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# Investigation of the Corrosion Inhibition Performance of a Benzothiazole-Based Schiff Base in Acidic Medium


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**Abstract:**

The present study focuses on the synthesis and comprehensive evaluation of a newly synthesized benzothiazole-based Schiff base compound as a potential corrosion inhibitor in acidic medium. The increasing deterioration of metallic materials in acidic environments poses significant challenges in industrial processes, particularly during acid pickling, cleaning, descaling, and oil and gas operations. Therefore, the development of efficient and environmentally acceptable corrosion inhibitors is of considerable importance. In the present investigation, the synthesized benzothiazole Schiff base was evaluated for its ability to protect metal surfaces against corrosion under acidic conditions. A systematic experimental approach was employed to investigate the corrosion inhibition performance of the synthesized compound. Electrochemical techniques were utilized to examine the influence of the inhibitor on the electrochemical corrosion behaviour of the metal substrate, while surface characterization techniques were employed to assess changes in surface morphology and the protective nature of the inhibitor film. The inhibition efficiency was studied as a function of inhibitor concentration and experimental conditions to understand the interaction between the inhibitor molecules and the metal surface. The results indicate that the benzothiazole Schiff base possesses significant corrosion inhibition potential, which can be attributed to the presence of heteroatoms and functional groups capable of interacting with the metal surface through adsorption. The formation of a protective adsorbed layer effectively reduces the interaction of the corrosive medium with the metal surface and consequently suppresses the corrosion process. The findings demonstrate that the synthesized benzothiazole Schiff base can serve as a promising candidate for corrosion protection in acidic environments. The study also provides useful insights into the relationship between the molecular structure of benzothiazole-based Schiff bases and their corrosion inhibition behaviour, thereby contributing to the development of efficient organic corrosion inhibitors for practical applications.



**Keywords:** Benzothiazole, Schiff Base, Corrosion, Corrosion Inhibitor, Acidic Medium, Metal Protection, Adsorption, Electrochemical Studies.


## Introduction

Corrosion is a natural physicochemical process in which a material, particularly a metal, undergoes gradual deterioration due to its interaction with the surrounding environment. In metals, corrosion is generally electrochemical in nature and involves oxidation and reduction reactions. Non-metallic materials such as plastics and ceramics may also degrade, but through different chemical or physicochemical mechanisms.

The control of metal corrosion has become increasingly important due to the growing use of metals in modern industries, the use of expensive metals in specialized applications, increasing environmental pollution, and the development of lightweight and thinner metallic structures. Corrosion not only reduces the service life of materials but also causes significant economic losses through equipment failure, maintenance costs, product contamination, reduced efficiency, and industrial shutdowns. It may also create serious environmental and safety hazards.

**Effects and Types of Corrosion**

Corrosion can occur in several forms depending on the material and environmental conditions. The major types include:

**1. Uniform Corrosion:** It occurs relatively evenly over the metal surface, such as the rusting of iron in the presence of moisture and oxygen.

**2. Galvanic Corrosion:** It occurs when two dissimilar metals are electrically connected in the presence of an electrolyte, resulting in accelerated corrosion of the more active metal.

**3. Crevice Corrosion:** It is a localized form of corrosion commonly found in narrow gaps, beneath gaskets, fasteners, deposits, and overlapping surfaces.

**4. Filiform Corrosion:** It appears as thread-like or filament-like corrosion beneath protective coatings, particularly under humid conditions.

**5. Erosion-Corrosion:** It results from the combined action of chemical corrosion and mechanical erosion caused by the movement of fluids or suspended particles over a metal surface.

**6. Hydrogen Embrittlement:** It occurs when hydrogen enters a metal and reduces its ductility and strength, which may ultimately lead to cracking and sudden failure.

Because of the serious effects of corrosion, the development of effective corrosion prevention methods is essential. Among various techniques, organic corrosion inhibitors have received considerable attention because they can adsorb onto metal surfaces and form protective films. Compounds containing heteroatoms such as nitrogen, oxygen, and sulfur, along with aromatic and conjugated systems, are particularly promising. Benzothiazole-based Schiff bases are therefore of significant interest as potential corrosion inhibitors, especially for protecting metals in acidic environments.

**Experimental Investigation and Corrosion Inhibition Studies**

The synthesized benzothiazole derivative, 2-[(1,3-benzothiazol-2-yl) amino]-N-(2,4,6-trifluorophenyl) acetamide, was investigated as a potential organic corrosion inhibitor for different metallic substrates in acidic medium. The molecular structure of the investigated inhibitor compound is presented in Fig. 1.

