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Medicinal Materials as Eco-friendly Corrosion Inhibitors for Industrial Applications: A Review

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Abstract
The inhibition of electrochemical reactions has several essential uses, including preserving metals and alloys against corrosion, leveling cathodic metal deposition, and so on. Corrosion of metals and alloys may be prevented by using inhibitors of electrochemical processes. Medication active ingredients are potent inhibitors because their chemical structures include lone pair electrons or electrons in other places. This is because they may adhere to metal surfaces via physical interactions and varying strengths of chemical bonding. This is because they can do both tasks. Because of the poisonousness of commonly applied corrosivity inhibiting materials, as well as the environmental restrictions laws around the usage and release, it is found a lot of concern in finding effective non-hazardous alternatives. Over the last several decades, extensive research and development have resulted in the discovery of new grades of safe chemical compounds that function as corrosion inhibitors for metallic structures. The use of a range of prescription chemicals that can act as corrosion inhibitors for metal and metal alloys has become more important. The most recent contributions of the previous work upon their usage of medicines as corrosivity inhibiting compounds for several metallic surfaces are summarized through this study.

Keywords Green corrosion inhibitor · Corrosive environment · Structure choice · Design concept · Corrosion inhibitor · Adsorption configuration

1 Introduction

Chemical corrosion inhibitors have a significant effect on corrosion prevention and alleviation techniques [1]. It is well known that the organic molecules with (P, S, N, and O) atoms, and or p bonds have a significant result in corrosion inhibition in different corrosive media. Furthermore, inorganic moieties such as $–CrO_4^{--}$, $–Cr_2O_7^{--}$, $–NO_3^-$, are the most powerful and efficient inhibitors [2–7]. However, because of the numerous detrimental impacts, these chemicals have had on the environment, their usage has recently been questioned [8]. As a result, the discovery of new corrosion inhibitors from natural sources that are non-toxic has been deemed increasingly necessary and desired [9]. Drugs (chemical medications) appear to be selected as a good alternative to replenish conventional harmful inhibitors for corrosion due to their natural origins, non-toxic properties, and low detrimental consequences on the aquatic environment [10–14].

The quest to produce environmentally acceptable corrosion inhibitors overlaps with several pharmacological examination goals, in identifying or developing compounds that have a desirable activity against microorganisms. Attempts for achieving the important task were heavily influenced using the concept of the resemblance of chemicals, which states that related molecules act similarly in general [15, 16]. Virtual screening is the technique of designating an undiscovered fragment to a category of effective or non-effective structures utilizing the measure of an inter-molecular resemblance [17]. It has previously been used to speed up the finding of possible corrosion mitigations [18]. More knowledge on computational methods of virtual screening, which is outside the scope of this study, may be obtained in a different place [19–21].

The findings of the scanning technique for weathering revisions are how similar the structures of medicines and

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inhibitors of corrosion stand out. In drug structures, carbocyclic and heterocyclic systems are common. As a result, substituted benzene rings are prevalent in drug structures, as are heterocycles including isoxazoles, imidazoles, thiophenes, furans, pyridines, and others. Corrosion protective qualities of several medicines have received much consideration in the current time because of the structural proximity stated above. This study summarizes existing research on many medicines employed as deterioration mitigators for a variety of alloys, laying the groundwork intended for categorization based upon therapeutic use. Antibiotics belonging to the b-lactam class are by far the most common antibacterial agents used in clinical practice. The fourth-membered N-comprising ring of b-lactam, which provides these medicines their anti bacterial action, is present in all of them structurally. Based on the arrangements of molecules encompassing and endorsing the committed position, they may be categorized into IV categories monobactams, carbapenems, cephalosporins, and penicillins.

These penicillins are the first b-lactam antibiotics, and they attack the cell wall [22, 23]. Penicillins are divided into four groups depending on their capability to destroy different kinds of microorganisms. These medicines used as corrosion inhibitors are classified into the following penicillin classes. The drug molecules have been adsorbed into Al_2O_3 through the carboxylic group since it is especially powerful and can occur by physical or chemical adsorption and the greatest adsorption has been observed whenever the pH of the solution is near the acidic region [24, 25]. In the case of amoxicillin, the pH may exist in a variety of acidic structures based upon, the pKa values since it is 2.4 and 7.4 [26]. The strong inhibitory effect of amoxicillin, amongst additional compounds, against the Al_2O_3 surficial is anticipated to the hydroxyl group's increased acidity. It was deduced that from the anodic polarization tests an escalation in amoxicillin load of about 5000 ppm did not imply a rise in deterioration prevention. In terms of this capacity to form ions of the proper metal complexes, the novelists presented double versions of the interface between aluminum and the molecule of amoxicillin, one involving the N-atom of the aliphatic amine and the other involving the oxygen atom of a cyclic amide [27].

The antibiotics have a wide range of action comparable to aminopenicillins, but they also exhibit action alongside the gram-negative bacteria from this Enterobacteriaceae series, containing several species of Pseudomonas Aeruginosa [28]. Cephalosporins, this second category of b-lactam antibiotics, combine most of the characteristics of the different penicillins. They are the most given antibiotics of their safest and extremely efficient comprehensive range of antimicrobial and/or bactericidal medicines. The heterocyclic ring system distinguishes cephalosporins from penicillins structurally. The nucleus of cephalosporins can be altered to give it varied characteristics. Cephalosporins are frequently classified into "generations" based on their antibacterial characteristics for convenience, however many medicines in the consistent group are not linked chemically and there is a wide range of actions. These earliest cephalosporins were labeled as the first generation, whereas later cephalosporins with a wider range were labeled as the next group. In most situations, this group of cephalosporins has considerably better antibacterial capabilities against gram-negative bacteria than the previous one, with reduced effectiveness versus gram-positive bacteria. Cephalosporins of the 4th group, on the other hand, exhibit real broad-spectrum action [29].

The physical character of the adsorption process was confirmed by a substantial drop in Gibbs free energy values with increasing temperature [30]. Because of its effectiveness and inexpensive cost, generic cephalexin is a popular alternative [31]. Because cephalexin is a zwitterion, meaning it includes mutually an acidic and basic grouping, a change in the pH of the solution causes a difference in the characteristic of the hydrophobic molecule. This cephalexin is mostly found in the zwitterionic form in the range of pH 4.5–6.5. On the other hand, cephalexin is mostly found in the cationic form in solution at lower pH levels [32–34]. Although these antibiotics are commonly employed to handle bacterial infections, there is no available data demonstrating the ability to prevent deterioration. The 3rd group of cephalosporins offers a wider range of action for improving the activity against gram-negative bacteria. Certain members of these groups' activity against gram-positive bacteria have decreased, and as a result, secondary reactions such as dimerization or condensation may occur, resulting in molecules with totally new chemical properties [35, 36].

Fourth-generation cephalosporins have emerged as a viable alternative to third-generation cephalosporins in recent years, owing to their unique characteristics, including higher resistance to b-lactamases [37]. Tetracyclines are organic compounds based on a model of an extremely oxygenized structure of hydro naphthacene. The first of these unique compounds to be identified as aureomycin, or chlortetracycline, and its potent action compared to a wide range of pathogenic bacteria quickly earned this one a prominent place in medical practice [38]. Tetracyclines are antibiotics that are employed to remedy toxicities in the upper respirational area. They are also used to treat atypical pneumonia, Lyme disease, some sexually communicated infections, and in certain cases, anthrax prevention in persons who have been exposed to anthrax spores. However, the establishment of widespread microbial resistance to tetracyclines has restricted their therapeutic usage in recent years [39]. Macrolides, a class of antimicrobials that target gram-positive bacteria, are frequently recommended to care for contaminations of the respirational expanse and sensitive skins. Sulphonamides, often known as sulfa medicines, are

antibacterial chemicals with the molecular structure of sulfanilamide that has been around for a long time. They have been used in therapeutic settings for more than 50 years, with the initial registration in the 1940s in Australia. Currently, antibiotics-based b-lactam are far above often applied to avoid contamination than sulfonamides, although due to their low cost, sulfonamides are still widely utilized in many regions of the world [40].

