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New Developments in Inhibition of the Sweet Environment in a Variety of Corrosive Media: A Review

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HIGHLIGHTS

- The corrosion of pipelines and crude oil storage tanks was reviewed.
- The influence of CO_2 on the corrosion process was estimated.
- Corrosion control via heterocyclic inhibitors was addressed.

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ABSTRACT

This paper aims to look at how pipeline steel and crude oil storage tanks resist corrosion in aqueous carbon dioxide (CO_2) environments. To this aim, we have studied different inhibitors, particularly the heterocyclic inhibitor, which is used to prevent mild steel corrosion in various situations. On mild steel, the corrosion-prevention mechanism of heterocyclic inhibitors is also investigated. CO_2 corrosion is the most frequent and dreaded type of corrosion in the oil and gas industry, and corrosion inhibitors are the most effective way to fight CO_2 corrosion in mild steel. Nonetheless, continual exposure to pollutants and corrosion causes such as sulfur and chromate on pipeline surfaces is unavoidable. Because of their toxicity, commercial corrosion inhibitors are being used less frequently to protect the environment. As a result of the advent of "green" chemistry and fruit waste, both of which have been demonstrated to be efficient corrosion inhibitors, plant extracts have become popular. This research aims to compile a list of carbon dioxide corrosion inhibitors that have been proved to protect against this type of attack. The material on this page is relevant to the gas and oil industries, which rely on steel pipelines and crude oil tanks to transport oil and gas products. This study will also help develop better CO_2 corrosion inhibitors for the gas and oil industries.

1. Introduction

Because of their good structural features and inexpensive cost, mild steels are commonly utilized in the oil and gas industry [1]. However, limited corrosion resistance in these environments with high concentrations of chlorides and carbon dioxide is one of the main issues encountered during its use. CO_2 is prevalent in many oil and gas fields, and it may be present in the oil due to CO_2 injection into the reservoir for secondary enhanced oil recovery processes [2,3]. When CO_2 is dissolved in the aqueous phase of industrial water, it acts as a reservoir for the continual generation and replenishment of H_2CO_3 [4]. This acid reacts with the iron in steel pipes, hastening the corrosion process. When organic corrosion inhibitors are utilized, mild steel is often the most cost-effective option, despite its low corrosion resistance under harsh environments. At least one of the following ingredients can be included in commercial corrosion inhibitors: Surfactants include amines, fatty diamines/amines, fatty amido/amines or imidazoline, quaternary amines, fatty acids, and various amine derivatives [5Many active chemicals, as well as additives and other solvents, are commonly found in commercially effective inhibitors [6]. There is growing concern regarding the impact of commercial inhibitors on the environment and human health because some of the active compounds employed in them are toxic and damaging to the environment [7]. The most extensively used sweet corrosion inhibitors in the oil and gas industry are organic chemicals based on long-chain imidazole and amines. They have electron-rich –bonds and nitrogen heteroatoms, which enable them to adsorb and form protective coatings on the steel surface, blocking active sites and slowing anodic and cathodic reaction rates. However, their corrosion-prevention characteristics have primarily been tested in static circumstances, which sometimes include turbulent low or hydrodynamic conditions [8]. These compounds are extremely harmful and expensive. In the presence of mineral acids, oxygen, CO_2, and H_2S, industrial activities (exploration, production, and transportation) must navigate a complicated maze of extremely corrosive conditions. Therefore, to keep corrosion rates under control, corrosion mitigation is necessary using effective

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materials. Despite its low corrosion resistance, mild steel is commonly used in the oil and gas industries because of its availability, strength, and cost-effectiveness [9]. When oil and gas are transported via steel pipes in the presence of CO_2 and water, a complicated mixture of gases and liquids is created, which promotes corrosion [10]. A lack of literature, particularly in this type of situation, provides a full explanation of the inhibitors utilized to tackle corrosion-related concerns [11]. The thermo-mechanical method allowed for a reduction in wall thickness and, in some cases, an increase in corrosion resistance as high-strength steel technology advanced [12]. The goal of this research, on the other hand, is to examine a variety of CO_2 corrosion inhibitors. Several studies of organic compounds in corrosion mitigation have been published because organic inhibitors are more sought in industrial applications. Compared to monomer compounds, polymer compounds can give good inhibitory efficiency when used in the formulation of corrosion inhibitors. Researchers are often exploring low-cost natural polymer sources, such as biomass, these days. It's important to remember that carbohydrate molecules account for over 40% of the chemical makeup of grassy and woody plant extracts, whereas lignin accounts for only 20% [13]. Because of the difficulties with commercial corrosion inhibitors, additional research has been done in this area. Natural corrosion inhibitors are frequently safe, environmentally benign, and cost-effective to produce because of their abundance [14]. Corrosion problems in oil and gas production can occur at any stage of the process, from extraction and treatment through storage, and are caused by the fluid water. As a result of a pipeline collapse, internal corrosion may cause a loss of strength, resulting in plant shutdown and, most likely, environmental calamity. Crude oil may escape from CO_2 corrosion, causing pollution of the environment and water, as well as fires [15]. This review aims to highlight the most recent sweet corrosion inhibition research published in the last decade (2011–2020), including new findings. This is a very extensive analysis of several types of applications. In the past, organic chemicals and natural products were rarely used.

2. An Overview of Carbon Dioxide Corrosion (Sweet Corrosion)

Corrosion is a chemical or electrochemical process that occurs when metals or alloys are attacked by their environment, such as air, water, or soil, resulting in the creation of more stable compounds [16]. Most metals are found as ores in nature, chemically coupled states. Many ore types have been discovered in the earth's crust since its origin, including oxides, sulfides, carbonates, and other chemical compounds [17]. Corrosion is the degradation of metal-induced by electrochemical interaction with its surroundings [18] and is caused by the natural tendency of most metals to revert to their original state [19]. The corrosion generated by carbon dioxide is referred to as sweet corrosion. In the oil and gas industry, dissolved CO_2 is primarily to blame, and it can be found in oil wells, storage tanks, and transportation networks. High chloride ion concentrations combined with CO_2 make the situation even more aggressive, leading to severe pitting corrosion [20, 21]. Because of its cost-effectiveness, carbon steel is always selected for pipelines and oil well processing equipment [22].