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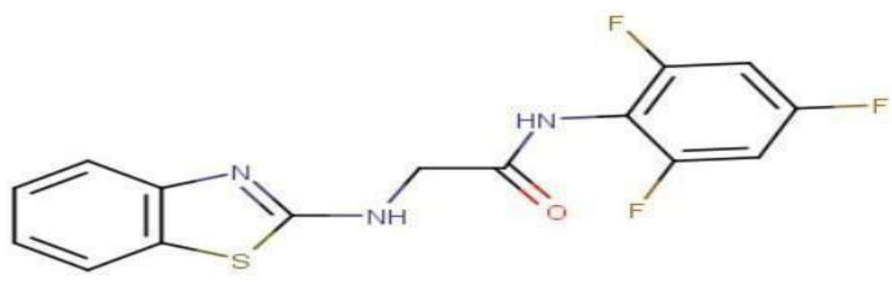

2-[(1,3-benzothiazol-2-yl)amino]-N-(2,4,6-trifluorophenyl)acetamide

**Fig. 1 – Structure of Inhibitor Compound**

The corrosion inhibition performance of the synthesized compound was evaluated using complementary experimental techniques, namely thermometric analysis, electrochemical impedance spectroscopy (EIS), potentiodynamic polarization (PDP), and scanning electron microscopy (SEM). These techniques provide information regarding the change in corrosion rate, charge-transfer resistance, electrochemical corrosion behaviour, and surface morphology of the metallic specimens in the absence and presence of the inhibitor.

**1. Thermometric Method**

The thermometric method was employed to evaluate the influence of the synthesized compound on the corrosion rate of the selected metal specimens. In this method, the heat evolved during the corrosion reaction was monitored as a function of time. A metal specimen was introduced into a reaction vessel containing 100 mL of the acidic test solution, initially maintained at 25 ± 0.1 °C. The temperature change of the reaction mixture was continuously monitored using a thermometer having an accuracy of 0.01 K. The initial temperature and the maximum temperature attained during the reaction were recorded.

The reaction number (RN), which represents the rate of temperature increase during the corrosion process, was calculated using:

$$RN=(T_m-T_0)/t$$

Where - $T_m$ is the maximum temperature recorded, $T_0$ is the initial temperature, and t is the time required to attain the maximum temperature.

The inhibition efficiency was calculated from the reaction numbers obtained in the uninhibited and inhibited solutions using:

$$\eta = [(RN_{free} - RN_i) / RN_{free}]*100$$

Where $RN_{free}$ represents the reaction number in the absence of the inhibitor and ($RN_i$) represents the reaction number in the presence of the inhibitor.

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**Table 1. Thermometric Analysis of Corrosion Inhibition**

| Metal specimen | Condition | RN (°C min⁻¹) | IE (%) |
|---|---|---|---|
| **Milled steel** | Uninhibited | 24.42 | — |
| **Milled steel** | Inhibitor | 7.53 | 69.16 |
| **Aluminium** | Uninhibited | 31.53 | — |
| **Aluminium** | Inhibitor | 11.53 | 63.43 |
| **Zinc** | Uninhibited | 34.53 | — |
| **Zinc** | Inhibitor | 10.45 | 69.74 |

The thermometric results demonstrate a considerable decrease in the reaction number in the presence of the benzothiazole inhibitor. The inhibition efficiencies were found to be 69.16% for milled steel, 63.43% for aluminium, and 69.74% for zinc. The decrease in RN indicates that the inhibitor effectively suppresses the corrosion reaction by interacting with the metal surface and reducing its exposure to the acidic environment.

**2. Electrochemical Impedance Spectroscopy (EIS)**

Electrochemical impedance spectroscopy was used to investigate the electrochemical behaviour of the metal/electrolyte interface and to determine the effectiveness of the inhibitor in reducing the corrosion process. The measurements were performed using an electrochemical cell connected to an Autolab potentiostat/galvanostat. The metal specimen was immersed in the acidic solution, and impedance measurements were recorded after allowing the system to attain a stable open-circuit potential.

EIS measurements were carried out over an appropriate range of frequencies, and the charge-transfer resistance $R_t$ was obtained from the impedance response. An increase in $R_t$ in the presence of the inhibitor indicates the formation of a protective layer on the metal surface and a corresponding decrease in the rate of electrochemical corrosion.

The inhibition efficiency based on charge-transfer resistance was calculated using:

$$ERT\,\% = 100*(Rt-Rt_0)/Rt$$

where (Rt) and ($Rt_0$) represent the charge-transfer resistance values in the inhibited and uninhibited solutions, respectively.