Any chemical with a SO_2NH_2 moiety is referred to as a sulfonamide. Based on their chemical structure, sulfonamides are classified into three categories [41]. Antibiotics having a phenylpropanoid structure are known as amphenicols. Because amphenicols inhibit protein and are efficient in the treatment of a variety of infectious illnesses, they are utilized in veterinary medicine for medicinal and preventive principles to improve feeding proficiency and increase organism development [42]. Evaluation of the inhibitory mechanism, including a decision of whether the QCP of these medications is evaluative. Fungi are the possible origin of a wide variety of illnesses known collectively as mycoses, which may range in severity from mild to life-threatening [43, 44]. Amphotericin B is the antifungal medication with the largest coverage versus mycological disease, and it was formerly considered the great requirement therapy for the dangerous mycological disease. Though, due to amphotericin's toxicity and the presentation of fewer poisonous fungicidal medications such as echinocandins and azoles, these are currently alternate therapeutic choices [45].

One of the highly frequently utilized fungicidal medicines as inhibitors for corrosion among these chemicals is azoles. Because of their effective metal inhibition properties, these synthesized compounds have gotten a lot of attention [46–49]. Few researchers have investigated fungicides as copper corrosion inhibitors in artificial saltwater [50, 51]. Their findings revealed that these compounds can prevent copper corrosion to a significant degree. These findings are in line with those of earlier studies [52, 53]. Helminth infections, which are caused by parasitic worms, are among the most widespread ailments affecting humans since they impact a significant proportion of people all over the world [54]. Medicines that either stun or kill helminths in the body are referred to as anthelmintics, while the term antihelminthics are more common. The authors did not make any assumptions regarding the underlying process that influenced their liquefaction [52, 55].

The acting category comprises ten chemically distinct medicines that appear to operate on the central nervous system. Antiviral medications are beneficial for both treating and preventing infection [56, 57]. Histamine is a biological amine found in mammalian tissues in large amounts. Its activities are facilitated by interfaces together with the receptors of the cell membrane. The drugs that inhibit the cell membrane receptors are commonly prescribed and have major therapeutic uses. These receptor adversaries suppress the immunological reaction and are used to treat diseases such as allergic rhinitis [58, 59]. This appears to be supported by studies on traditional antihistamines, which found that the $–NH_2$ mediety is always alkaline, with pHs varying from 8.5 to 10 and therefore protonated when attached to the metal surface [60]. The charge distribution in molecules of any chemical structure depends on the situation condition between the metal and the solution interface, such as metal nature, metallic surface charge, and kind of corrosive medium all have a major impact on the adsorption process [61–66].

Antipsychotic medicines (antipsychotics) are used to treat a variety of mental illnesses. They constitute the cornerstone of treatment for schizophrenia, delusional illness, and dementia-related psychosis. Antipsychotics are divided into two types: normal and atypical. The first successful antipsychotics were conventional antipsychotic medications. The first was chlorpromazine, which was discovered in 1952 by French physicians. Haloperidol, fluphenazine, and thiothixene were among the others that followed [67]. There are currently many atypical antipsychotics that have a reduced risk of significant or long-term adverse effects than traditional antipsychotics [68–72]. On the other hand, the authors appear to overlook the fact that these chemicals are pH-dependent [73]. Diketopiperazine was the main deprivation yield below $pH = 5$, whereas the diacid, enalaprilat, was the most important deprivation yield at $pH = 5$ and above. Imatinib mesylate was later used to prevent mild steel corrosion in H_2SO_4. It is found that the estimated electronic parameters were generally in agreement with the published papers [74]. Regardless of the theoretical foundations, the investigation revealed that antihypertensive medications are quite effective in preventing mild steel corrosion [26]. The etiological agent of an amoebic liver abscess and amoebic dysentery is Entamoeba Histolytica. It is an infective Entamoeba, and Entamoeba Dispar, a non-pathogenic Entamoeba, are two different but physically indistinguishable Entamoeba species. Entamoeba Histolytica can infect the mucosa of the intestine, causing intestinal amoebiasis as well as extraintestinal amoebiasis.

2 Categories of Corrosion Inhibitors

2.1 Mixed Corrosion Inhibitors

The second type is semisynthetic penicillin, which includes dicloxacillin, cloxacillin, nafcillin, and oxacillin. Methicillin was the first member of this group, and it was supported by dicloxacillin, cloxacillin, nafcillin, and oxacillin. These medications are sometimes referred to as anti-staphylococcal penicillin because they are effective against

penicillinase-producing gram-positive cocci, particularly staphylococcal genera [75]. It has been hypothesized that cefatrexyl inhibits activity by a mechanism similar to that postulated here. When compared to cefatrexyl in terms of tenures of reserve effectiveness (as measured by the Tafel polarization process), it was found that cefotaxime was more effective in inhibiting corrosion by about 95.8 percent [76–78]. In the case of sulfate and phosphate solutions, however, a considerable fraction of cefatrexyl can occur in the chargeless state, which can easily bind to the surface of iron [79].

However, it is not unexpected that research on the antibiotic's corrosion inhibitory characteristics appears. Cefazolin sodium is a 7-aminocephalosporanic acid derivative. It is employed to care for bacterial diseases in the respirational system, genital treatise, structure of the skin, biliary tract, bone, and joint diseases [80]. WL and EIS tests provided clues about cefazolin's inhibitory mechanism. Furthermore, a rise in temperature of 35–65 oC resulted in a reduction in inhibitory effectiveness. Cefadroxil's behavior was shown to be superior to that of cephalexin in terms of other characteristics studied [81–83] as seen in Table 1. The very electron-releasing feature of p-OH was used to explain the greatest inhibition of cefadroxil. Cefadroxil's interaction with various metallic ions is well-established, and testimony shows that cefadroxil can produce metal ions complexes [84].

Additionally, in the existence of a donor group, it is not the only criterion for improving the inhibiting action, since cefadroxil's chemical structure plays a significant role in its inhibitory strength [132, 133]. Ceftibuten, ceftazidime, cefdinir, cefpodoxime, cefoperazone cefixime, ceftriaxone, and cefotaxime, are 3rd generation cephalosporins [134]. Ceftriaxone (Rocephin) is an antibacterial drug that is widely used to treat serious infections [135]. They also found that the aromatic ring has a p-electron as well as a lone pair of electrons on the N atom. This is significant since p-electron and lone pair electrons are the most important components in determining the efficiency of the ceftriaxone inhibitor. There is a possibility that the spectrum study will be useful in acquiring a deeper understanding of the ceftriaxone inhibitory mechanism [136]. The IR chart of ceftriaxone's ternary complexes with metallic ions such as Zn^{2+} and Cd^{2+} was concluded and published. Though, it has been hypothesized that the free ceftriaxone's b-lactam carbonyl group is involved in the coordination. These findings lead to the conclusion that ceftriaxone stands on the surface of steel via a physical bond between b-lactam –CO with $–COO^{-}$, functional groups preventing corrosion.