On the other hand, as the temperature rises, the viscosity of brine water decreases, increasing brine water conductivity and, as a result, an increase in the rate of corrosion [23]. Even though there are corrosion-resistant alloys that can survive CO_2 corrosion, carbon steel is always preferred for pipelines and oil well processing equipment due to its cost-effectiveness. Carbonic acid (H_2CO_3) is formed when CO_2 is broken down in an aqueous media, and it dissociates further to create HCO_3^- and CO_3^{2-} [24, 25].

$$CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)} \quad (1)$$

$$H_2CO_{3(aq)} \rightarrow H^+_{(aq)} + HCO^{3-}_{(aq)} \quad (2)$$

$$HCO^{3-}_{(aq)} \rightarrow H^+_{(aq)} + CO_3^{2-} \quad (3)$$

Several processes have been postulated in the literature to explain Fe dissolution in aqueous abandoned CO_2 solutions [24, 26]. The corrosion process is triggered by three cathodic processes that result in hydrogen evolution:

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)} \quad (4)$$

$$2H_2CO_{3(aq)} + 2e^- \rightarrow H_{2(g)} + 2HCO^{3-}_{(aq)} \quad (5)$$

$$2HCO^{3-}_{(aq)} + 2e^- \rightarrow H_{2(g)} + 2CO_3^{2-}{}_{(aq)} \quad (6)$$

The anodic dissolution of Fe is given as :

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^- \quad (7)$$

This reaction provides the electrons required to keep the process going . As a result, the corrosion layer is precipitated on the metal surface as described below[27,28,29]:

$$Fe^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightarrow FeCO_{3(s)} \quad (8)$$

$$Fe^{2+}_{(aq)} + 2HCO^{-3}_{(aq)} \rightarrow Fe(HCO_3)_{2(s)} \quad (9)$$

$$Fe(HCO_3)_{2(s)} \rightarrow FeCO_{3(s)} + CO_{2(g)} + H_2O_{(l)} \quad (10)$$

It has been demonstrated experimentally that the corrosion rate of H_2CO_3 is greater at a given pH than that of strong acids such as H_2SO_4 and HCl, which fully dissolve in water. This key insight explains why the rate of hydrogen evolution in strong acids is controlled by the rate of H^+ transport from the solution to the metal surface. Because the mass transfer-regulated limiting current in solutions with a pH > 4 is low, the presence of H_2CO_3 allows hydrogen evolution to proceed at a much higher rate. Temperature, pH, and CO_2 partial pressure are the main regulators of the mechanism (pCO_2) [24]. In addition, other parameters, such as the number of chlorides and dissolved oxygen, flow velocity, and so on, influence the total corrosion rate.

2.1 **pH:** In CO_2 corrosion, pH is thought to be the most important factor. By inhibiting the expression of cathodic reactant H+, a rise in pH immediately lowers CO_2 corrosion. The solubility of $FeCO_3$ decreases as pH rises. As a result, the protective $FeCO_3$ layer on the steel surface becomes more precipitated. At pH_4, the cathodic process of H+ reduction takes over. Carbonic acid reduction is the primary cathodic reaction in the pH range of 4 to 6. The bicarbonate reduction is the primary cathodic process at pH > 6.

2.2 **Temperature:** The corrosion rate increases progressively as the temperature rises at low pH, where $FeCO_3$ layers do not form. The increased temperature speeds up $FeCO_3$ precipitation, generating a protective layer when $FeCO_3$ solubility is surpassed, and a protective layer is formed, usually at pH > 5.

2.3 **CO_2 partial pressure:** Even when the pH remains constant and all other parameters remain constant, a rise in pCO_2 increases the corrosion rate. In addition, the concentration of H_2CO_3 rises as pCO_2 rises, speeding up the other major cathodic processes and, finally, the corrosion rate.

2.4 **Oxygen concentration:** In an aerobic environment, there is no growth of a protective surface layer because $FeCO_3$ is unstable. The cathodic process (Eq. 11) will be increased if the oxygen content is more than 40 ppb, resulting in the oxidation of Fe^{2+} to Fe^{3+} [30].

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (11)$$

2.5 **Iron content:** The rate of $FeCO_3$ synthesis is controlled by the precipitation of Fe^{2+} and CO_3. For film formation to occur, the degree of supersaturation (the ratio of the product of Fe^{2+} and $CO3^{-2}$ concentration to the solubility limit [Ksp]) must be larger than one.

$$\text{Degree of supersaturation} = [Fe^{+2}]\,[CO^{-2}] \,/\, Ksp \quad (12)$$

As a result, a high Fe^{2+} concentration causes more supersaturation and faster $FeCO_3$ film formation, which reduces corrosion [31].

2.6 **Influence of flow rate:** The rate of CO_2 corrosion in steel is affected by the flow rate, which can be achieved through mass transfer or mechanical techniques. Turbulent flow can improve the mass transfer of a species to and away from the steel surface. On the other hand, a vigorous flow could mechanically degrade the $FeCO_3$ protective layer or inhibitor films.

3. General Types and Classification Of Inhibitors

Corrosion inhibition is any way of preventing corrosion by incorporating a chemical component that stops the metal from oxidizing. The chemical inhibitor can be used as a liquid, vapor, or both in the system. The transport of the inhibitor to the metal surface and the inhibitor's contact with the metal surface are the two processes involved in the corrosion inhibitor's activity. Because both require a chemical reaction, a corrosion inhibitor's contact with a metal surface is analogous to a pharmaceutical molecule's interaction with human physiology.

