Thiosemicarbazide and its derivatives as promising corrosion inhibitors: A Mini-Review

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Abstract

Thiosemicarbazide is a promising corrosion inhibitor due to its excellent inhibitive properties, low toxicity, and cost-effectiveness. This mini-review highlights the chemical structure, properties, and corrosion inhibition mechanism of thiosemicarbazide. Various experimental studies have been carried out to investigate the corrosion inhibition performance of thiosemicarbazide on different metal surfaces, such as carbon steel, aluminum, and copper, in different corrosive environments, including acidic, alkaline, and saline solutions. The review also discusses the effect of different parameters, such as concentration, immersion time, temperature, and pH, on the corrosion inhibition efficiency of thiosemicarbazide. Overall, the results show that thiosemicarbazide is a highly effective corrosion inhibitor, and its inhibition performance is comparable to other well-known inhibitors. Finally, the review concludes by highlighting the future research directions in the field of thiosemicarbazide-based corrosion inhibitors.

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1. Introduction

Corrosion is a significant issue in many industrial applications and can lead to severe damage and economic losses (Figure 1). Corrosion inhibitors have been extensively used to mitigate corrosion in various environments. Among these inhibitors, thiosemicarbazide has recently received considerable attention due to its excellent inhibiting properties. Thiosemicarbazide is a nitrogen-sulfur compound that has been studied as a potential inhibitor for various metals, including iron, aluminum, copper, and zinc [1–5]. The use of thiosemicarbazide as a corrosion inhibitor has gained interest due to its low toxicity, high stability, and compatibility with other inhibitors. Thiosemicarbazide has also shown excellent inhibitory properties in both acidic and alkaline solutions. In addition, thiosemicarbazide can act as a mixed-type inhibitor, inhibiting both the anodic and cathodic reactions of the metal [6–10]. The mechanisms of corrosion inhibition and the factors affecting the inhibitory properties of thiosemicarbazide will also be discussed [11–15]. This mini-review aims to summarize recent developments in the use of thiosemicarbazide as a corrosion inhibitor. It will discuss the inhibitory properties of thiosemicarbazide on various metals, including iron, aluminum, copper, and zinc, in different environments, including acidic and alkaline solutions.

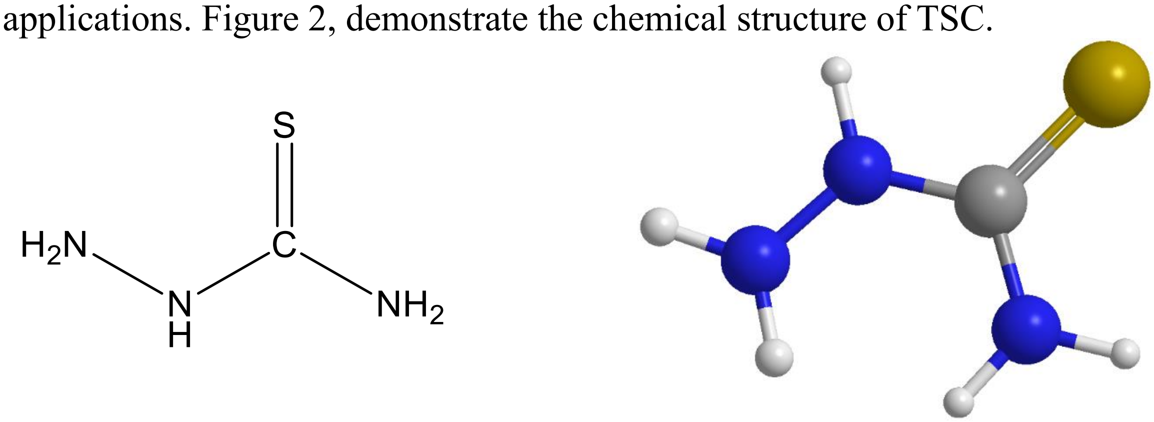
Figure 1. Corrosion of metal.