Cefotaxime is the second medication in this category that is used as an inhibitor for steel corrosion (Table 1). Because of its strong and broad range of antibiotic action, cefotaxime looks to be best fitted for newborn septicemia pharmacologically. However, the medication is costly (often excessively so) and is sold under many brand names such as cefotaxime sodium (kefotex, cefotax, Claforan) [137]. The greatest permanence of cefotaxime sodium was found in the pH range from 4.5 to 6.5, with and temperature of 25 °C. They stated that, when Cl ions are present on the steel surface, the following fast reaction occurs:

$$\left(H_2O\right)_{ads} + Cl^{-} = Cl^{-}_{ads} + H_2O \quad (1)$$

They concluded that cefotaxime sodium's high inhibitory effect is owing to the occurrence of an unrestricted amino functional group since it is highly positively charged (protonated) because of its existence in hydrochloric acid solution. The inventors appear to have overlooked the unpredictability of sodium salt of cefotaxime in an acidic medium [138, 139]. At this low pH, b-lactam cleavage or de-esterification would be anticipated to hydrolyze cefotaxime sodium [120, 140–143]. They discovered that ceftazidime regulates both cathodic and anodic processes throughout the corrosion process and its effectiveness for suppression of corrosion procedure is related to the quantity of adsorbed inhibitor. For this suppression, the values of ΔH_{ads} with estimated values in the assortment from 24 to 45 kJ mol^{-1}, and a combined method of protection through both physical and chemical adsorption were recommended. The ceftazidime is also could be positively charged in an acidic media so that the obtained complex may be electrostatically bonded to the surface of mild steel since it already has a positively charged surface because of its existence in this medium [144].

This suggests that ceftazidime breakdown products (such as pyridine and methylene derivatives) have a significant impact on ceftazidime's inhibitory action in 1 M HCl solution [145]. However, earlier research on the permanence of ceftazidime electrolytes indicated that this molecule is only steady in the dehydrated form and is susceptible to hydrolytic breakdown, resulting in additional pyridine discharge when reconstituted with water [146–148]. At pH 4.5–6.5, maximum constancy in the solution of ceftazidime has been recorded [149, 150]. Cefepime's breakdown was predicted, as two related compounds, ceftazidime, and cefpirome, had comparable breakdowns [151–154]. It was also discovered that ring-opening occurs before N-methyl pyrrolidine cleavage. The relative quantities of breakdown products detected in mass scans after varied doses of cefepime led to this result. Furthermore, given the value of $\Delta Gads = 33.52$ kJ mol^{-1} at 303 K, chemical adsorption of cefixime on the surface of steel was proposed. Based on the findings, it is tempting to link the chemical adsorption of cefixime fragments on metallic surfaces owing to the collaboration of p-orbitals. On the other hand, the cefixime contains a lactam and $–NH_2$ bond in its molecular arrangement, which makes it susceptible to basic and acidic breakdown. The degradation of cefixime trihydrate underneath various aggressive circumstances

Table 1 Drugs act as a mixed corrosion inhibitor

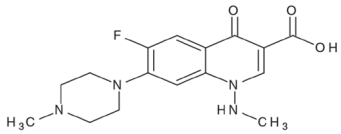
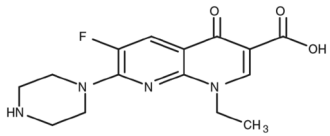
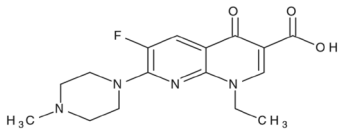
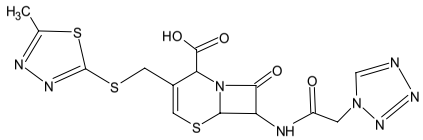
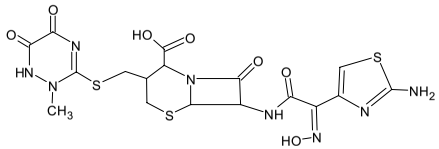
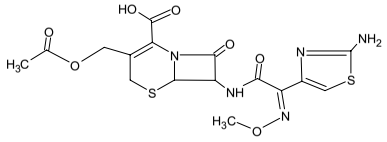
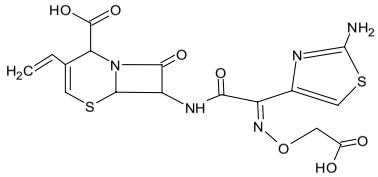
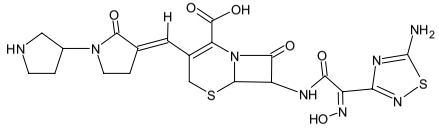
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Amifloxacin		Typhoid fever, cystitis, prostatitis, sinusitis, infectious diarrhea	NaCl	Mild steel	[73]
Mixed	Enofloxacin		Urinary tract infections that are not complex	NaCl	Mild steel	[73]
Mixed	Pefloxacin		Infections of the gastrointestinal tract and genitourinary tract caused by gram-negative bacteria	NaCl	Mild steel	[73]
Mixed	Cefazolin		Illnesses caused by bacteria in the skin or lungs or bones or joints or the stomach or heart valve and urine tract	HCl	Mild steel	[85]
Mixed	Ceftriaxone		As well as infections of the lungs, skin, urinary system, blood, bones, and joints, gonorrhoeic and pelvic inflammatory diseases are also common	HCl	Mild steel	[86]
Mixed	Cefotaxime		Septicemia, meningitis, and infections of the respiratory tract, skin, bones, joints, and urogenital system	HCl	Mild steel	[87]
Mixed	Cefixime		Gonorrhea, tonsillitis, and pharyngitis are all common illnesses	HCl	Mild steel	[88]
Mixed	Ceftobiprole		Illnesses affecting the skin or soft tissue	HCl	Mild steel	[89]

Table 1 (continued)

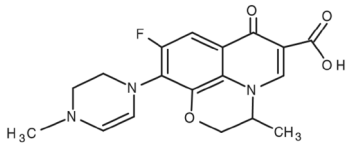
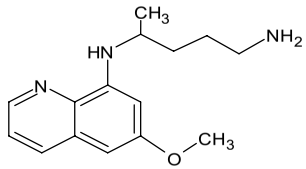
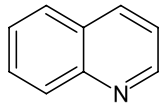
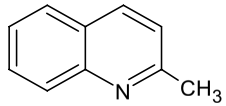
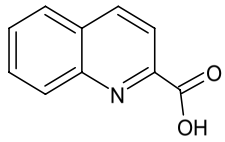
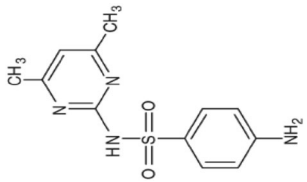
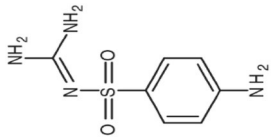
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Ofloxacin		For more information on gonorrhoeic and other conditions that affect the lungs, visit www.gonorrhea.org	HCl	Mild steel	[73, 90–93]
Mixed	Primaquine		Malaria and pneumocystis pneumonia are both serious health threats	HCl	Mild steel	[94]
Mixed	Quinoline		Treatment with antimalarials	HCl	Mild steel	[95]
Mixed	Quinaldine		Treatment with antimalarial	HCl	Mild steel	[95]
Mixed	Quinaldic acid		Treatment using antimalarial drugs	HCl	Mild steel	[95]
Mixed	Sulfamethazine		Bacterial enteritis, metritis, and caecal coccidiosis are examples of diseases that can occur in poultry	HCl	Mild steel	[96, 97]
Mixed	Sulphaguanidine		Intestinal infections, bacillary dysentery (caecal coccidiosis), gastrointestinal illnesses	HCl	Mild steel	[96, 97]

Table 1 (continued)