**Table 2. EIS Parameters for the Investigated Metal Specimens**

| Metal specimen | Condition | (Rt) (Ω cm²) | $ER_t$ (%) |
|---|---|---|---|
| **Milled steel** | Uninhibited | 6.34 | — |
| **Milled steel** | Inhibitor | 22.34 | 71.62 |
| **Aluminium** | Uninhibited | 8.65 | — |
| **Aluminium** | Inhibitor | 23.34 | 62.94 |
| **Zinc** | Uninhibited | 7.24 | — |
| **Zinc** | Inhibitor | 24.45 | 70.39 |

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The EIS results clearly demonstrate an increase in charge-transfer resistance after the addition of the synthesized inhibitor. The inhibition efficiencies were approximately 71.62% for milled steel, 62.94% for aluminium, and 70.39% for zinc. The increased (Rt) values suggest that the inhibitor molecules are adsorbed onto the metal surfaces, thereby increasing the resistance to charge transfer and decreasing the corrosion rate.

**3. Potentiodynamic Polarization (PDP) Method**

Potentiodynamic polarization measurements were performed using a conventional three-electrode electrochemical cell connected to an Autolab potentiostat. The working electrode consisted of the metal specimen, while suitable reference and counter electrodes were used to complete the electrochemical cell. The metal samples were mounted appropriately in resin, leaving a defined surface area exposed to the acidic test solution.

After immersion and stabilization of the working electrode, polarization curves were recorded by scanning the electrode potential at a rate of approximately 0.0066 V $s^{-1}$ over the selected potential range of −1.5 to +1.5 V. The corrosion current density $I_{corr}$ was determined from the polarization curves.

The inhibition efficiency was calculated from the corrosion current densities obtained in the absence and presence of the inhibitor:

$$IE\%=(I_{corr} - I^{1}_{corr}/I_{corr}) *100$$

where $I_{corr}$ is the corrosion current density in the uninhibited solution and $I_{corr}^{inh}$ is the corrosion current density in the presence of the inhibitor.

**Table 3. Potentiodynamic Polarization Results**

| Metal specimen | Condition | $I_{corr}$ (A cm⁻²) | IE (%) |
|---|---|---|---|
| **Milled steel** | Uninhibited | 0.5433 | — |
| **Milled steel** | Inhibitor | 0.1832 | 66.28 |
| **Aluminium** | Uninhibited | 0.4532 | — |
| **Aluminium** | Inhibitor | 0.1722 | 62.00 |
| **Zinc** | Uninhibited | 0.5323 | — |
| **Zinc** | Inhibitor | 0.1634 | 69.30 |

A significant decrease in corrosion current density was observed for all three metals after the addition of the inhibitor. The calculated inhibition efficiencies were 66.28% for milled steel, 62.00% for aluminium, and 69.30% for zinc. The reduction in (I_{corr}) confirms the ability of

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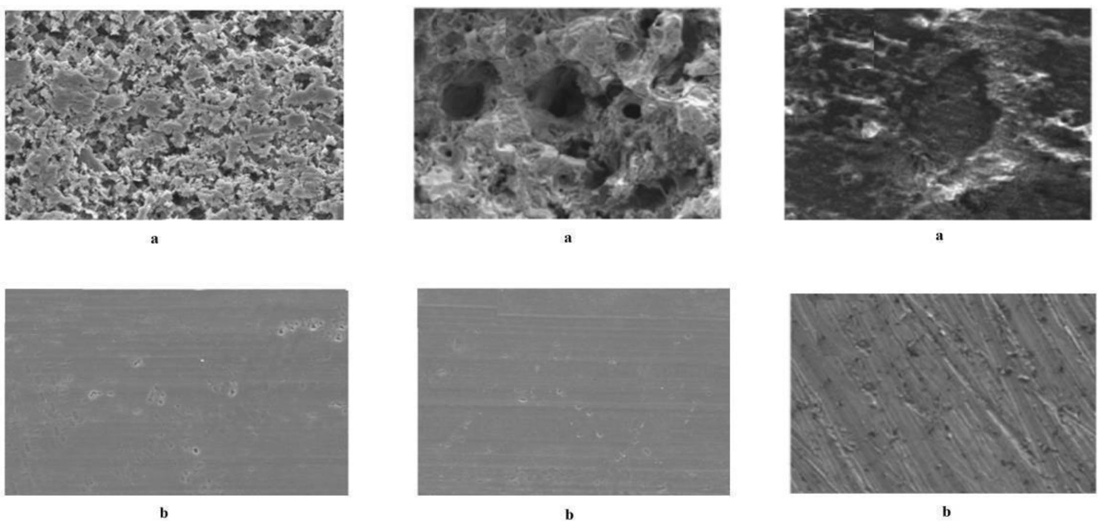
the synthesized compound to suppress the electrochemical corrosion reactions occurring at the metal/electrolyte interface.