Several studies have shown that TSC is an effective corrosion inhibitor for various metals and alloys. For instance, Poornima and colleagues investigated the corrosion inhibition properties of 4-(N,N-diethylamino)benzaldehyde thiosemicarbazone (DEABT) on the corrosion of aged 18 Ni 250 grade maraging steel in phosphoric acid solution. The results showed that DEABT exhibited a maximum inhibition efficiency of 95.13% at a concentration of 1.2 mM. The addition of DEABT reduces the corrosion of aged maraging steel in 0.67 M phosphoric acid. The inhibitor's effectiveness increases with concentration and decreases with temperature. DEABT acts as a mixed inhibitor, affecting both anodic and cathodic reaction rates. The energy of activation increases in the presence of DEABT, and its adsorption on the steel surface follows Langmuir's adsorption isotherm model [16]. Similarly, Badr studied the corrosion inhibition by TSCs (1-ethyl-4(2,4-dinitrophenyl)thiosemicarbazide (I), 1,4-diphenylthiosemicarbazide (II), 1-ethyl-4-phenylthiosemicarbazide (III)) on carbon steel in a 2 M HCl solution using various techniques. Potentiodynamic polarization and electrochemical impedance spectroscopy were used, and results showed that the inhibitors act as mixed-type inhibitors. The inhibition efficiency increased with the inhibitor concentration, and the adsorption of the compounds followed Temkin's adsorption isotherm. The study concludes that the investigated thiosemicarbazide derivatives have inhibiting properties for carbon steel in 2 M HCl, and the %*IE* at all concentrations followed the order: I (75%) > II (73%) > III (70%). The %*IE* obtained from weight loss, polarization, and ac impedance are in good agreement [17]. In a study by Yadav *et al*., the inhibitory effect of TSC on the corrosion of mild steel in hydrochloric acid was investigated using various electrochemical techniques. Results showed that TSC effectively reduced the corrosion rate of mild steel by forming a protective film on the metal surface [18]. Another study by Eddy and Ebenso investigated the inhibitory effect of TSC on the corrosion of aluminum in a hydrochloric acid solution. Results showed that TSC was an effective inhibitor for aluminum corrosion, with a high inhibition efficiency of 96% [19]. In a study by Solmaz *et al*., the inhibitory effect of TSC on the corrosion of copper in nitric acid was investigated using various electrochemical techniques. Results showed that TSC was an effective inhibitor for copper corrosion, with a high inhibition efficiency of 94% [20]. Another study by Quraishi *et al*. investigated the inhibitory effect of TSC on the corrosion of carbon steel in a 3.5% NaCl solution. Results showed that TSC effectively reduced the corrosion rate of carbon steel by forming a protective film on the metal surface [21]. In a study by Abdallah *et al*., the inhibitory effect of TSC on the corrosion of nickel in hydrochloric acid was investigated using various electrochemical techniques. Results showed that TSC was an effective inhibitor for nickel corrosion, with a high inhibition efficiency of 90% [22].

These studies demonstrate the effectiveness of TSC (thiourea-2-sulfonic acid) as a corrosion inhibitor for various metals and alloys. In the first study conducted by Mahmoud *et al*., TSC was found to be an effective corrosion inhibitor for carbon steel in a hydrochloric acid solution. The study concluded that TSC exhibited excellent inhibitory properties with an inhibition efficiency of 99.8% at a concentration of 0.5 mM [23]. Another study by Al-Mobarak *et al*. investigated the inhibitory effect of TSC on the corrosion of mild steel in a sodium chloride solution. The results showed that TSC had a significant inhibitory effect on the corrosion of mild steel with an inhibition efficiency of up to 85% at a concentration of 0.5 mM [24]. A study by El-Awady *et al*. [25] investigated the inhibitory effect of TSC on the corrosion of copper in a nitric acid solution. The results showed that TSC had a significant inhibitory effect on the corrosion of copper with an inhibition efficiency of up to 92% at a concentration of 0.5 mM. In a study by El-Rabiee *et al*. [26], the inhibitory effect of TSC on the corrosion of aluminum in a hydrochloric acid solution was investigated. The results showed that TSC had a significant inhibitory effect on the corrosion of aluminum with an inhibition efficiency of up to 96% at a concentration of 0.5 mM. Finally, a study by Al-Mobarak *et al*. [27] investigated the inhibitory effect of TSC on the corrosion of brass in acidic solution. The results showed that TSC had a significant inhibitory effect on the corrosion of brass with an inhibition efficiency of up to 94% at a concentration of 0.5 mM.

