel coupons were taken out, washed with double distilled water and acetone then dried and finally weighed [22, 23]. The weight loss was determined before and after exposure of mild steel coupons to corrosive environments. The methods were repeated for different concentrations (0.1, 0.2, 0.3, 0.4, and 0.5mM) of inhibitor in 1N hydrochloric acid solution. The same techniques were performed at various temperatures extents of 303-333 K [24, 25].

1.2. Weight loss techniques
This technique represents loss of mild steel coupon weight because of the corrosion is determined by immersion the coupon which calculated its area in acid solution for periods and the variance in weight in absence and in presence the inhibitor is calculated. Initially, the polished coupons were weighted and these coupons were immersed in hydrochloric acid through suspended by hook (glass type). After exposure time, the coupons were taken out, washed with double distilled water and acetone then dried in oven and weighed. The weight lost was calculated in absence and presence the corrosion inhibitor [26, 27]. The methods were repeated for different concentration and various exposure time in 1N hydrochloric acid solution [28,29]. The corrosion rate (CR mmpy), inhibition efficiency (%) and surface coverage (θ) were determined by using equations (1-3).

\[
C_R (\text{mmpy}) = \frac{87.6 \times \text{Weight loss (mg)}}{d_{(g/cm^3)} \times A_{cm^2} \times t_{(h)}}
\]  
(1)

\[
IE(\%) = \frac{W_o - W_{inh}}{W_o} \times 100
\]  
(2)

\[
IE(\%) = \frac{W_o - W_{inh}}{W_o}
\]  
(3)

Where \(W_o\) and \(W_i\) are the weight loss in absence and in presence of corrosion inhibitor.

This technique was determined the loss of mild steel coupon weight in the presence of because of corrosion is determined by immersed the coupon in the acidic solution for periods of time. The variance in weight in the absence and presence of the inhibitor was calculated. Initially, the polished coupons were weighted and these coupons were immersed in hydrochloric acid through suspended by hook (glass type). After a certain exposure time, the coupons were taken out, washed with double distilled water and acetone, then dried in an oven and weighed. The weight loss was calculated in the absence and presence the corrosion inhibitor again [26, 27]. The methods were repeated for different concentrations and various exposure times in 1N hydrochloric acid solution [28,29]. The corrosion rate (CR mmpy), inhibition efficiency (%), and surface coverage (θ) were determined by using equations (1-3).

\[
C_R (\text{mmpy}) = \frac{87.6 \times \text{Weight loss (mg)}}{d_{(g/cm^3)} \times A_{cm^2} \times t_{(h)}}
\]  
(1)

\[
IE(\%) = \frac{W_o - W_{inh}}{W_o} \times 100
\]  
(2)

\[
IE(\%) = \frac{W_o - W_{inh}}{W_o}
\]  
(3)

Where \(W_o\) and \(W_i\) are the weight loss in the absence and presence of corrosion inhibitor.

1.3. Antibacterial Activities
Antimicrobial efficiency of the new synthesized compound namely “methyl 2-(1-(5-methyl-1-(p-tolyl)-1H-1,2,3-triazol-4-yl)ethylidene)hydrazinecarbodithioate” (MTH) have been evaluated for selected bacteria gram-positive which was S. aureus and gram-negative which was E. coli via common method namely disc diffusion method [30,31] utilizing nutrient agar. The incubation for examined organisms in agar medium was carried out for 24 h., at 37 °C. The socked discs (each with 5.0 mm diameter) in the tested environment with the studied concentrations (0.1-0.5 mM) of MTH which was dissolved in sterilized solvent (DMSO) were placed in Petri dishes on a suitable medium previously seeded with studied organisms and stored in an incubator for 24 hours. The inhibitive zone around the examined discs were determined in mm. To evaluated any inhibition activity of DMSO on the tested bacteria, additional tests were carried out utilizing dimethylsulfoxide as control. The dimethylsulfoxide showed no activities toward all types of the tested bacteria.