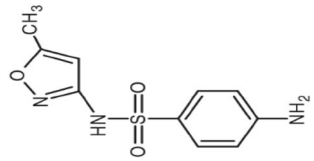
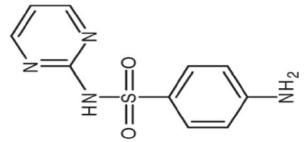
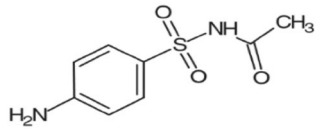
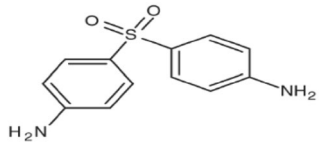
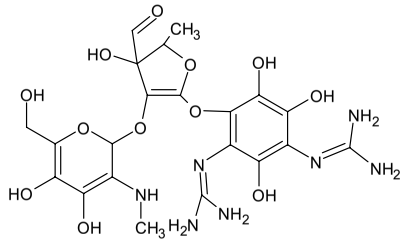
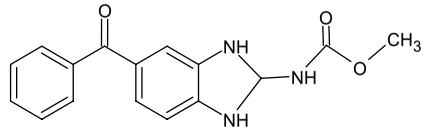
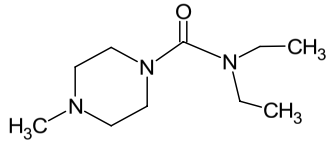
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Sulfamethoxazole		As well as Malaria, Conjunctivitis, Toxoplasmosis, and UTIs	HCl	Mild steel	[96, 97]
Mixed	Sulfadiazine		Toxoplasmosis, urinary tract infections,	HCl	Mild steel	[96, 97]
Mixed	Sulfacetamide		Acne and seborrheic dermatitis are two common skin conditions	HCl	Mild steel	[96, 97]
Mixed	Dapsone		Leprosy and dermatitis herpetiformis	HCl	Mild steel	[96, 97]
Mixed	Streptomycin		Infections of the urinary tract, Brucellosis, Calymmato bacterium granulomatous klebsiella pneumonia, mycobacterium tuberculosis, Pasteurella pestis, and enterococcus faecalis are some of the bacteria that can cause illness	HCl	Mild steel	[98]
Mixed	Mebendazole		Worms of the digestive tract, lungworms, and magnesia are seen in ruminants	HCl	Mild steel	[99]
Mixed	Diethylcarbamazine		In addition to ascariasis and filariasis,	HCl	Mild steel	[100]

Table 1 (continued)

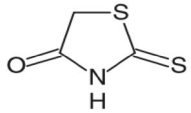
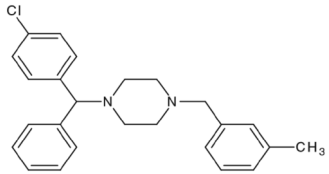
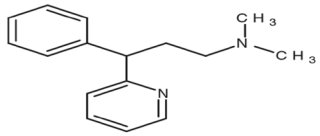
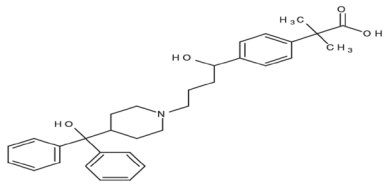
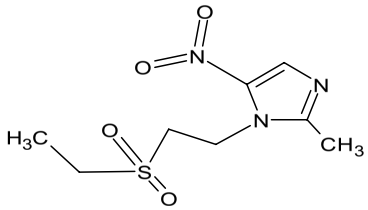
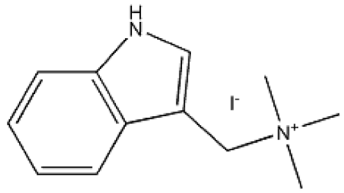
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Rhodamine		Picornaviruses	HCl	Mild steel	[101]
Mixed	Meclizine		Motion sickness causes nausea, vomiting, and dizziness	HCl	Mild steel	[102]
Mixed	Pheniramine		Conditions of the eyes and nasal passages caused by allergies, common cold, and other respiratory tract illnesses	HCl	Mild steel	[103]
Mixed	Fexofenadine		Seasonal allergies and chronic urticaria are treated	HCl	Mild steel	[104]
Mixed	Tinidazole		Infections caused by amoebas and parasites	HCl	Mild steel	[105]
Mixed	Donaxine		It has antimutagenic properties	HCl	Mild steel	[106]

Table 1 (continued)

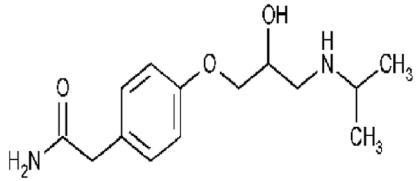
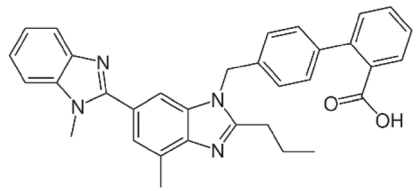
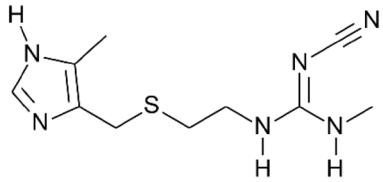
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Atenolol		As a beta blocker, Atenolol belongs to a class of drugs known as beta blockers Treatments for high blood pressure and irregular heartbeats are available with this drug (arrhythmia) Additionally, it can be used to reduce angina-induced chest discomfort	HCl	Mild steel	[100]
Mixed	Telmisartan		Treatment of hypertension using this drug (hypertension). To avoid strokes, heart attacks, and renal issues, lowering high blood pressure is essential to your health. Drugs termed angiotensin receptor blockers include telmisartan (ARBs) It works by relaxing blood vessels, allowing the blood to flow more freely through them	HCl	Mild steel	[107]
Mixed	Cimetidine		After taking CIMETIDINE, the stomach's acid is prevented from being released into the bloodstream. Orally, it is used to treat stomach or intestinal ulcers. If you have acid reflux or ulcer discomfort, it may be able to ease your suffering	HCl	Mild steel	[108]

Table 1 (continued)

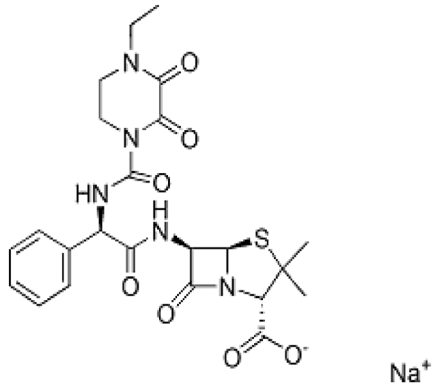
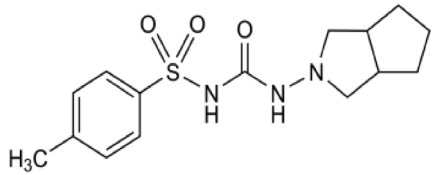
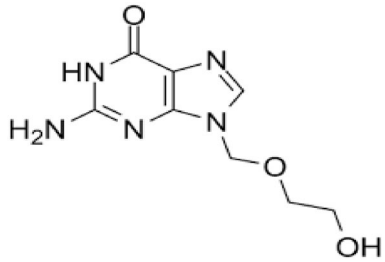
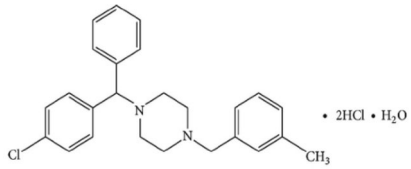
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Piperacillin Sodium		Antibacterial injections that include piperacillin / tazobactam are used to treat bacterial pneumonia as well as cutaneous, gynecological, or abdominal infections. A penicillin antibiotic, piperacillin is a member of the penicillin family of drugs You may use this to treat infections by destroying the germs causing them	HCl	Mild steel	[105]
Mixed	Gliclazide		Type 2 diabetes is treated with a drug called gliclazide Along with decreasing blood sugar levels, Gliclazide also enhances the body's production of insulin	HCl	Mild steel	[109]
Mixed	Acyclovir		Acyclovir can be used to treat some types of viral infections If you have a cold sore around your mouth that is caused by herpes, shingles, or chicken pox, you can take this medicine to cure them. This medication type can also be used to treat genital herpes outbreaks	HCl	Mild steel	[110]
Mixed	Meclizine hydrochloride		Among other symptoms of motion sickness, meclizine is an antihistamine used to prevent and treat symptoms such as nausea, vomiting, and dizziness. It can also be used to treat vertigo and dizziness caused by inner ear diseases, as well	HCl	Mild steel	[111]