Bitumen and tar were used by the Romans in ancient times to protect their iron, and some of the foundations of corrosion events were discovered at the turn of the eighteenth century. Inhibition is more difficult in the oil and gas industry, and different inhibitors are needed depending on where they'll be used, such as refineries, wells, recovery units, pipelines, etc. The two stages involved in the corrosion inhibitor's activity are the inhibitor's delivery to the metal surface and its interaction with the metal surface. Deposits are reduced by using slag inhibitors in conjunction with corrosion inhibitors. Pipelines contain both water and oil-soluble inhibitors, and adsorption-type inhibitors are frequently used to prevent interior corrosion in pipes conveying refined petroleum products. Inhibitors that are both water- and oil-soluble are in pipelines adsorption-type inhibitors are routinely used to prevent internal corrosion of pipes delivering refined petroleum products. The relationship between the surface-active characteristics of organic corrosion inhibitors and their ability to hold CO_2 erosion from carbon steel can be broken down into three categories[32-35]:

1. Adsorption to the steel surface (diffusion or protective layer).
2. Altering the steel surface's wettability (so that it is not wetted with water).
3. Absorption at oil-water contacts (changing the oil-water interfacial tension and making it easier for the oil to entrain the water).

The problem of inhibition in a corrosion system, where organic corrosion inhibitors are assumed to adsorb on the steel surface and suppress corrosion processes, persists despite major breakthroughs in inhibitor chemistry [36,37].

3.1 **Classification of Inhibitors**

As illustrated in Figure 1, there are two types of inhibitors, inorganic and organic inhibitors. Compared to traditional surface passivating inorganic inhibitors, organic inhibitors appeal due to their high efficiency and environmental friendliness. Organic inhibitors are widely employed in a wide range of industries and environments. Their ability to inhibit is determined by chemical structure and physical characteristics such as functional group type, electron density, and so on in molecular electronic structure, donor atom density, and p-orbital character. Adsorption is the main cause of inhibition . Most industrial inhibitors are barrier inhibitors, which lower the apparent corrosion rate by modifying the metal's surface by producing a coating on the corroding metal surface. Because of this action, barrier inhibitors are also known as film-forming inhibitors [38].

3.1.1 Anodic corrosion inhibitors

These inhibitors function by preventing anodic reactions and lowering the rate of corrosion. Nitrite (NO^{2-}), chromate (CrO^{2-}), orthophosphate (PO_4^{3-}), and molybdate (MoO_4^{2-}) are examples of anodic inhibitors [39]. They are typically used in solutions with a pH close to neutral and soluble corrosion products (oxides, salts, and hydroxides). They are also referred to as passivation inhibitors [40]. Inhibitors are a type of passivation that changes the equilibrium of the corrosion process, as seen in the effect of the anodic inhibitor on the Tafel slope in Figure 2. This figure illustrates the electrochemical behavior of an active-passive metal in a solution (a) anodic inhibitor and (b) without an inhibitor, as well as the typical anodic dissolutions of an active-passive metal. These inhibitors impede the anodic reactions and thus reduce the corrosion rate by increasing the anode potential and decreasing the corrosion current. Raising the anode voltage slows the inhibitor's oxidation process.

3.1.2 Cathodic corrosion inhibitors

Cathodic poisons and cathodic precipitators are the two primary kinds of cathodic inhibitors. Cathodic poisons are used to slow down the corrosion response because different types of poison can slow down the rate of corrosion reduction. Some poisons, such as selenides and sulfides, adsorb on metal surfaces, whereas others, such as arsenic and antimony compounds, solidify. The metallic layer is reduced at the cathode, resulting in a reduced metallic layer. Furthermore, chemicals such as silicates, phosphates, and borates reduce corrosion rates by forming a protective layer that restricts the movement (by diffusion) of ions oxygen tothe metal surface. On the other hand, cathodic precipitators function byraising alkalinity at the cathodic sites and preferentially precipitating insoluble chemicals [40,41]. The cathodic Tafel slope and the downward shift illustrated in Figure 3. illustrated Tafel slope (a) with cathodic inhibitor and (b) without inhibitor. This suggests that the inhibitor has affected the reaction process. The inhibitor acts by inhibiting the active sites if only the slope is altered [42].