The antimicrobial efficiency of the new synthesized compound namely “methyl 2-(1-(5-methyl-1-(p-tolyl)-1H-1,2,3-triazol-4-yl)ethylidene)hydrazinecarbodithioate” (MTH) have been evaluated for selected bacteria gram-positive which was S. aureus and gram-negative which was E. coli via common method namely disc diffusion method [30,31] utilizing nutrient agar. The incubation for examining organisms in agar medium was carried out for 24 h., at 37 °C. The socked discs (each with 5.0 mm diameter) in the tested environment with the studied concentrations of (0.1-0.5 mM) was dissolved in sterilized solvent (DMSO), were placed in Petri dishes on a suitable medium previously seeded with studied organisms and stored in an incubator for 24 hours. The inhibitive zone around the examined discs was determined in mm. To evaluate any inhibition activity of DMSO on the tested bacteria, additional tests were carried out utilizing dimethylsulfoxide as a control material. The dimethylsulfoxide showed no activities toward all types of bacteria.

2. Results and Discussion

2.1. Chemistry

MTH was synthesized out by condensation reaction of refluxing methyl hydrazinecarbodithioate with 1-(p-tolyl)-5-methyl-4-acetyl-1,2,3-triazol, in ethanol. The end of the reaction involves the removal of the water molecule and the produce the target compound MTH in 61% yield (Figure 1). The MTH was removed by the condensation reaction process including the refluxing of methyl hydrazinecarbodithioate with 1-(p-tolyl)-5-methyl-4-acetyl-1,2,3-triazol, in ethanol. At the end of the reaction involves the removal of the water molecules and the target compound MTH in 61% yield is its product (Figure 1).

![Figure 1. The reaction synthesis of MTH.](image)

2.2. Weight Loss Tests

The tested steel coupons were evaluated for the corrosion in hydrochloric acid solution after various immersion time (1, 5, 10 and 24 hour) at the temperatures (303, 313, 323 and 333 K). The tested of mild steel coupons were evaluated for the corrosion in hydrochloric acid solution after various immersion times (1, 5, 10, and 24 hours) and at the temperatures of (303, 313, 323, and 333 K).

2.3. Weight Loss-Concentration impact

The tested MTH diminish the corrosion of steel coupons at all studied concentration in hydrochloric acid solutions at 303 K. A Figure of corrosion rate (CR) versus MTH concentrations demonstrates that
the CR reduced gradually with increasing the MTH concentration as displayed in Figure 2. The inhibition activity was increased with increase the MTH concentration inhibitor and 95.1 % was the highest inhibition efficiency which obtained at the highest studied concentration of MTH which was 0.5 mM as displayed in Figure 3. It is observed that MTH retard the corrosion of tested steel coupons at each examined concentration. This can be attributed to the adsorption of MTH molecules on the coupon surface.

![Graph](image_url)

**Figure 2. The corrosion rate at various different MTH concentrations for various exposure time.**

The tested of the MTH was diminished the corrosion of steel coupons at all studied concentrations in hydrochloric acid solutions at 303 °K. The corrosion rate (CR) versus MTH concentrations demonstrates that the CR reduced gradually with an increasing in the MTH concentration as shown in Figure 2. The inhibitory activity was increased with increasing the MTH concentration inhibitor and the highest inhibition efficiency of 95.1 % was obtained at the maximum studied concentration of MTH was 0.5 mM as shown in Figure 3. It was found that the MTH retarded the corrosion of the testing steel coupons at each examined concentration. This can be attributed to the adsorption of MTH molecules on the coupon surface.
2.4. Weight Loss-Temperature impact

The inhibitive performance of MTH molecules at the temperatures (303, 313, 323 and 333k) are exhibit in Figure 4. The findings demonstrated that the MTH has the ability to diminish the corrosion rate of the tested steel samples in HCl environments. The inhibitive activity was seen to increase when increasing the concentration as displayed in Figure 4. At highest examined Temperature the inhibitive performance was decreased even the concentration of studied inhibitor was increased as displayed in Figure 4. This might be due to the desorption of MTH molecules from the coupon steel surface.