Table 1 (continued)

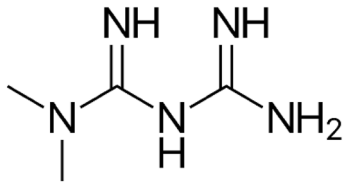
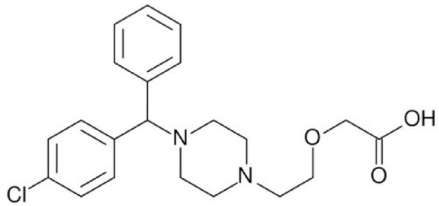
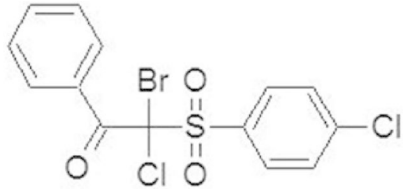
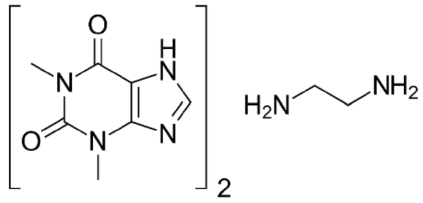
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Metformin		As well as metformin, diet and exercise are used to lower high blood sugar levels Anyone suffering from Type II Diabetes will be able to get the benefits of it. Maintaining a healthy blood sugar level can help you avoid kidney damage and other health problems such as blindness or nerve damage, amputations, and problems with sexual function	HCl	Mild steel	[112]
Mixed	Cetirizine		Cetirizine is used to treat eczema in addition to allergy symptoms including watery eyes, itchy eyes and nose, sneezing, and hives. When you have an allergic reaction, your body generates histamine, therefore it inhibits it	HCl	Mild steel	[113]
Mixed	Ketosulfone		Ketosulfone is considered a new class of non-cytotoxic urease inhibitors	HCl	Mild steel	[114]
Mixed	Aminophylline		Aminophylline can be used to treat a wide range of lung diseases. Asthma, chronic bronchitis, and other lung disorders can produce wheezing and shortness of breath, which can be prevented and treated with it. Breathing gets easier because the lungs' air passages are opened, and the muscles relax	HCl	Mild steel	[115]

Table 1 (continued)

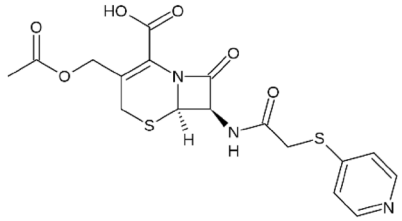
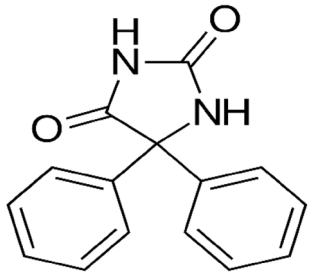
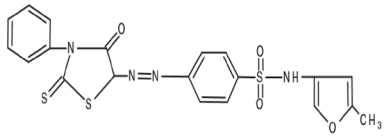
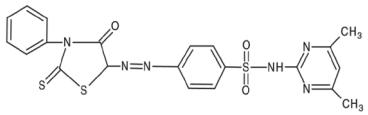
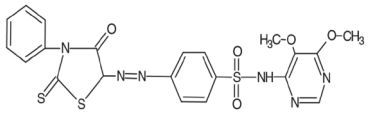
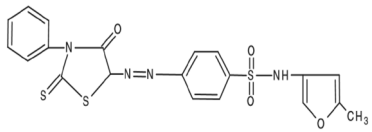
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Cephapirin		Gram-negative and gram-positive microorganisms are both susceptible to cephapirin. In addition, it is an antibacterial agent	HCl	Carbon steel	[96]
Mixed	Phenytoin		Phenytoin is used to treat some types of seizures, including those that occur during or after surgery on the nervous system. This family of medicines is called anticonvulsants used to treat seizures. Erroneous electrical activity in the brain is reduced	HCl	Carbon steel	[116]
Mixed	5-Sulphadiazineazo-3-phenyl-2-thioxo-4-thiazolidinedione		Infections caused by the virus	HCl	Stainless steel 304	[117, 118]
Mixed	5-Sulphamethazineazo-3-phenyl-2-thioxo-4-thiazolidinedione		Infections caused by the virus	HCl	Stainless steel 304	[117, 118]
Mixed	5-Sulphadimethoxineazo-3-phenyl-2-thioxo-4-thiazolidinedione		Infections caused by the virus	HCl	Stainless steel 304	[117, 118]
Mixed	5-Sulphamethoxazoleazo-3-phenyl-2-thioxo-4-thiazolidinedione		Infections caused by the virus	HCl	Stainless steel 304	[117, 118]

Table 1 (continued)

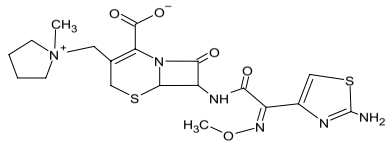
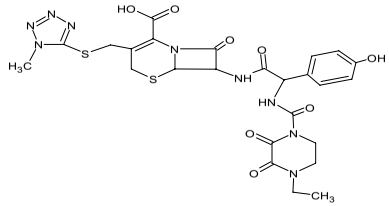
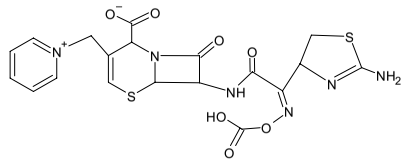
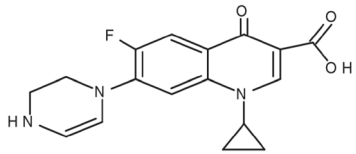
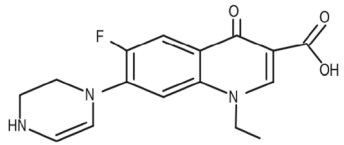
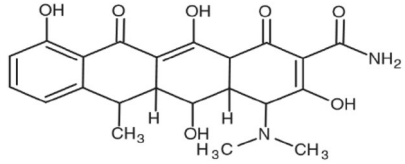
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Cefepime		Pneumonia, skin infections, and urinary tract infections are among the most common	HCl	Stainless steel 304	[119]
Mixed	Cefoperazone		Infections induced by susceptible bacteria	HCl	Stainless steel 304	[119]
Mixed	Ceftazidime		Blood and gynecological tract infections as well as lung and skin infections	HCl	Stainless steel 304, Mild steel	[119, 120]
Mixed	Ciprofloxacin		Typhoid fever, cystitis, prostatitis, sinusitis, infectious diarrhea	NaCl, HCl	Stainless steel 304, Mild steel	[15, 73, 90, 91, 93]
Mixed	Norfloxacin		In addition, there are syphilis, prostatitis, gonorrhoeic, and cystitis	NaCl, HCl	Stainless steel 304, Mild steel	[15, 73, 90, 91, 93]
Mixed	Doxycycline		Several conditions can affect men, including prostatitis, syphilis, chlamydia, pelvic inflammatory disease, and rickettsia diseases	KCl, HCl	Co-Cr alloy, Mild steel	[121, 122]