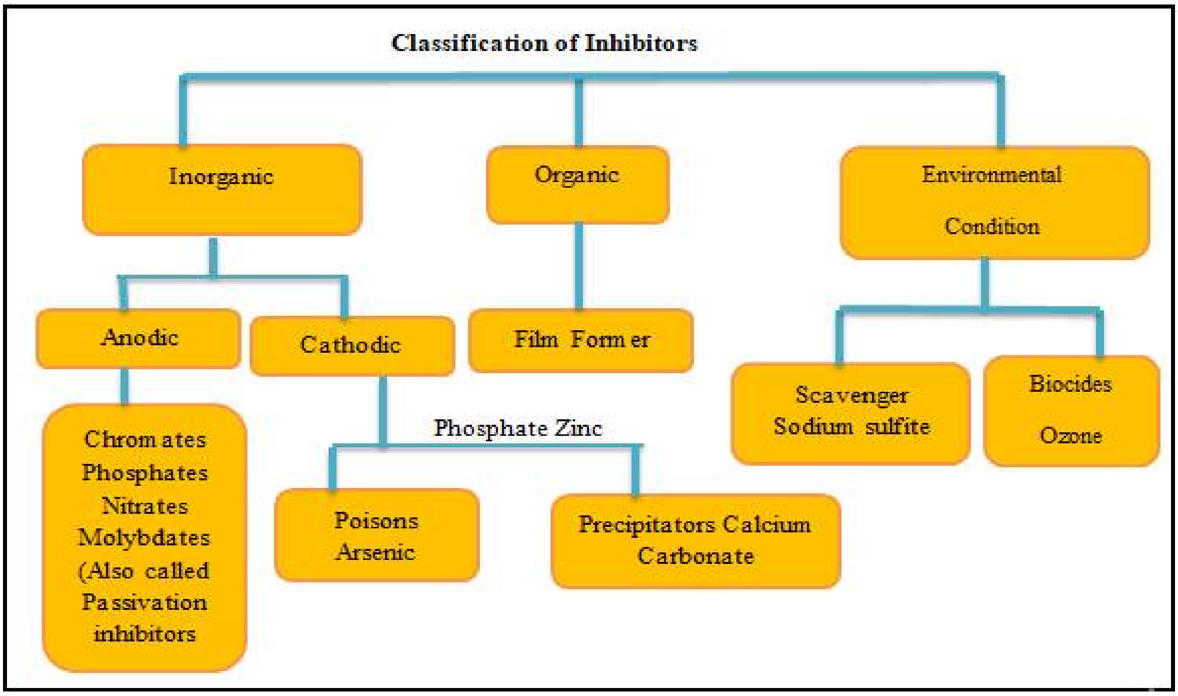

Figure 1: Classification of inhibitors [38]

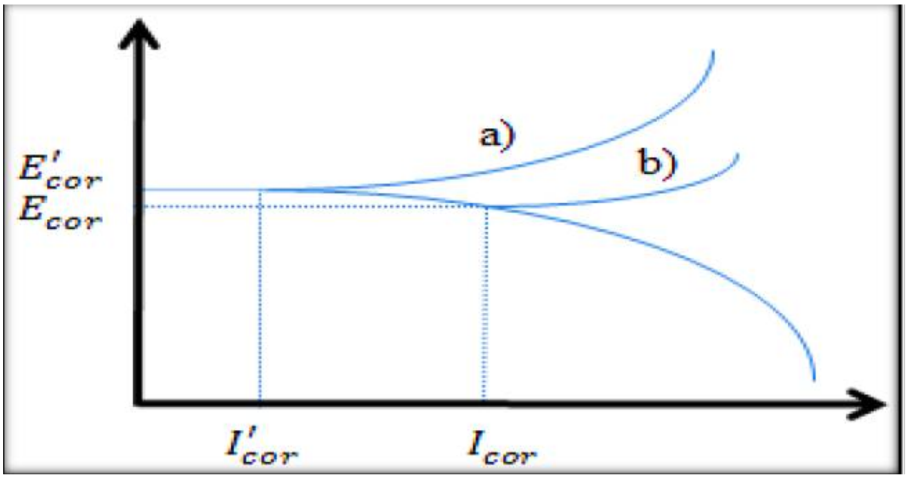

Figure 2: Anodic inhibitors effect on the Tafel slope [40]

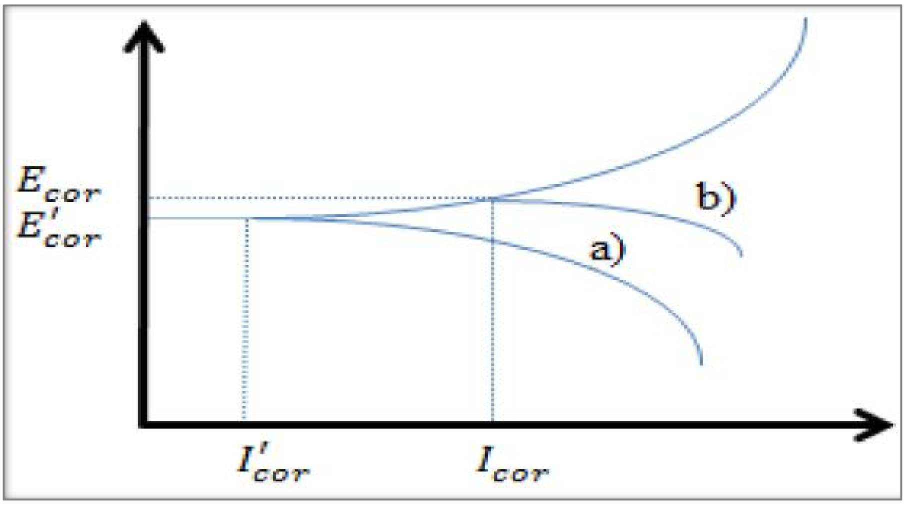

Figure 3: Cathodic inhibitors effect on the Tafel slope [40]

3.1.3 Mixed adsorption corrosion inhibitors

Mixed inhibitors are non-anodic and non-cathodic chemical compounds that account for 80% of all inhibitors. To avoid corrosion, they adsorb inorganic molecules at the metal-solution contact. These organic molecules become adsorbed to the metal surface. They form a solid connection as the surface adsorption process progresses, reducing the apparent corrosion rate. This corrosion inhibition decreases corrosion rate by lowering the number of exposed surface sites. Mixed inhibitors are sometimes known as adsorption inhibitors because of their inhibition method. As demonstrated in Figure 4, the surface charge of the metal, the kind of electrolyte, and the inhibitor all influence the adsorption process. The inhibitor's film concentration and contact time determine its effectiveness. The inhibitor’s potency is influenced by the quantity of metal surface covering and the extent to which the inhibitor is adsorbed.

Barrier inhibitors such as oil and solvent-based corrosion inhibitors function by creating coatings on the metal surface to prevent water from interacting with it. Depending on the chemical with high water-rejecting qualities, this inhibitor develops a thick coating that might be soft, greasy, multicolored, translucent, or semi-hard. On the other hand, water-based inhibitors reduce corrosion by changing the characteristics of the metal surface, lowering corrosion resistance [40,41,42]. The Parameters in Selecting an Inhibitor's Effectiveness in Corrosive Environments:

1) Understanding the state of the metal's surface.
2) The temperature and pressure at which the machine is in operation.
3) Fluid characteristics.
4) The pH and chemistry of the solution.
5) Flow conditions are required, such as flow velocity and single- or multi-phase flows.
6) Dissolved gases, notably oxygen and carbon dioxide, and fluid dynamic scanning significantly impair inhibitor efficacy. In addition, contact between the metal wall and the moving fluids causes corrosion in oil and gas production pipelines [6].