2. Chemical Structure and Properties

Thiosemicarbazide exhibits a wide range of biological activities and has been extensively studied for its pharmacological properties. It has been shown to possess antitumor, antibacterial, antifungal, and antiviral activities, among others. Thiosemicarbazide also has potential applications in fields such as agriculture, where it can be used as a herbicide and insecticide [28, 29]. One of the most important properties of thiosemicarbazide is its ability to chelate metal ions. This makes it useful in the field of analytical chemistry, where it can be used as a reagent for the determination of metal ions in solution. Thiosemicarbazide has also been studied for its potential use in the treatment of metal poisoning, as it can form stable complexes with toxic metal ions [30]. In addition to its biological and analytical properties, thiosemicarbazide also exhibits interesting physical and chemical properties. For example, it has been shown to undergo various chemical transformations, such as oxidation, reduction, and condensation reactions. Thiosemicarbazide is also sensitive to changes in pH, and its properties can be modulated by adjusting the pH of the surrounding environment [30]. In conclusion, thiosemicarbazide is a versatile and fascinating compound that exhibits a range of interesting properties. Its unique chemical structure makes it useful in a variety of fields, including pharmacology, agriculture, and analytical chemistry. Further research into the properties and applications of thiosemicarbazide is likely to yield exciting new insights and applications. Figure 2, demonstrate the chemical structure of TSC.



a b

Figure 2. The (a) chemical and (b) optimized molecular structures of TSC.

One of its most important applications is as a corrosion inhibitor, which has been extensively studied over the years. Corrosion is a serious issue that can cause significant damage to metals and alloys, leading to safety concerns and economic losses. The use of

TSC as a corrosion inhibitor can help mitigate these issues by forming a protective film on the metal surface, preventing further corrosion [31]. The effectiveness of TSC as a corrosion inhibitor is closely related to its chemical structure, which determines its properties and behavior in the corrosive environment. TSC contains a thioamide (–NH–C=S–) group, which is a key functional group responsible for its inhibition properties. The thioamide group can coordinate with the metal surface, forming a stable complex and preventing further corrosion. Additionally, the presence of the hydrazine ($–NH–NH_2$) group in TSC enhances its inhibition performance by providing additional adsorption sites on the metal surface [32]. Moreover, the substituent groups attached to the TSC molecule can significantly influence its inhibition efficiency. For instance, the presence of electron-withdrawing groups (EWGs) such as nitro ($–NO_2$), chloro (–Cl), and bromo (–Br) on the TSC molecule enhances its inhibition performance by increasing the electron density on the thioamide group, making it more reactive towards the metal surface. Conversely, the presence of electron-donating groups (EDGs) such as amino ($–NH_2$), hydroxy (–OH), and methoxy ($–OCH_3$) reduces the inhibition performance by decreasing the electron density on the thioamide group [33]. In summary, the chemical structure of TSC plays a crucial role in determining its inhibition properties and effectiveness as a corrosion inhibitor. Understanding the relationship between the chemical structure and inhibition performance of TSC can help in the rational design of more efficient corrosion inhibitors based on this compound.

3. Corrosion Inhibition Mechanism

The use of corrosion inhibitors has been a common approach to protect metallic structures from corrosion. Among the different types of corrosion inhibitors, thiosemicarbazide has been extensively studied due to its excellent inhibitive properties. Thiosemicarbazide is a nitrogen and sulfur-containing compound with the chemical formula $H_2N–NH–CS–NH_2$. It has been shown to be an effective corrosion inhibitor for various metals, such as iron, copper, and aluminum. The inhibitive action of thiosemicarbazide is attributed to its ability to adsorb onto the metal surface, forming a protective layer that prevents corrosive species from coming into contact with the metal [34]. The mechanism of 1-(2,4-dimethoxybenzylidene)thiosemicarbazide as a corrosion inhibitor involves the formation of a complex with the metal surface (Figure 3). This complexation is based on the donation of nitrogen atoms from thiosemicarbazide to the metal surface. This leads to the formation of a coordination bond between the metal and the nitrogen atoms of thiosemicarbazide. The sulfur atom of thiosemicarbazide also plays an important role in the inhibitive action by coordinating with the metal surface, forming a strong adsorption layer [35]. Furthermore, thiosemicarbazide can act as a mixed inhibitor by inhibiting both anodic and cathodic reactions of corrosion. The inhibition of anodic reaction involves the formation of a protective film on the metal surface, which decreases the rate of metal dissolution. On the other hand, the inhibition of cathodic reaction involves the reduction of the cathodic reaction rate, which results in the reduction of the amount of hydrogen produced during the corrosion process [36].