Table 1 (continued)

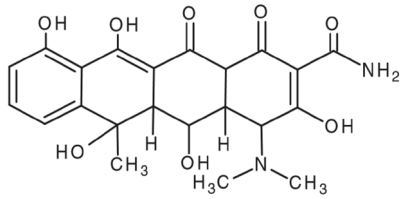
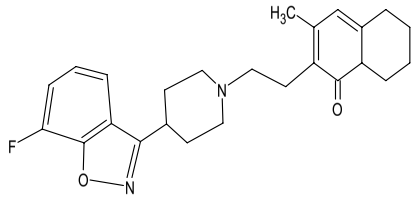
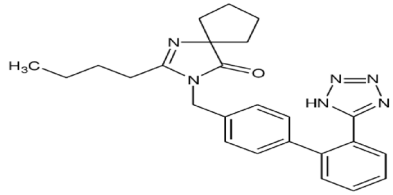
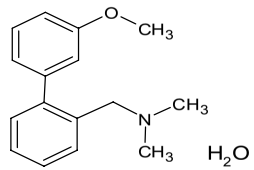
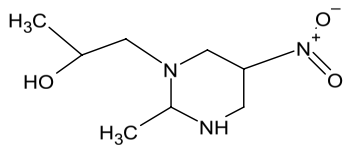
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Oxytetracycline		Chlamydia and other sexually transmitted diseases are also common. Examples include pneumonia, bronchitis, urinary tract infections, gonorrhoeic and syphilis, acne, conjunctivitis, rickettsia infections, cholera, leptospirosis, and tetanus	KCl, NaCl	Co-Cr alloy, Stainless steel, Ti	[121, 123]
Mixed	Risperidone		The symptoms of schizophrenia, mania, aggressive or self-destructive behavior, and mood swings include schizophrenia, mania, and abrupt mood shifts	HCl, H_2SO_4	Mild steel	[108]
Mixed	Irbesartan		High blood pressure (hypertension) and diabetes-related kidney damage are treated with irbesartan	HCl, H_2SO_4	Mild steel	[124]
Mixed	Tramadol		There is an acute pain relieve	HCl, H_2SO_4	Mild steel	[125]
Mixed	Secnidazole		Amoebiasis, giardiasis, trichomoniasis, and bacterial vaginosis are among the parasitic diseases	H_2SO_4	Mild steel	[116]

Table 1 (continued)

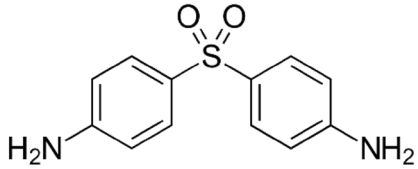
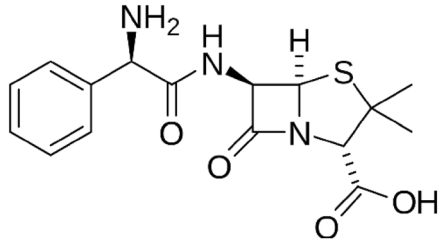
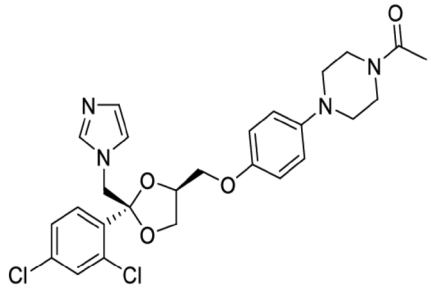
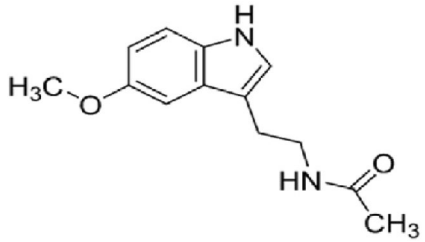
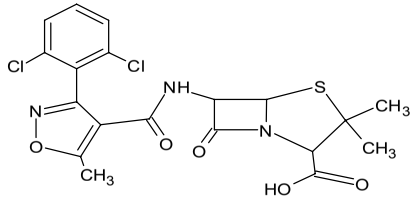
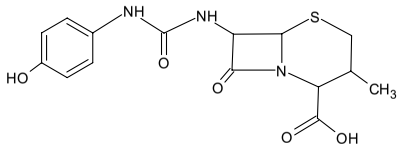
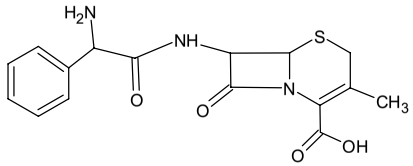
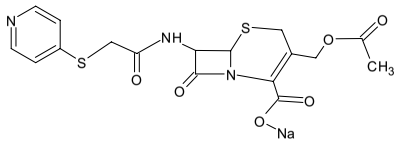
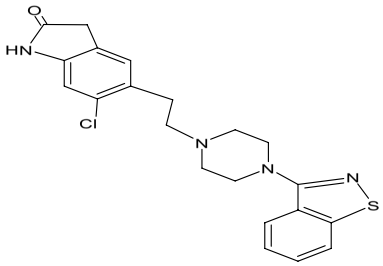
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Dapsone		Some skin disorders can be treated with this drug	H_2SO_4	Mild steel	[97]
Mixed	Ampicillin		Ampicillin is used to treat some bacterial disorders such as meningitis (infection of the membranes around the brain and spinal cord) and infections of the throat, sinuses, lungs, reproductive organs, and urinary and gastrointestinal systems	H_2SO_4	Mild steel	[126]
Mixed	Ketoconazole		Ketoconazole is used to treat skin infections such as athlete's foot, jock itch, and ringworm. Dermatologists may also use it to treat pityriasis (teeth discoloration). Infection with a fungus causes the skin of the neck and chest, as well as the arms and legs, to lighten or darken	H_2SO_4	Mild steel	[127]
Mixed	Melatonin		There is limited evidence that melatonin is effective in the treatment of delayed sleep phase and circadian rhythm sleep problems in the blind	H_2SO_4	Carbon steel	[98]

Table 1 (continued)

Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Mixed	Dicloxacillin		Cellulitis, impetigo, otitis externa, folliculitis, boil, carbuncle, mastitis, and septicemia are all skin diseases caused by Staphylococcus aureus (SAU)	H_3PO_4	Al 6063	[128, 129]
Mixed	Cefadroxil		Throat infections, skin infections, and urinary tract infections	H_3PO_4	Al 6063	[129]
Mixed	Cefalexin		infections of the upper respiratory tract, middle ear, bones & skin as well as the reproductive & urine systems	HCl, H_3PO_4	Mild steel, Al 6063	[129, 130]
Mixed	Cefadroxil		Endocarditis, prophylaxis, and surgical septicemia are all examples of surgical septicemia	HCl, H_2SO_4, H_3PO_4, $HClO_4$	Mild steel	[131]
Mixed	Ziprasidone		Bipolar disorder and schizophrenia are both mental illnesses	HCl, H_2SO_4	Zinc	[107]

such as alkaline or acidic breakdown has been investigated and spectrophotometry is used to measure oxidation [110].