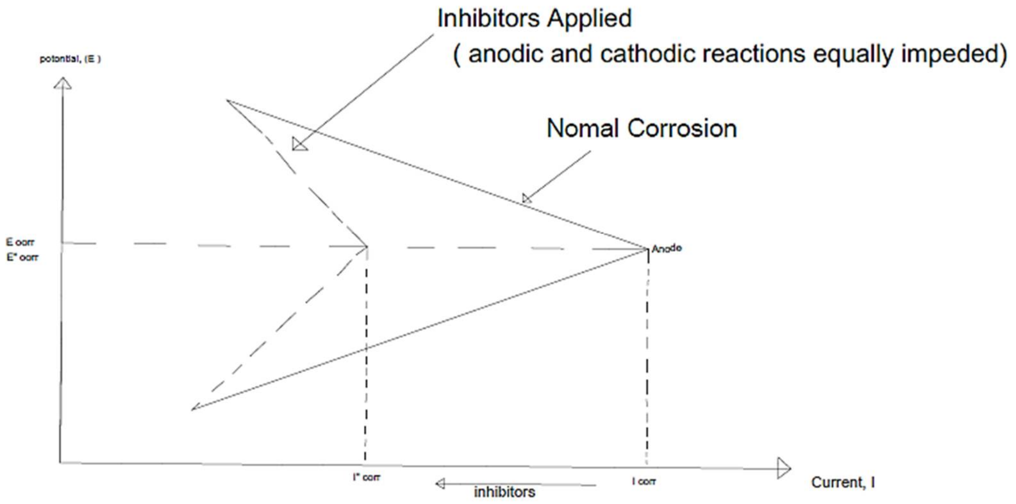

Figure 4: Mixed inhibitor's effect on Tafel slopes [40]

3.2 Commercial Corrosion Inhibitors

As corrosion-related difficulties have become more prominent, notably in the oil and gas industries, corrosion experts have devised several solutions, such as corrosion inhibitors [43]. The bulk of corrosion inhibitors comprises organic and inorganic composites, with organic inhibitors reducing corrosion by adsorption and inorganic inhibitors reducing corrosion through chemical interactions. Corrosion can be avoided by interacting with the process's anodic or cathodic components [44]. A carbocyclic compound is an organic molecule that has atoms of carbon organized into the shape of a ring. A heterocyclic compound is one in which one of the carbon atoms is replaced by an atom from another element, resulting in a cyclic structure [6, 7]. Sulfur (S), nitrogen (N), and oxygen (O) are the most common heteroatoms (O).

On the other hand, hetero-aromatic rings with additional heteroatoms are well-known [45]. Inhibiting agents have both advantages and disadvantages when working with inorganic materials. They have the advantage of being able to perform at high temperatures for extended periods while also being lightweight. Over longer periods, organic inhibitors are less expensive. However, inorganic inhibitors lose their hold more easily than organic inhibitors in higher acid solutions. For example, hydrochloric acid is 17 % more difficult to mix and can produce harmful arsine gas due to corrosion [46]. Despite their potency at large concentrations, these inhibitors are certainly damaging to the environment. Novel inhibitors based on polymers and plants have been developed to overcome this issue [47]. Polymers, on the other hand, were classed as moderate inhibitors, which necessitated greater refinement at a higher cost [48]. As a result, extensive research is being conducted on plant parts that are both readily available and affordable.

3.3 Green-Based Corrosion Inhibitors

Green inhibitors, also known as environmentally friendly inhibitors, are low-cost and renewable. Corrosion inhibitors are made from normal extracts of plant tissues, such as fruit and leaf peels [49]. When applied at extremely low concentrations, green corrosion inhibitors protect the metal surface from corrosive media. By modifying the anodic or cathodic reaction kinetics, the plant can accelerate the rate of diffusion of hostile ions from interacting with the metal surface. The rate of corrosion on the metal surface due to adsorption can also be increased. A film layer can be formed by gradually raising the metal surface's electrical resistance [50]. Plant extracts can be easily made with low-cost solvents like water or ethanol. When the extracts have a low water solubility, ethanol solvents are utilized. Extracts may contain tannins, pigments, steroids, flavonoids, flavones, and essential oils, to name a few natural components [51].

4. The Principle and Mechanism of Carbon-Dioxide Corrosion Inhibition

One of the essential requirements in developing multifunctional inhibitors is the molecule's chemical structure. For example, the molecule must have a lipophilic structure with a hydrophilic functional group and a hydrophobic long-chain radical [52]. The hydrophilic functional group of the hydrophilic functional group molecule will affect the many biochemical processes occurring in bacterial cells, resulting in their destruction and death. On the other hand, the hydrophobic radical exerts an inhibiting effect on metal electrolyte boundaries. CO_2 corrosion can be avoided by employing a variety of techniques. It's critical to select the best technique for the job, which is heavily influenced by corrosion conditions and mechanisms. Steel corrosion is an electrochemical process that occurs in aqueous media with dissolved carbon dioxide. The first method entails fabricating the cathodic protection using any accessible means. The first technique entails the creation of highly inhibitive protective carbonate oxide films or deposits, whereas the second technique entails the creation of protective carbonate oxide coatings or deposits. Physical and chemical measures must be utilized to adjust the pH and temperature of the medium to apply the second technique. Three types of inhibitors can be applied to slow the cathodic process properly.