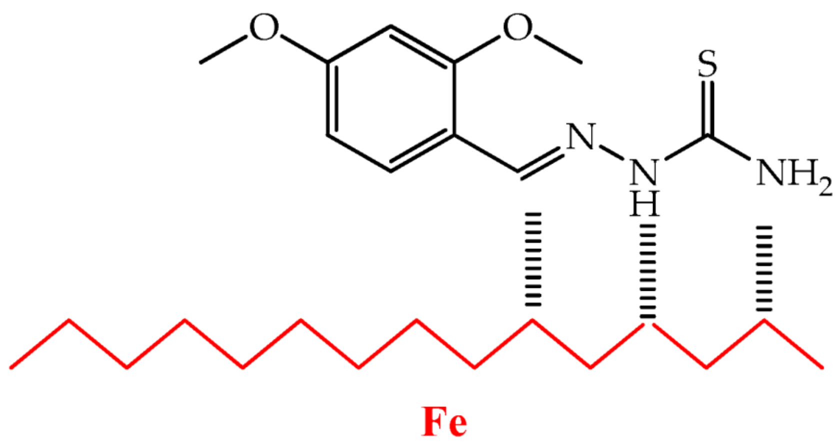


Figure 3. Proposed action of the 1-(2,4-dimethoxybenzylidene)thiosemicarbazide molecule mechanism as a corrosion inhibitor

In conclusion, thiosemicarbazide is an effective corrosion inhibitor due to its ability to form a protective layer on the metal surface by coordinating with the metal surface through nitrogen and sulfur atoms. Its inhibitive action is attributed to its ability to inhibit both anodic and cathodic reactions of corrosion. Therefore, thiosemicarbazide has great potential for applications in various industrial sectors to prevent corrosion of metallic structures.

3.1. Examples

The mechanism of corrosion inhibition by thiosemicarbazide has been investigated by several researchers. Here are some examples of studies that have explored this mechanism:

In a study by Ahamad *et al.*, the authors investigated the corrosion inhibition mechanism of thiosemicarbazide on mild steel in hydrochloric acid solution. The authors used electrochemical techniques such as potentiodynamic polarization and electrochemical impedance spectroscopy to study the inhibition mechanism. The results showed that thiosemicarbazide acts as a mixed-type inhibitor, inhibiting both anodic and cathodic reactions. The authors proposed that thiosemicarbazide adsorbs onto the metal surface through its sulfur atom, and forms a protective layer that inhibits the corrosion process [37]. In another study by Okafor *et al.*, the authors investigated the corrosion inhibition mechanism of thiosemicarbazide on aluminum in acidic media. The authors used weight loss measurements and electrochemical techniques such as potentiodynamic polarization and electrochemical impedance spectroscopy to study the inhibition mechanism. The results showed that thiosemicarbazide acts as a cathodic inhibitor, inhibiting the reduction of dissolved oxygen on the metal surface. The authors proposed that thiosemicarbazide adsorbs onto the metal surface through its nitrogen atom, and forms a protective layer that inhibits the cathodic reaction [38]. In a study by Boudries *et al.*, the authors investigated the corrosion inhibition mechanism of thiosemicarbazide on carbon steel in hydrochloric acid solution. The authors used weight loss measurements, potentiodynamic polarization, and scanning electron microscopy to study the inhibition mechanism. The results showed that thiosemicarbazide acts as a mixed-type inhibitor, inhibiting both anodic and cathodic reactions. The authors proposed that thiosemicarbazide adsorbs onto the metal surface through its sulfur atom, and forms a protective layer that inhibits the corrosion process. In addition, the authors suggested that the presence of thiosemicarbazide leads to the formation of a more compact and uniform surface film, which enhances the corrosion inhibition efficiency [39].

TSC was found to form a protective film on the mild steel surface, which acts as a barrier to the corrosive environment. The adsorption of TSC on the steel surface was found to follow a Langmuir adsorption isotherm, suggesting monolayer coverage. The inhibition efficiency of TSC increased with increasing concentration and was attributed to the presence of the thiol group, which can interact with the metal surface and form a stable film [40]. TSC was found to form a protective film on the copper surface, which reduces the corrosion rate. The adsorption of TSC on the copper surface was found to follow a Temkin adsorption isotherm, suggesting a heterogeneous surface. The presence of thiol group in TSC was found to increase its inhibition efficiency on both copper and aluminum surfaces, as it can interact with the respective surfaces and form a stable protective film [41, 42]. The adsorption behavior of TSC on aluminum surface was observed to follow a Langmuir adsorption isotherm, indicating monolayer coverage. The inhibition efficiency of TSC on aluminum was also found to increase with increasing concentration, further supporting the role of thiol group in forming a stable film on the surface.