It is now frequently applied in clinics for its authorized signs, which include practical monotherapy for feverish neutropenia, pneumonia, bacteremia, and infections of the urinary system, abdomen, skin, or sensitive tissues [155]. They also explained why IE differed depending on the molecular weight of the chemical compound. However, the influence of pH on cefepime stability has already been considered [149]. Furthermore, the provided mass spectrometry results revealed that cefepime degradation comprises and destroys of N-methyl pyrrolidine bond as well as opening the ring of β-lactam [156–159]. This categorization indicates a larger gram-negative profile. MRSA is one of the most prevalent bacteria responsible for severe clinic and population-developed illnesses, along with a soaring death and illness rate [59, 160, 161]. Since acidic pH enhances ceftobiprole binding ability and the adsorption of the chemical structure of ceftobiprole might occur because of p-electrons interacting with the steel surface after the physically adsorbed protonated molecules are deprotonated [162].

The 2nd group of quinolones such as flumequine and pipemidic acid had been created, although it was not much better than the first. Flumequin-fluorinated quinolone was used to create the 3rd group of quinolones. Tarivid, a brand name for ofloxacin, was first introduced in 1985, in Japan and afterward introduced in Europe and the United States. The carboxylic acid group of fluoroquinolone acts as an antiseptic with antibacterial properties due to its attack with DNA gyrase inhibition [163]. Ciprofloxacin is the most extensively used of the enhanced fluoroquinolones [164]. They discovered that, among other medicines, ciprofloxacin had the highest inhibitory effectiveness. Ciprofloxacin has the greatest negative ΔG_{ads} value (48.54 kJ mol^{-1}) in the range of values tested. Chemical adsorption of these compounds was postulated since the negative values of ΔGads were all higher than − 40 kJ mol^{-1} [165]. The strongest inhibitory impact of ciprofloxacin as a corrosion inhibitor was similarly attributable to the energy of its (HOMO) according to the border orbital energies. The most frequent ring systems are five and six members; however, tiny ring systems are also popular. The quinoline moiety can be found in a variety of commercially marketed antimalarial medicines, including mefloquine, quinidine, quinine, primaquine, and chloroquine [166].

In the 1940s, the United States launched a massive research program to create more effective and less dangerous antimalarial medicines. Three compounds were chosen for future research from this program: pentaquine, isopentaquine, and primaquine. The compound primaquine was found to be the most effective [167]. At a concentration of 0.4 mM, primaquine's inhibitory action was at its highest level, 98%. They hypothesized that the primary mechanism by which this drug inhibits the corrosion of mild steel is electrostatic interactions, which cause protonated molecules to adsorb on the surface of the metal. Primaquine, in its protonated form, can collect on metal surfaces, where it blocks surface-active sites. This is likely related to the fact that primaquine has a weakly basic nature [168]. Quinoline compounds have been discovered to be potent inhibitors. The maximum inhibitory effect was observed for quinaldic acid (94.21%), whereas the lowest was reported for quinoline (88.71%). Quinolones are compounds that are structurally generated from the chemical structure of quinoline since it contains a heterobicyclic aromatic ring, which gets its known name from the oily material that results after quinine's alkaline distillation [169, 170].

Fluoroquinolones are identified as antiseptic drugs that are synthesized rather than obtained from microorganisms. The quinolones, an older, similar family of antibacterial medicines, were poorly absorbed and could only be employed to care for infections of the urinary tract [171, 172]. Oxytetracycline is an antibiotic that belongs to the naturally occurring tetracycline family and has been widely used to treat plant and animal diseases [173, 174]. For some anti-corrosive metals, it is well known that Ti has an extremely high negatively potential of about 1.60 V, implying that it has a powerful chemical driving force for corrosion but in the case of molybdenum and chromium content in Vitallium, has been observed to play a major impact in its corrosion resistance [175, 176]. The sulfonylarylamines are the first group, having a sulfonamide fraction precisely linked to the ring of benzene at the N4 position and an unreplaced amine group (-NH_2). Sulfonamide antibiotics (sulfadiazine, sulfamethoxazole, sulfisoxazole, sulfapyridine, sulfaguanidine, sulfabromomethazine, sulfaethoxypyridazine, sulfamethoxypyridazine, sulfachlorpyridazine, sulfachlorpyri [177].

Soon after, oxytetracycline, also known as Terramycin, as well as tetracycline and 6-demethyltetracycline, had a similar function. All these compounds' distinctive chemotherapeutic action is reliant on the preservation of all organizational and stereochemical structures, all these features are considered the main reason for their effectiveness in the biosystem and corrosion protection of the metallic structure. For more explanation, they have a sulfonamide group that is not linked (free to link for any active site). The historical work proved that sulfamethazine was the first compound used to remedy bacteriological infections in people. Sulfathiazole, sulfadiazine, and sulfamethoxazole are other medications that are closely linked to sulfamethazine [178]. Regarding the environmental impact, all sulfa drugs are safer than sulfamethazine because of their shorter half-lives, making them, in principle, a healthier substance for the environment [179]. The most effective inhibitor was discovered to be sulfadiazine. When sulphadiazine and sulfamethoxazole

were compared in terms of inhibition efficiency, sulphadiazine was found to be more effective than sulfamethoxazole [180]. The proof that adding sulfacetamide to an acidic media like 1.0 M HCl slowed the corrosion of carbon steel was revealed see Table 1 [181].

The results indicated that at a dose of 10 mM, sulfacetamide had inhibitory effectiveness of up to 84.7%. UV–Vis spectrophotometry and HPLC were used to validate the electrochemical degradation of sulfacetamide. It was proposed that sulfacetamide molecules from the aqueous phase adsorb to the electrode surface. In an acidic medium, it appears that the cationic species involved should be included since they appear to better represent the real experimental condition. This was once again verified in the instance of sulfacetamide [182–184]. In terms of IE, they observed that 1 M HCl had a higher inhibitory efficacy (93.33 percent) than 0.5 M H_2SO_4 (90.66 percent). The predicted physical adsorption of dapsone on the surface of mild steel is based on calculated Gads of 33.49 and 32.55 kJ mol^{-1} in 1 M HCl and 0.5 M H_2SO_4. If the oxygen atom in $–SO_2$ is connected to the ring boosts, it has more electronegativity. The electron density of the $–NH_2$ functional group and its influence on deprotonation of this group, as well as the difference in providing Dapsone back to a lower pK value consequently, Dapsone's basicity is low [185].

The creation of metal ion complexes with dapsone may occur at low pH, resulting in decreased metal dissolution. Aminoglycosides are commonly used in conjunction with the antibiotics of b-lactam to treat varieties of systemic diseases, but they can be employed alone to treat urinary tract infections. These compounds are the most frequent members. Streptomycin is still used to treat gentamicin-resistant enterococcal infections [186]. The molecule of streptomycin could be adsorbed onto the surface of mild steel in its protonated state, according to these facts, is the fundamental process that affects inhibitor effectiveness in acid solution. Streptomycin is acid hydrolyzed to produce streptidine and streptobiosamine and the best conditions are pH from 3 to 7 as well as a temperature below 28 °C [187, 188]. As a result, any recommendation for a corrosion inhibition method must take streptomycin's chemical breakdown into account. Countless compounds of benzimidazole carbamate have been discovered thus, a few of them, such as mebendazole and albendazole, has been authorized for human use as chemotherapeutic drugs, and these substances have been reviewed [189, 190].