1. Inhibitors can displace depolarizers (HCO^{3-}ions, H_2CO_3, and CO_2H_2O molecules) on the metal's surface.
2. Inhibitors that may form mixed-type films and are impervious to depolarizers.
3. Inhibitors can form bonds with depolarizers (HCO^{3-} ions, H_2CO_3, and CO_2H_2O molecules).

Corrosion inhibitors are extensively employed in oil and gas production systems to prevent interior corrosion of carbon steel structures. Even without knowing the inhibitory mechanism, nitrogen-based organic inhibitors, such as Imidazolines or their salts, have been effectively employed in these instances [53]. According to research, the physical-chemical properties of the molecule (connected to its functional groups), steric effects, and the electronic density of donor atoms all play a role in organic inhibitor adsorption. In addition, adsorption is influenced by potential orbital interactions [54]. Corrosion inhibitors are made up of nitrogen-containing compounds, where various amines (primary, secondary, tertiary, aliphatic, and heterocyclic) from the pyridine and imidazoline classes, and their salts, amino alcohols, and triazines, are utilized as corrosion inhibitors [55].

These chemicals are easy to use, have a long shelf life, and provide excellent corrosion protection. They must, however, increase their operational characteristics, capabilities, and range, which needs, first and foremost, the study of new sorts of raw materials. Organic acids of various structures (from oil and oil fractions), synthetic greasy acids, and other similar substances are preferable. Imidazolines (IMs) and their derivatives are the most well-investigated inhibitors [56]. The findings are listed in Table 1. In addition to IMs, non-IM-based inhibitors such as azoles, pyridines, and macrocyclic compounds have been described as synthetic heterocyclic corrosion inhibitors in CO_2. Table 2 describes the results of past case studies of inhibitors from green and commercial sources from 2011 to 2020. In this investigation, hexamethylenetetramine was one of the organic inhibitors utilized. The formula for HMTA is ($C_6H_{12}N_4$), a non-toxic, odorless amine with a cage structure with four nitrogen atoms free of a steric hindrance as shown in Figure.5,6 [57,58] and suited for use in an oil pipeline, steam boiler, or hot water boiler in a common boiler. Because HTMA is commonly utilized in practical applications, the question of whether it causes corrosion has been raised. Corrosion is the only consequence of HMTA and other materials when used together. Only brine corrosion affects HMTA. The effect of HMTA corrosion on temperature relationships is the subject of several theories. As the temperature rises, hexamethylenetetramine (HMTA) solubility in water decreases. The reaction center had to be the four nitrogen atoms of hexamine with a high electron density. The inhibition action can be accounted for by the interaction of a lone pair of electrons at the nitrogen atom on the positively charged metal surface. The presence of six ethylene groups also helps to enhance electron density at the nitrogen atoms, which enhances their adsorption on the metal surface. This results in enhanced inhibitory efficiency (I.E.), macromolecular size, and a higher number of "N" atoms in Hexamine, which may have covered practically all of the mild steel's active sites. As a result, the inhibitive action is most likely due to adsorption blocking the anodic and cathodic sides, allowing an insoluble protective coating to form. As a result, we may deduce that the decreasing trend of the I.E. with rising temperature is due to hexamine desorption, which should be quicker than the rate of adsorption at higher temperatures [59], as seen in Figures 5 and 6. Inhibitor compounds with hydrophobic motifs may, in addition to having polar groups that interact with the metal surface, help create protective layers. A hydrophobic surface layer assists in removing water at the metal–solution contact of an immersed water molecule. This acts as a deterrent to metals dissolving in the water. The electrolyte is represented in Eq. 13 [60]:

$$\mathrm{Org}_{(sol)} + n\mathrm{H_2O}_{(ads)} \rightarrow \mathrm{Org}_{(ads)} + n\mathrm{H_2O}_{(sol)} \tag{13}$$

Table 1: Corrosion inhibitors are selected for use in a sweet environment

Name of inhibitor	Inhibition efficiency	References
N,N'-(pyridine-2,6-diyl)bis(1-(4-methoxyphenyl)-methanimine)	93%	[61]
2-(4-methoxyphenyl)-4,5-diphenyl-1H-imidazole	90%	[62]
4,5-diphenyl-2-(p-tolyl)-1H-imidazole	84%	
2-(4-nitrophenyl)-4,5-diphenyl-1Himidazole	77%	
1,3-bis(4-methoxybenzyl)-2-(4-methoxyphenyl)imidazolidine	92%	[63]
1,3-bis(4-methoxybenzyl)-2-phenylimidazolidine	86%	
1,3-bis(4-methoxybenzyl)-2-(4-nitrophenyl)imidazolidine	83%	
1,2,4,7,9,10-hexaazacyclo-pentadeca-10,15-dien-3,5,6,8-tetraone	92%	[64]
5,10,15,20-tetra(4-pyridyl)-21H,23Hporphine	92%	[65]
5,10,15,20-tetraphenyl-21H,23Hporphine	81%	
5,10,15,20-tetrakis(4-hydroxyphenyl)-21H,23H-porphine	84%	
2-undecyl-1-ethylamino imidazoline	97%	[66]
1-(2-(2-(heptadeca-1,3,5,7,9,11,13,15-octayn-1-yl)-4,5-dihydro-1H-imidazol-1-yl) ethyl) thiourea	95%	[67]
1-(2-tetradecyl-4,5-dihydro-1H-imidazol-1-yl)ethan-1-one	81%	[68]
Imidazoline derivative	82%	[69]
2-(2-undecyl-4,5-dihydro-1Himidazol-1-yl)ethan-1-amine	87%	[70]
1-(2-aminoethyl)-1-(2-hydroxyethyl)-2-undecyl-4,5-dihydro-1H-imidazol-1-iumchloride	98%	

Table 2: Summary of research for green and commercial corrosion inhibitors from (2011 to 2020) of Mild Steel in a sweet environment