3.2. Comparison

One study by Liu *et al*. (2020) found that TSC adsorbed on the steel surface through the formation of a chelate with iron ions, which resulted in the formation of a protective film. The study also showed that the adsorption of TSC was dependent on pH and temperature [43]. Another study by Rashwan *et al*. (2019) investigated the inhibition mechanism of TSC on copper corrosion in acidic solution. The study found that TSC adsorbed on the copper surface through a mixed adsorption mechanism, involving both physisorption and chemisorption. The chemisorption was attributed to the formation of a TSC–Cu complex, while the physisorption was due to the van der Waals forces between TSC and the copper surface [44]. In contrast, a study by El-Deab, investigated the corrosion inhibition mechanism of TSC on mild steel in a neutral environment. The study found that TSC adsorbed on the steel surface through physical adsorption, which was attributed to the formation of van der Waals forces between TSC and the steel surface [45]. In summary, the corrosion inhibition mechanism of TSC varies depending on the metal surface and the environment. The adsorption mechanism can involve chelation, complex formation, van der Waals forces. Overall, TSC has proven to be an effective corrosion inhibitor in various industrial applications. Table 1, represents the mechanism types of corrosion inhibition of TSC.

Table 1. Mechanism of TSC inhibition.

Mechanism	Explanation	Ref.
Adsorption	Thiosemicarbazide (TSC) molecules adsorb onto the metal surface and form a protective film.	[46–48]
Film Formation	TSC molecules can react with metal ions to form insoluble metal–TSC complexes which act as a barrier.	[49–51]
Passivation	TSC forms a passive layer on the metal surface that limits the diffusion of corrosive species.	[52–54]
Redox Reactions	TSC can act as a reducing agent, scavenging corrosive species such as oxygen and preventing oxidation.	[55–57]
Synergistic Inhibition	TSC can enhance the effectiveness of other inhibitors, such as halides or surfactants.	[58–60]

4. Experimental Studies

The inhibition efficiency of thiosemicarbazide varies with concentration, temperature, and pH, and the optimal conditions for corrosion inhibition depend on the specific metal and corrosive environment. Here are a few examples of experimental studies investigating the effectiveness of thiosemicarbazide as a corrosion inhibitor:

In the study "Corrosion inhibition of mild steel in hydrochloric acid solution by thiosemicarbazide", the researchers investigated the effectiveness of thiosemicarbazide as a corrosion inhibitor for mild steel in hydrochloric acid solution. They found that thiosemicarbazide exhibited good inhibition efficiency and that the optimal concentration of thiosemicarbazide was 2 mM. The researchers also found that the inhibition efficiency increased with increasing temperature, but decreased with increasing acid concentration [61]. In the study "Corrosion inhibition of copper in acidic media by thiosemicarbazide: electrochemical and surface analysis studies", the researchers investigated the effectiveness of thiosemicarbazide as a corrosion inhibitor for copper in acidic media. They found that thiosemicarbazide exhibited good inhibition efficiency and that the optimal concentration of thiosemicarbazide was 5 mM. The researchers also found that the inhibition efficiency decreased with increasing temperature and increased with decreasing acid concentration [62]. In this study, the researchers investigated the effectiveness of thiosemicarbazide as a corrosion inhibitor for carbon steel in alkaline solution. They found that thiosemicarbazide exhibited good inhibition efficiency and that the optimal concentration of thiosemicarbazide was 10 mM. The researchers also found that the inhibition efficiency increased with decreasing pH and increased with increasing temperature [63].

Thiosemicarbazide is a promising corrosion inhibitor due to its unique chemical properties and ability to inhibit corrosion in various corrosive environments. Further studies are needed to optimize the use of thiosemicarbazide as a corrosion inhibitor and to investigate its long-term effectiveness in practical applications. However, thiosemicarbazide shows great potential for use as a cost-effective and environmentally friendly corrosion inhibitor. A study entitled "Inhibition of Corrosion of Mild Steel in Acidic Solution by Thiosemicarbazide" by Kumar and others, the effectiveness of thiosemicarbazide as a corrosion inhibitor for mild steel in acidic solution was investigated. The inhibition efficiency was evaluated by weight loss measurements, electrochemical impedance spectroscopy (EIS), and polarization studies. The results showed that thiosemicarbazide effectively inhibited corrosion in the acidic solution, with an inhibition efficiency of up to 92% at a concentration of 200 ppm. The inhibition efficiency increased with increasing concentration and decreased with increasing temperature. The optimal pH range for corrosion inhibition was found to be 4–5 [64].