**4. Scanning Electron Microscopy (SEM) Analysis**

Scanning electron microscopy was employed to examine the morphological changes occurring on the metal surfaces before and after exposure to the acidic medium. SEM analysis provides direct visual evidence of the extent of surface deterioration and the protective effect of the inhibitor.

**Fig. 2: SEM Micrographs of Metal Surfaces in the Absence and Presence of the Inhibitor**




Milled Steel Specimen (a) without inhibitor (b) with inhibitor | Al Specimen (a) without inhibitor (b) with inhibitor | Zn Specimen (a) without inhibitor (b) with inhibitor

The surface morphology of the metal specimens was examined under both uninhibited and inhibited conditions. In the absence of the inhibitor, the metal surfaces exhibited comparatively greater damage, roughness, and corrosion related surface irregularities due to their direct interaction with the acidic medium. In contrast, the specimens exposed to the inhibitor showed a comparatively smoother and more homogeneous surface. The comparatively smooth surface observed in the inhibited samples suggests the formation of a protective layer of adsorbed inhibitor molecules. This protective layer acts as a barrier between the metal surface and the aggressive acidic species, thereby reducing the rate of metal dissolution and surface degradation.

**Conclusion**

The comprehensive investigation carried out using different analytical and electrochemical techniques demonstrates the significant corrosion inhibition potential of the synthesized benzothiazole-based compound, 2-[(1,3-benzothiazol-2-yl) amino]-N-(2,4,6-trifluorophenyl) acetamide, for different metallic substrates in acidic medium. The results obtained from thermometric analysis, electrochemical impedance spectroscopy (EIS), potentiodynamic polarization, and SEM analysis provide consistent evidence of its protective action.

Thermometric analysis revealed a considerable decrease in the reaction rate in the presence of the inhibitor. The inhibition efficiencies were found to be 69.16% for milled steel, 63.43% for aluminium, and 69.74% for zinc. The significant reduction in reaction number indicates that the synthesized compound effectively suppresses the corrosion reaction and reduces the interaction between the metal surface and the acidic environment.

The EIS results further confirmed the effectiveness of the inhibitor. A considerable increase in charge-transfer resistance was observed in the presence of the synthesized compound, with inhibition efficiencies of 71.62% for milled steel, 62.94% for aluminium, and 70.39% for zinc. The increase in charge-transfer resistance suggests the formation of a protective layer on the metal surface, which hinders the transfer of charge and consequently decreases the corrosion rate.

The potentiodynamic polarization studies showed a significant reduction in corrosion current density after the addition of the inhibitor. The inhibition efficiencies obtained were 66.28% for milled steel, 62.00% for aluminium, and 69.30% for zinc. These results indicate that the synthesized compound effectively interferes with the electrochemical reactions responsible for corrosion and provides appreciable protection to the investigated metals.

SEM analysis provided additional evidence for the protective ability of the inhibitor. The uninhibited metal specimens exhibited comparatively rough and damaged surfaces as a result of their exposure to the acidic medium, whereas the inhibited specimens showed relatively smoother and less deteriorated surfaces. This difference in surface morphology indicates the formation of an adsorbed protective film by the inhibitor molecules.

The corrosion inhibition behaviour of the synthesized compound can be attributed to its adsorption onto the metal surface. The presence of nitrogen-containing groups, heteroatoms, aromatic rings, and electron-rich sites in the benzothiazole-based molecular structure provides suitable active centres for interaction with the metal surface. The resulting adsorbed layer acts as a barrier, reducing the penetration of aggressive species and limiting the anodic and cathodic corrosion reactions.

Overall, the results obtained from the different experimental techniques are in good agreement and demonstrate that the synthesized benzothiazole compound possesses considerable corrosion inhibition efficiency toward milled steel, aluminium, and zinc in acidic medium. The relatively high inhibition efficiencies observed by all the methods establish the compound as a promising organic corrosion inhibitor. Further studies involving concentration, temperature, adsorption isotherms, thermodynamic parameters, and long-term stability may provide additional information regarding its inhibition mechanism and practical applications.

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