Details	Corrosive Media	Reference /Year
1. Guar gum and methyl methacrylate (GG-MMA) composite 2. Experiments: Weight loss, surface analysis(SEM), (EIS), (PDP), (AFM), (SECM). 3. Parameters: Concentration (100,200,300,400 p.p.m). Temperature : (323, 343, 363 and 383 K) . immersion time 6 hour 4. Results obtained at 400ppm and 323k the IE is 90%. 300 ppm +KI(0.5Mm) and 323K, the IE is 96.8%	3.5wt% NaCl solution	[71] / 2020
1.2-(2-pyridyl) benzimidazole(2PB) 2. Experiments: Electrochemical measurements (EIS), (PDP Surface analysis(SEM), (ATR-IR). 3.Parameters: Concentration (1.28,2.56) mM. Speed rotation: (500,1000,2000,4000) r.p.m immersion time:(1,4,8,12) hour 4. Results obtained at 2.56 ppm (2PB),1000 rpm, and 12 hours the IE is 87.2% (2PB+0.14mMThiobarbituric acid TBA) 4000rpm;12hour; IE 95.6%.	Brine	[72] /2020
1.Hexamethylene-1,6-bis(N–D-glucopyranosylamine) HGA 2. Experiments: electrochemical techniques, EIS, EFM, LPR, PDP, Surface analysis SEM/ EDX, FTIR 3.Parameters: Concentration (0.45,0.91,1.36,2.27) x10$^{\wedge-4}$. Temperature: 298 k immersion time:1 hour 4. Results obtained: The IE is 91.82 % at a concentration of 2.27 ×10$^{\wedge-4}$	3.5wt.% NaCl	[73] / 2019
1. Gum Arabic (GA) 2. Experiments: Weight loss, electrochemical techniques (EIS), (PDP), surface analysis (SEM, FT-IR) 3. Parameters:Concentration (0.2,0.3,0.4,0.5,0.9,1) g.L^{-1} Temperature: 298,323 k immersion time:24 hour 4. Results obtained: The IE is 68.78 % at a concentration of 0.5g.L^{-1} and 298k.	0.5M of KCl	[74] / 2019
1. multi-mannich base (MBT). 2. Experiments: Weight loss, Electrochemical Measurements (EIS), (PDP), surface analysis (AFM) 3. Parameters: Concentration(50,100,200 ppm). Temperature : (313, 323,333,343,353,363 K) . immersion time 72 hour 4. Results obtained at 300 ppm and 323k the IE is 86.6%.	3 wt % NaCl	[75] / 2019
1. Two novel thiadiazole derivatives (BTTA)(DSTA). 2. Experiments: potentiodynamic polarization Measurements (EIS), surface analysis(SEM) 3.Parameters: Concentration (0.005,0.01,0.025,0.05,0.1,0.2) mM of BTTA, (0.001,0.0025,0.005,0.01,0.025,0.05) mM of DSTA. Temperature: (333K). immersion time 72 hours 4. Results obtained at 0.025mM and 333k showed the IE is 99.37% DSTA. But at 0.2Mm and 333k, the IE is 99.3% BTTA.	produced water	[76] / 2018
1.Diethylenetriamine (DETA) 2. Experiments LPR (SEM), X-ray spectroscopy (EDS), and FTIR 3. Parameters: Concentration (440,880 ppm) . Temperature: (393,423 k) immersion time:8 hours 4. Results obtained at 440 ppm and 423 k the IE is 61%.	1 wt % NaCl solution	[77] / 2018
1. Asymmetric Gemini 2. Experiments: weight loss, electrochemical measurement EIS, SEM 3.Parameters: Concentration (0,5,10,20,40 and 80 ppm) . Temperature : (343,423 k) immersion time: 72 hours 4. Results obtained at 80 ppm and 343 k, the IEWL is 83%. IEEIS, on the other hand, is 88.2 % at 80 ppm, 343K.	Brine Solution	[78]/ 2017
1. N,N′-(pyridine-2,6-diyl)bis(1-(4-methoxyphenyl) methanimine (PM) 2. Experiments: weight loss, potentiodynamic polarization, EIS, X-ray, diffraction XRD, contact angle, SEM, AFM, SECM Parameters: Concentration(50,100,200,400). Temperature : (313,373 K) . immersion time 7 days. 4. Results obtained: At 400 ppm, the IE is 93% (J55 steel) and 90% (N80 steel) at 313 k.	3.5 wt.% NaCl	[79] / 2017
1. aimidazoline derivative (IM) and l-cysteine (CYS) 2. Experiments: weight loss, potentiodynamic polarization, EIS, X-ray, (XPS) 3. Parameters: Concentration(5,10,20,50,100ppm). Temperature : (333 K) , immersion time : 72 hour. 4. Results obtained: At concertation of 50 (IM), 10 (CYS) ppm, and 333K, the IE $_{EIS}$ is 82% and 50 (IM), 10 (CYS) ppm, 333K, IE 90.9%	brine solution	[80]/ 2016
1. Oligomer 4-Vinylpyridine O(4-VP) 2. Experiments: weight loss and linear polarization 3. Parameters: Concentration(5,10, 50,100,150,200ppm). Temperature : (303,323 ,343 k) . immersion time: 24 hours. 4. Results obtained at 200 ppm and323k the IE $_{LP}$ is 89.9 %, but at 50 ppm and 323k, the IE $_{WL}$ is 69%.	Brine Solution	[81] / 2016
1. Calotropis procera leaves 2. Experiments: Electrochemical techniques(LPR), EIS test, Potentiodynamic scans, SEM, FTIR 3. Parameters: Concentration(25,50,100,150,200 ppm Temperature : (298,313,323 ,343 k) . 4 . Results obtained at 200 ppm and 313 k the IE is 93%.	3.5 wt% NaCl	[82] / 2016
1. novel green surfactants based on cottonseed oil 2. Experiments: Electrochemical techniques(LPR), EIS Potentiodynamic polarization, SEM, FTIR 3. Parameters: Concentration(25,50,75,100 ppm) Temperature : (323 k). immersion time: 20 hour 4. Results obtained at 100 ppm and 323 k the IE is 99.34%.	1% NaCl	[83]/ 2015