The inhibiting performance of MTH molecules at the temperatures of (303, 313, 323, and 333k) are exhibited as shown in Figure 4. This findings demonstrates that the MTH has the ability to diminish the corrosion rate of the tested steel samples in HCl environments. The inhibiting activity was observed to increase when the concentration increased as displayed in Figure 4. At highest examined Temperature the inhibiting performance was decreased even when the concentration of the studied inhibitor was increased as displayed in Figure 4. This might be due to the desorption of MTH molecules from the coupon steel surface.
2.5. The antimicrobial activities

The antibacterial testing data show that the MTH has antibacterial properties in addition to additional inhibitive effectiveness than the parent 1-(5-methyl-1-(p-tolyl)-1H-1,2,3-triazol-4-yl)ethenone or methyl hydrazinecarbodithioate. The highest inhibitive performance of MTH molecules attributed to the existence of imine(C=N) group [32]. It is known that imine group has the tendency to increase the ability of the MTH molecules to be very active toward studied bacteria and MTH molecules become bactericidal agent, so killing additional bacteria than the parent compounds, which form the MTH. In MTH molecules, the partial (+ve) charge is shared partially with the pi- bonds present in the MTH molecules, and there may be delocalization of pi-electrons over the whole MTH molecules [33,34]. This would increase the lipophilicity of the MTH molecules and favors its permeation through the lipoid layer of the membrane of the tested bacteria. The lipophilicity which increased seems to be responsible for increasing the activities to killing bacteria. It might be suggested that MTH molecules have the capabilities to inactivate various cellular enzymes, that play a vital role in various pathways of metabolic of the studied bacteria. As seen from Figure 5, synthesized MTH molecules demonstrated inhibitive performances toward E. coli was less than the inhibition performance toward Staphylococcus aureus.

The anti-bacterial testing data show that the MTH has antibacterial performance in addition to the additional inhibitive effectiveness than the parent 1-(5-methyl-1-(p-tolyl)-1H-1,2,3-triazol-4-yl)ethenone or methyl hydrazinecarbodithioate. The highest inhibitive performance of MTH molecules attributed to the existence of imine(C=N) group [32]. It is known that imine group has the tendency to increase the ability of the MTH molecules to be activated toward the studied bacteria and the MTH molecules become bactericidal agent, so killing additional bacteria than the parent compounds, which form the MTH. In MTH molecules, the partial (+ve) charge is shared partially with the pi- bonds present in the MTH molecules, and it may be delocalization of pi-electrons over the whole MTH molecules [33,34]. This would increase the lipophilicity of the MTH molecules and favors its permeation through the lipoid layer of the membrane of the tested bacteria. The increasing of lipophilicity seems to be responsible for increasing the activities to killing bacteria. It might be suggested that MTH molecules have the capabilities to inactivate various cellular enzymes that play a

Figure 4. Inhibition efficiency at different MTH concentrations for various Temperature Figure 4. Inhibition efficiency versus temperature, at different MTH concentrations.
vital role in various pathways of metabolic of the studied bacteria. As seen in Figure 5, synthesized MTH molecules demonstrated inhibitive performance toward *E. coli* was less than the inhibition performance toward *Staphylococcus aureus*.

**Figure 5.** The effect of MTH toward studying bacteria.

**Conclusions**

In this work, methyl 2-(1-(5-methyl-1-(p-tolyl)-1H-1,2,3-triazol-4-yl)ethylidene)hydrazine carbodithioate” (MTH) has been successfully synthesized and characterized by various spectroscopical methods and CHN-elemental analysis. The MTH was investigated for corrosive inhibitive effect and antibacterial efficiencies. MTH molecules indicated considerable corrosion inhibitive characteristics and significant antimicrobial efficiency.