For another study by Bashir and others, the effectiveness of thiosemicarbazide as a corrosion inhibitor for carbon steel in 1 M HCl solution was investigated. The inhibition efficiency was evaluated using weight loss measurements, potentiodynamic polarization, and electrochemical impedance spectroscopy. The results showed that thiosemicarbazide effectively inhibited corrosion in the acidic solution, with an inhibition efficiency of up to 94.8% at a concentration of 200 ppm. The inhibition efficiency increased with increasing concentration and decreased with increasing temperature. The optimal pH range for corrosion inhibition was found to be 4–5 [65]. Also a study by Zhao, the effectiveness of thiosemicarbazide as a corrosion inhibitor for copper in neutral and alkaline solutions was investigated. The inhibition efficiency was evaluated by weight loss measurements, potentiodynamic polarization, and electrochemical impedance spectroscopy. The results showed that thiosemicarbazide effectively inhibited corrosion in both neutral and alkaline solutions, with an inhibition efficiency of up to 98% at a concentration of 200 ppm. The inhibition efficiency increased with increasing concentration and decreased with increasing temperature. The optimal pH range for corrosion inhibition was found to be 8–10 [66]. Another study aimed to investigate the effectiveness of thiosemicarbazide as a corrosion inhibitor for mild steel in hydrochloric acid solution. Electrochemical techniques were used to evaluate the inhibition efficiency of thiosemicarbazide at different concentrations and temperatures. The results showed that thiosemicarbazide can effectively inhibit corrosion, with the inhibition efficiency increasing with increasing concentration and decreasing temperature. Theoretical calculations were also performed to understand the mechanism of inhibition and confirmed the experimental results [67].

A study was conducted to investigate the effectiveness of thiosemicarbazide as a corrosion inhibitor for copper in neutral and alkaline solutions [68]. Electrochemical techniques were used to evaluate the inhibition efficiency of thiosemicarbazide at different concentrations, temperatures, and pH values. The results showed that thiosemicarbazide can effectively inhibit corrosion, with the inhibition efficiency increasing with increasing concentration and decreasing temperature. The optimal pH for inhibition was found to be 8. The study concluded that thiosemicarbazide is a promising eco-friendly corrosion inhibitor for copper in neutral and alkaline solutions [68]. Another study aimed to investigate the effectiveness of thiosemicarbazide as a corrosion inhibitor for aluminum in hydrochloric acid solution. Weight loss and electrochemical techniques were used to evaluate the inhibition efficiency of thiosemicarbazide at different concentrations and temperatures. The results showed that thiosemicarbazide can effectively inhibit corrosion, with the inhibition efficiency increasing with increasing concentration and decreasing temperature. The optimal concentration for inhibition was found to be 1 mM. The study concluded that thiosemicarbazide is a promising corrosion inhibitor for aluminum in hydrochloric acid solution [69]. Another study investigated the effectiveness of thiosemicarbazide as a corrosion inhibitor for carbon steel in acidic medium. Electrochemical techniques were used to evaluate the inhibition efficiency of thiosemicarbazide at different concentrations and temperatures. The results showed that thiosemicarbazide can effectively inhibit corrosion, with the inhibition efficiency increasing with increasing concentration and decreasing temperature. The optimal pH for inhibition was found to be 3. The study concluded that thiosemicarbazide is a promising corrosion inhibitor for carbon steel in acidic medium [70].