Table 2: Continued

Details	Corrosive Media	**Reference /Year**
1.Thiosemicarbazide-imidazole derivative (TH-IM) 2. Experiments: Weight loss, Electrochemical technique, EIS Potentiodynamic polarization, SEM, FTIR 3. Parameters: Concentration(50, 100, 200, 400 ppm) Temperature : (298, 313, 333 and 353k) immersion time: 72 h 4. Results obtained at 400 ppm and 333 k the IE is 98%.	3wt% NaCl	[84] / 2015
1. Novel naphthenate surfactants 2. Experiments: Electrochemical techniques(LPR), EIS Potentiodynamic polarization, SEM, FTIR, EDRF) 3. Parameters: Concentration(25,50,75,100 ppm) Temperature : (323 k) immersion time: 20 hour 4. Results obtained at 100 ppm and 323 k showed the IE is 99.76%	Brine	[85] / 2015
1. Heptadecyl-tailed mono- and bis-imidazolines 2. Experiments: Electrochemical technique Tafel extrapolation method, LPR), Measurement of surface tension 3.Parameters:Concentration(2,3,5,7,9ppm) (1,2,5,8,10,15,50,100 ppm) Temperature : (303,308, 313,318,333k). 4. Results obtained: The IE is 86% (Tafel method) at 100 ppm, 313 k, and 96% (polarization method) at 7 ppm and 313 k.	saline	[86]/ 2012
1. Rosin Amide Imidazoline (RAIM) 2. Experiments: Electrochemical technique EIS surface analysis SEM, AFM 3.Parameters:Concentration 50,100,200 ppm) Temperature : (293, 313,333 k). 4. Results obtained at 200ppm and 313k the IE is 97%	Formation Water	[87] / 2011
1. N-[2-[(2-aminoethyl) amino] ethyl]-9-octadecenamide (AAOA) 2. Experiments: Electrochemical technique Polarization, EIS surface analysis SEM, AFM 3. Parameters:Concentration (0.07, 0.14, 0.27, 0.82, 1.36, 2.72, 4.08, 5.44×10^{-5} mold m^{-3}) Temperature: (293, 313, 333 k). 4. Results obtained at 2.72×10^{-5} mold m^{-3} and 313K the IE is 99 %.	5 wt% NaCl	[88] / 2011
1. Dicyclohexylamine and oleylamine (DCHA+O) 2. Experiments: Electrochemical technique Polarization, EIS, LPR, WL surface analysis SEM 3. Parameters: Concentration (50 ppm). Temperature : (293,343k). immersion time: 72 hours. 4. Results obtained at 50 ppm and 343 k, the IE is 98.6%.	3 wt. % NaCl	[89] / 2012
1. Complex Surfactants 2. Experiments: Electrochemical technique Polarization LPR, WL surface analysis SEM, FTIR, EDRF analysis 3.Parameters:Concentration (25,50.75,100,150 ppm) Temperature : (323 k). immersion time: 20 hours. 4. Results obtained at 150 ppm, 323 k, the IE are 98.51 and 99.72%	1% NaCl	[90] / 2012

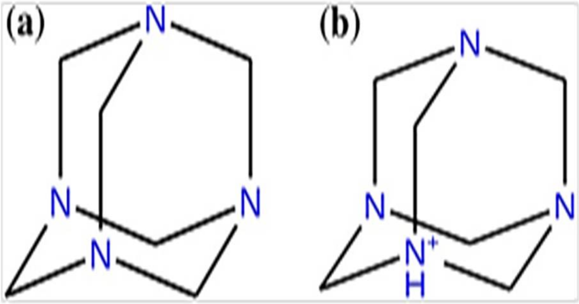

Figure 5: 2D structure of (a) neutral and (b) protonated hexamethylenetetramine (HMTA)[58]

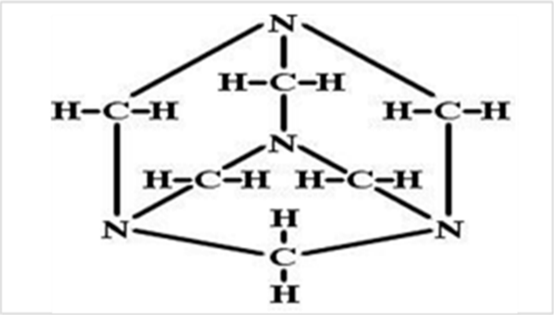

Figure 6: The chemical structure of hexamine [59]

5. Conclusions

Corrosion is a major problem in the industrial sector, particularly in the oil and gas industry, and it causes significant losses and environmental disasters. While this problem cannot be completely eliminated, preventive measures are taken to prevent corrosion of metal surfaces and environmental disasters. In the oil and gas sector, carbon dioxide corrosion is one of the most studied types of corrosion. This is primarily due to crude oil and natural gas. CO_2 is frequently obtained from an oil reservoir or a gas well. Even though commercial inhibitors are toxic and contaminate the environment, they are nevertheless used. Because of their high efficiency and availability, organic inhibitors containing nitrogen or sulfur functionalities were utilized in the oil and gas industry. CO_2 has two effects: it increases the amount of hydrogen produced on the cathode and produces carbonate-oxide layers on the metal's surface. The highest efficiency can be used 1-(2-aminoethyl)-1-(2-hydroxyethyl)- 2-undecyl-4,5-dihydro-1H-imidazol-1-iumchlorideobtained as inhibitor obtained 98%. This review could help in the creation of high-quality CO_2 corrosion inhibitors.

Author contribution

All authors contributed equally to this work.

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The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

Authors declare that their present work has no conflict of interest with other published works.

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