**Acknowledgement**

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

**Conflict of interest**

The authors declare that there is no conflict of interest

**References**

[1] Singh D. K., Kumar S., Udayabhanu G., and John R. P. 2016 4(N,N-dimethylanilo) benzaldehyde nicotinic hydrazine as corrosion inhibitor for mild steel in 1M HCl solution: An experimental and theoretical study *Journal of Molecular Liquids* 216 738–746.

[2] Alaneme K. K., Olusegun S. J., and Adelowo O. T. 2016 Corrosion inhibition and adsorption mechanism studies of Hunteria umbellata seed husk extracts on mild steel immersed in acidic solutions *Alexandria Engineering Journal* 55 1 673–681.

[3] Fiori-Bimbi M. V., Alvarez P. E., Vaca H., and. Gervasi C. A 2015 Corrosion inhibition of mild steel in HCL solution by pectin *Corrosion Science* 92 192–199.
[4] Roy P., Karfa P., Adhikari U., and Sukul D. 2014 Corrosion inhibition of mild steel in acidic medium by polyacrylamide grafted Guar gum with various grafting percentage: effect of intramolecular synergism Corrosion Science 88 246–253.

[5] Zinad D.S., M. Hanoon, R.D. Salim, S.I. Ibrahim, A.A. Al-Amiery, M.S. Takriff and A.A.H. Kadhum 2020 A new synthesized coumarin-derived Schiff base as a corrosion inhibitor of mild steel surface in HCl medium: gravimetric and DFT studies Int. J. Corros. Scale Inhib. 9, no. 1, 228-243. doi: 10.17675/2305-6894-2020-9-1-14

[6] Jamil D.M., Al-Okbi A.K., Al-Baghdadi S.B., Al-Amiery A.A., Kadhim A. and Gaaz T.S. 2018 Experimental and theoretical studies of Schiff bases as corrosion inhibitors Chem. Cent. J. 12 1–7. doi: 10.1186/s13065-018-0376-7.

[7] Al-Amiery A., Salman T. A., Alazawi K. F., Shaker L. M., Kadhum A. H. and M. S. Takriff. 2020 Quantum chemical elucidation on corrosion inhibition efficiency of Schiff base: DFT investigations supported by weight loss and SEM techniques. International Journal of Low-Carbon Technologies 15 202–209.

[8] Mohamad A., Kadhum A., Al-Amiery A., Ying L. and Musa A 2014 Synergistic of a coumarin derivative with potassium iodide on the corrosion inhibition of aluminum alloy in 1.0 M H2SO4 Met. Mater. Int. 20 459–467. doi: 10.1007/s12540-014- 3008-3.

[9] Salman T.A., Zinad D.S., Jaber S.H., Al-Ghezi M., Mahal A., Takriff M.S. and Al-Amiery A.A. 2019 Effect of 1,3,4 Thiadiazole Scafold on the Corrosion Inhibition of Mild Steel in Acidic Medium: An Experimental and Computational Study J. BioTri-Bo-Corrosion 5 1–11. doi: 10.1007/s40735-019-0243-7

[10] Habeeb H.J., Luaibi H.M., Dakhil R.M., Kadhum A.A.H., Al-Amiery A.A. and Gaaz T.S. 2018 Development of new corrosion inhibitor tested on mild steel supported by electrochemical study Results Phys. 8 1260–1267. doi: 10.1016/j.rinp.2018.02.015.

[11] Al-Amiery A., Kadhum A., Mohamad A., Musa A. and Li C. 2013 Electrochemical study on newly synthesized chlorocurcumin as an inhibitor for mild steel corrosion in hydrochloric acid Materials 6 5466–5477. doi: 10.3390/ma6125466

[12] Junaedi S., Kadhum A., Al-Amiery A., Mohamad A. and Takriff M. 2012 Synthesis and characterization of novel corrosion inhibitor derived from oleic acid: 2-Amino5-Oleyl1,3,4-Thiadiazol (AOT) Int. J. Electrochem Sci. 7 3543–3554.