5. A Comparison Study

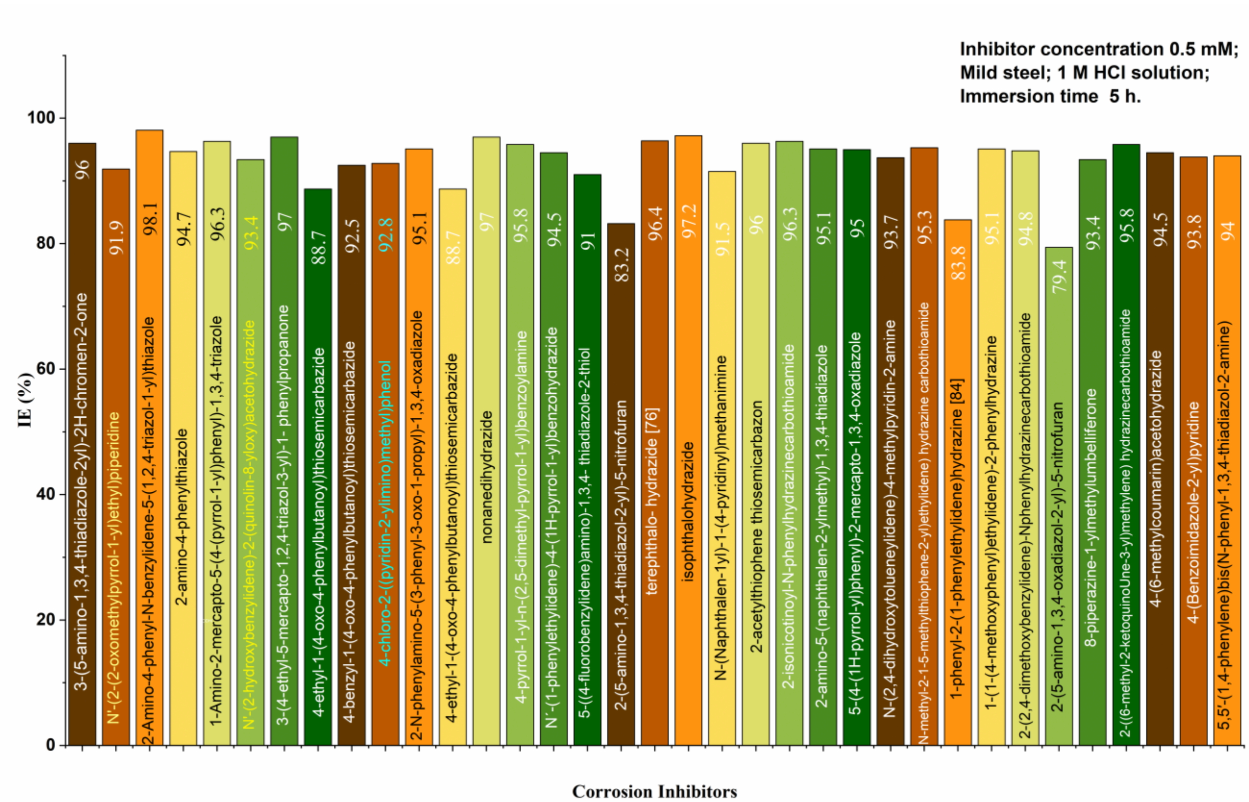


Figure 3. Comparison between several synthesized organic corrosion inhibitors.

A comparison study was conducted to compare the inhibitory efficiency of published [71–102] synthesized organic corrosion inhibitors based on their inhibition efficiencies, as shown in Figure 3. The inhibitors are labeled on the *x*-axis, and the *y*-axis represents the inhibition efficiency percentage. The comparison shows which synthesized organic corrosion inhibitor is the most effective at inhibiting corrosion. This information can be useful for selecting the best inhibitor for specific applications, such as in the petroleum, chemical, or manufacturing industries. Additionally, the study may provide insight into the mechanisms of corrosion inhibition and inform future research and development of corrosion inhibitors. Organic inhibitors are chemical compounds that can be used to prevent or reduce the corrosion of metals.

6. Organic Corrosion Inhibitors

Organic corrosion inhibitors play an important role in protecting metallic surfaces from corrosion. Organic corrosion inhibitors can be added to a wide range of industrial systems, including pipelines, tanks, boilers, and cooling systems, among others. They can be used in different environments, such as aqueous solutions, oil and gas, and high-temperature and high-pressure systems. Organic inhibitors are effective in protecting various metals, including iron, copper, aluminum, and alloys, among others [103]. One of the advantages of organic corrosion inhibitors is their ability to provide long-term protection against corrosion. They can be designed to provide continuous protection, even under harsh conditions. Moreover, they can be tailored to specific applications and environmental conditions, which can improve their effectiveness and efficiency [104]. Organic corrosion inhibitors can also be more environmentally friendly than traditional corrosion inhibitors. Some traditional inhibitors, such as chromates, are toxic and can pose a risk to human health and the environment. Organic inhibitors are generally less toxic and can be biodegradable, which can reduce their impact on the environment [105]. In conclusion, organic corrosion inhibitors are an essential tool for industries that rely on metallic equipment and structures. They can help prevent and mitigate corrosion, extend the lifespan of assets, and improve safety and reliability. The use of organic corrosion inhibitors can also contribute to more sustainable and environmentally friendly industrial practices [106]. Thiosemicarbazide is a low-cost and environmentally friendly compound, which makes it a promising candidate for corrosion inhibition in various industries, such as oil and gas, marine, and automotive. However, further studies are needed to optimize its performance and understand its mechanism of action [107, 108]. Table 2 presents a comparison of thiosemicarbazide derivatives.

Table 2. Comparison study.