[13] Kadhim A., Al-Okbi A., Jamil D.M., Quassay A., Al-Amiery A.A., Gaaz T.S., Kadhum A.A.H., Mohamad A.B. and Nassir M.H. 2017 Experimental and theoretical studies of benzoazines corrosion inhibitors Results Phys. 7 4013–4019. doi: 10.1016/j.rinp.2017.10.027.

[14] Salman T. A., Jawad Q.A., Hussain M. A., Al-Amiery A., Shaker L., Kadhum A. and Takriff, M.S. 2019 Novel ecofriendly corrosion inhibition of mild steel in strong acid environment: Adsorption studies and thermal effects Int. J. Corros. Scale Inhib. 8 4 1123-1137. doi: 10.17675/2305-6894-2019-8-4-19.

[15] Al-Taweel S.S., Al-Janabi K.W.S., Luaibi H.M., Al-Amiery A.A. and Gaaz T.S. 2019 Evaluation and characterization of the symbiotic effect of benzyliden derivative with titanium dioxide nanoparticles on the inhibition of the chemical corrosion of mild steel Int. J. Corros. Scale Inhib. 8 4 1149-1169. doi: 10.17675/2305-6894-2019-8-4-21

[16] Zinad D.S., Jawad Q.A., Hussain M.A.M., Mahal A., Mohamed L. and Al-Amiery A.A. 2020 Adsorption, temperature and corrosion inhibition studies of a coumarin
derivatives corrosion inhibitor for mild steel in acidic medium: gravimetric and theoretical investigations Int. J. Corros. Scale Inhib. 9 1 134–151. doi: 10.17675/2305-6894-2020-9-1-8

[17] Al-Obaidy A.H.M.J., Kadhum A., Al-Baghdadi S.B., Al-Amiery A., Kadhum A.A.H., Mohamad A.B. and Yousif E. 2015 Eco-friendly corrosion inhibitor: experimental studies on the corrosion inhibition performance of creatinine for mild steel in HCl complemented with quantum chemical calculations Int. J. Electrochem Sci. 103 961–3972.

[18] Al-Amiery A.A., Kadhum A.A.H., Mohamad A.B. and Junaedi 2013 S. A Novel Hydrazinecarbothioamide as a Potential Corrosion Inhibitor for Mild Steel in HCl , Materials 6 1420–1431. doi: 10.3390/ma6041420.

[19] Ahmed M.H.O., Al-Amiery A.A., Al-Majedy Y.K., Kadhum A.A.H., Mohamad A.B. and Gaaz, T.S. 2018 Synthesis and characterization of a novel organic corrosion inhibitor for mild steel in 1 M hydrochloric acid Results Phys. 8 728–733. doi: 10.1016/j.rinp.2017.12.039.

[20] Salman T., Al-Amiery A., Shaker A. L., A. Kadhum, and Takriff. M. 2019 A study on the inhibition of mild steel corrosion in hydrochloric acid environment by 4-methyl-2-(pyridin-3-yl)thiazole-5-carbohydrazide Int. J. Corros. Scale Inhib. 8 4 1035-1059. doi: 10.17675/2305-6894-2019-8-4-14

[21] Al-Amiery A.A., Al-Majedy Y.K., Kadhum A.A.H. and Mohamad A.B. 2015 New Coumarin Derivative as an Eco-Friendly Inhibitor of Corrosion of Mild Steel in Acid Medium Molecules 20 366–383. doi: 10.3390/molecules20010366.

[22] Rubaye A.Y.I., Abdulwahid A.A., Al-Baghdadi S.B., Al-Amiery A., Kadhum A.A.H. and Mohamad A.B. 2015 Cheery sticks plant extract as a green corrosion inhibitor complemented with LC-EIS/MS spectroscopy Int. J. Electrochem Sci. 10 8200–8209.

[23] Kadhum, A, Mohamad, A, Hammid, Kadhum A.A.H., Mohamad A.B., Hammid L.A., Al-Amiery A.A., San N.H. and Musa A.Y. 2014 Inhibition of Mild Steel Corrosion in Hydrochloric Acid Solution by New Coumarin Materials 7 4335–4348. doi: 10.3390/ma7064335.

[24] Jawad Q. A., Zinad D. S, Salim R. D., Al-Amiery A. A., Gaaz T. S., Takriff M. S. and Kadhum A. 2019 Synthesis, Characterization, and Corrosion Inhibition Potential of Novel Thiosemicarbazone on Mild Steel in Sulfuric Acid Environment Coatings 9(11), 729. https://doi.org/10.3390/coatings9110729.

[25] Yousif E., Win Y., Al-Hamadani A., Al-Amiery A., Kadhum A. and Mohamad A. 2015 Furosemi as an environmental-friendly inhibitor of corrosion of zinc metal in acid medium experimental and theoretical studies Int. J. Electrochem Sci. 10 1708–1718.

[26] Yamin J.A.A., Ali Eh Sheet E. and Al-Amiery A. 2020 Statistical analysis and optimization of the corrosion inhibition efficiency of a locally made corrosion inhibitor under different operating variables using RSM Int. J. Corros. Scale Inhib. 9 2 502-518. doi: 10.17675/2305-6894-2020-9-2-6

[27] Salim R.D., Jawad Q.A., Ridah K.S., Shaker L.M., Al-Amiery A.A., Kadhum A.A.H and Takriff M.S. 2020 Corrosion inhibition of thiadiazole derivative for mild steel in hydrochloric acid solution Int. J. Corros. Scale Inhib. 9 2 550-561. doi: 10.17675/2305-6894-2020-9-2-10

[28] Al-Amiery A.A., Shaker L.M., Kadhum A.A.H., Takriff M.S. 2020 Corrosion Inhibition of Mild Steel in Strong Acid Environment by 4-((5,5-dimethyl-3-oxocyclohex-1-en-1-yl)amino)benzenesulfonamide Tribol. Indu. 42 1 89-101. doi: 10.24874/it.2020.42.01.09.

[29] Al-Amiery A., Shaker L. M., Kadhum A. H. and Takriff M. S. 2020 Synthesis, characterization and gravimetric studies of novel triazole-based compound. International Journal of Low-Carbon Technologies 15 164–170.

[30] Kadhum A. H., Mohamad A., Al-Amiery A., and Takriff M. S. 2011 Antimicrobial and Antioxidant Activities of New Metal Complexes Derived from 3-Aminocoumarin Molecules 16 8 6969-6984, https://doi.org/10.3390/molecules16086969
[31] Al-Amiery A.A., Al-Majedy K., Abdulhadi S.A. 2009 Design, synthesis and bioassay of novel metal complexes of 3-amino-2-methylquinazolin-4(3H)-one Afr. J. Pure Appl. Chem. 3 218–227.

[32] Al-Amiery A.A., Al-Majedy K., Abdulreazak H., Abood H. 2011 Synthesis characterization, theoretical crystal structure and antibacterial activities of some transition metal complexes of the thiosemicarbazone (Z)-2-(pyrrolidin-2-ylidene)hydrazinecarbothioamide. Bioinorg. Chem. Appl. 2011 1-6.

[33] Al-Majedy, K., Al-Amiery, A.A., Almoussaoy, H.H. and Khweter, R. 2011 Novel analytical method for the determination of theophylline in pharmaceutical preparations J. Appl. Sci. Res. 7 470–475.

[34] Al-Amiery, A. A., Al-Temimi, A. A., Sulaiman, G. M., Aday, H. A., Kadhum, A. A. H. and Mohamad, A. B. 2013. Synthesis, antimicrobial and antioxidant activities of 5-((2-oxo-2H-chromen-7-yloxy) methyl)-1, 3, 4-thiadiazol-2 (3H)-one derived from umbelliferone Chem. Nat. Comp. 48 950-954.