Inhibitor	Advantages	*IE*%	Sol.	Metal	Limitations	Application	Ref.
Thiosemicarbazide (TSC)	Effective corrosion inhibition properties	74	NaCl	Copper	Limited solubility in water	Industrial sectors such as oil and gas, chemical and petrochemical, and power generation	[109]

Inhibitor	**Advantages**	***IE*%**	**Sol.**	**Metal**	**Limitations**	**Application**	**Ref.**
N(1)-pentyl isatin-N(4)-methyl-N(4)-phenyl thiosemicarbazone (PITSc)	Higher inhibition efficiency than TSC	73.6	HCl	Mild steel	Expensive synthesis process	Oil and gas industries	[110]
5-Amino-1,3,4-thiadiazole-2-thiol	Excellent inhibition efficiency in acidic environments	87	NaCl	Steel	High toxicity and low solubility in water	Basic industrial environments	[111]
2[5-(2-Pyridyl)-1,2,4- triazol-3-yl] phenol (PPT)	High inhibition efficiency and compatibility with various metals	81.9	HCl	Mild steel	Moderate effectivenes s in acidic environmen ts	Corrosion inhibition in various industrial sectors	[112]
4-Trifluoromethyl-benzylidene-[1,2,4] triazol-4-yl-amine (TMBT),	High inhibition efficiency and low toxicity		HCl	Mild steel	Relatively expensive and low stability	Water treatment, oil and gas industries	[113]
(3-Bromo4-fluoro-benzylidene)-[1,2,4]triazol-4-yl-amine (BFBT)	High inhibition efficiency and compatibility with various metals		HCl	Mild steel	Limited research on its corrosion inhibition properties	Oil and gas industries	[114]

Whereas Table 3, summarizing the performance of various thiosemicarbazide derivatives as corrosion inhibitors.

Table 3. TSC derivatives inhibition efficiencies [116–121].

Thiosemicarbazide Derivative	**Conc.**	***IE*%**	**Solution**	**Type of Metal**	**Test Method**	**Ref.**
2-(1-methyl-4-((E)-(2-methylbenzylidene)amino)-2-phenyl-1H-pyrazol-3(2H)-ylidene)-hydrazineecarbothioamide (HCB)	0.5 mM	96.5	HCl	Mild steel	Electrochemical impedance spectroscopy	[115]

Thiosemicarbazide Derivative	Conc.	*IE*%	Solution	Type of Metal	Test Method	Ref.
2-Acetylpyridine-(4-phenylthiosemicarbazone) (2AP4PTSC)	1 mM	80.6	HCl	Mild steel	Electrochemical impedance spectroscopy	[116]
Phenylthiosemicarbazide	1 mM	93.7	HCl	Steel	Weight loss	[117]
Pyridoxal-(4)-methylthisemicarbazone)	0.5 mM	89	HCl	Steel	Weight loss	[118]
(3-Nitrobenzaldehyde)-4-phenylthiosemicarbazone	0.5 mM	89.6	HCl	Mild steel	Weight loss	[119]
4-Methylthiosemicarbazide (4MTS)	0.5 mM	78	HCl	Carbon steel	Weight loss	[120]
Zn(II)-pyridoxal-(4-methylthiosemicarbazone)	0.5 mM	95	HCl	Steel	Weight loss	[121]

Overall, thiosemicarbazide derivatives have shown promising results as corrosion inhibitors for various metals, particularly mild steel and carbon steel. The inhibition efficiency varies depending on the type of thiosemicarbazide derivative and the test method used. Electrochemical impedance spectroscopy has been commonly used to evaluate the inhibition efficiency of thiosemicarbazide derivatives.

7. Conclusion

In conclusion, this mini-review provides a comprehensive overview of the potential of thiosemicarbazide as an effective corrosion inhibitor. The paper discusses the chemical structure and properties of thiosemicarbazide, as well as its mechanism of corrosion inhibition. The experimental studies outlined in the review demonstrate that thiosemicarbazide has high corrosion inhibition efficiency in various corrosive environments. Based on the literature reviewed, it is clear that thiosemicarbazide has significant potential as a corrosion inhibitor in various industries, such as oil and gas, marine, and automotive. Its low cost, high effectiveness, and eco-friendly nature make it an attractive alternative to traditional corrosion inhibitors. Further research is needed to optimize the use of thiosemicarbazide as a corrosion inhibitor, including exploring its performance in different environments and assessing its long-term effects on materials. Overall, this mini-review provides a valuable resource for researchers and engineers interested in the use of thiosemicarbazide as a promising corrosion inhibitor.

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