In this case, the IE was determined to be the maximum (96.2%) at a concentration of 2.5×10^{-4} M, according to these findings of weight loss results. They further proposed that mebendazole adsorption on mild steel surfaces is mediated by the donating p-electrons, and/or the aromatic rings since it occurs through the lone pair of electrons on the oxygen of the methoxy group, as well as the lone pair of electrons on the nitrogen atoms of the benzimidazole ring. In the case of diethylcarbamazine is a medication that is frequently used to treat people and animal trichinosis, as well as filariasis [191, 192]. Diethylcarbamazine generates methyl piperazine carboxylic acid because of hydrolysis in an acidic medium [193]. Additionally, it has been observed that diethylcarbamazine undergoes gradual hydrolysis to methyl piperazine in neutral or alkaline solutions [43]. Given these constraints in terms of measuring and studying this chemical, it is critical to examine the impact of pH. Apart from these medication classes, rhodamine, arlidone, ganciclovir, acyclovir, rifampin, and ribavirin are all significant antiviral medicines [194]. Due to their remarkable biological activity, the derivatives of rhodanine have been established to be appealing molecules that have undergone fast development [195, 196]. Semisynthetic opium derivatives such as hydrocodone and oxycodone as well as synthetic agonists along with comparable effects such as fentanyl are examples of opioid analgesics [197].

The major impact of tramadol, which is widely known to be concerned with a unique central action as a synthetic analgesic due to the aminocyclohexanol group's presence with opioid-like activities, falls into this category. [198–200]. When tramadol was used as a corrosion inhibitor, they discovered that it reduced the rate of mild steel corrosion in HCl and/or H2SO4, but that it was most successful in HCl (82.6 percent IE) at a concentration of 21.6×104 M. (76 percent IE). These observations prompted the scientists to believe that, in contrast to H_2SO_4, the cationic version of the tramadol molecule may easily adsorb on steel surfaces in HCl. Tramadol is soluble in both acidic and basic media [201]. It is debatable, however, whether the proposed mechanism considers the possibility that the tertiary alcoholic group of tramadol, when exposed to exceedingly acidic conditions, may result in a rearrangement similar to that of pinacolone [202].

The treatment of motion sickness is another significant application of H1-antagonists. Anticholinergic antihistaminics reduce the symptoms of motion sickness. Acid production is reduced by H2 receptor antagonists, which are used to treat diseases including gastro-oesophageal reflux disease [203]. Physical adsorption of meclizine on steel surfaces is a frequent finding of their research. Physisorption of this drug was indicated due to a reduction in inhibitory effectiveness at increased temperatures, despite the stated ΔG_{ads} estimate of 38 kJ mol^{-1} at 30 °C [204, 205]. Quetiapine, clozapine, ziprasidone, risperidone, sertindole, and olanzapine are examples of antipsychotic medications [206]. They came to the same conclusions as in the quotation above. This appears to be supported by the discovery that in mildly acidic conditions, no significant quantity of risperidone is decomposed [181]. Antiamoebic therapy is the most common treatment

for infection. Luminal amoebicides tissue amoebicides and mixed amoebicides are the three types of amoebicides [73].

It is proposed that amoxicillin, cloxacillin, ampicillin, and flucloxacillin (floxacillin) block ampicillin, cloxacillin, and flucloxacillin (floxacillin) in NaCl by forming a durable complicated protected layer on the surface of aluminum since it works together with the antibiotics (Table 1). There was an agreement between these models [128]. Using the DFT technique, discovered that the preferred nucleophilic and electrophilic attack sites for cloxacillin adsorption on mild steel are the carbon atom of the phenyl group and the link of C–Cl, correspondingly [207]. They are effective against streptococcal and staphylococcal infections, including skin and soft-tissue infections and streptococcal pharyngitis. Cefatrexyl, cefazolin, and cefalexin are the only cephalosporins utilized as iron corrosion inhibitors in acidic conditions now. The inhibiting effects of cefatrexyl on mild steel in Cl^{-}, SO_4^{--}, and PO_4^{---} solutions were investigated. The development of a soluble Fe(II)–cefatrexyl–Cl complex, corresponding to the obtained data of PD and EIS, was postulated to explain cefatrexyl's poorer inhibitory efficacy in chloride and acidic solution of about 1 M HCl, as well as the adsorption, was examined for cefazolin on mild steel [85, 131].

Using electrochemical and WL techniques, the inhibitory effect of cefalexin medication for mild steel corrosion in 1 N hydrochloric acid was studied. [130]. This might be due to structural similarities in the use of p-hydroxy derivatives for these groups of medications (cephalexin), such as cefadroxil, floxacillin, dicloxacillin, and cloxacillin. The most efficient inhibitor was cefadroxil, which inhibited corrosion on Al6063 in H_3PO_4 solution by 64.2 percent, while the least effective inhibitor was floxacillin, which inhibited corrosion by 44.9 percent [129]. Ceftriaxone was proposed as a mild steel corrosion inhibitor in chloride solution. (Table 1) [86]. In the case of cefotaxime sodium, the PD, EIS, and WL instruments were used to investigate the corrosion inhibition of mild steel in an acidic solution of roughly 1 M HCl. They concluded that the adsorption was not purely physical ($DG_{ads} = 36.91$ kJ mol^{-1}. The proposed mode of action is similar to that happens for using cefotaxime sodium [87]. In a recent scientific article, ceftazidime was found to have a significant inhibitory effect as a perfect corrosion inhibitor for mild steel in an HCl media see Table 1 [208].

They observed a maximal IE (92.2%) of 9.31 104 M ceftobipirole at 35 °C and high temperatures (from 45 to 65 °C), however, IE reduced values were seen. At larger inhibitor concentrations, however, this reduction was minor. Ceftobiprole physisorption on mild steel surfaces was indicated to be comparable to cefixime. As seen in Table 1, cefixime's corrosion behavior as a mild steel corrosion inhibitor is investigated utilizing gravimetric and electrochemical techniques such as WL, PD, and EIS, respectively. [88, 209]. They discovered that the compounds inhibited corrosion in the following order: cefoperazone > ceftazidime > cefepime and quantum chemical calculations were used to determine the corrosion mechanisms for these compounds [119]. In Canada and Switzerland, the medication was licensed for the treatment of troublesome skin and skin-building illnesses, such as diabetic foot infections. The effect of ceftobiprole on mild steel corrosion behavior in 1 M HCl media was investigated using the WL, EIS, PD, and AFM techniques. The experiment was also used to demonstrate that amifloxacin, ofloxacin, pefloxacin, enofloxacin, norfloxacin, and ciprofloxacin all prevented mild steel corrosion in a 3.4 percent NaCl solution containing various concentrations of these compounds [89]. Even with rising temperature and inhibitory efficiency, there was evidence that. At 40 ppm, the greatest efficiency was achieved, with values reaching 98.9%, which was attributed to the inhibitor molecules' size. Norfloxacin and ciprofloxacin were shown to be ineffective compared to the other antibiotics. Although these findings of the research described above yielded positive outcomes, they were limited to sodium chloride medium [15].

The inhibitory impact and mechanism of action of ofloxacin, norfloxacin, and ciprofloxacin on the corrosion behavior of mild steel in 1.0 M HCl are explored using both experimental and theoretical methods [90]. These findings from this research were consistent with their published research [91]. With these facts in hand, set out to test the inhibitory effects of derived (ofloxacin) for the mild steel corrosion behavior in H_2SO_4 [92]. At a concentration of about 3×103 M at 30 °C, this inhibitor had a maximum inhibitory efficacy of 94.74 percent. The inhibitory action of ciprofloxacin, ofloxacin, sparfloxacin, and norfloxacin on mild steel corrosion behavior in H_2SO_4 was investigated further. [93]. After studying the inhibitory effects of quinoline and its derivatives, a similar result was obtained after attempting to pinpoint the inhibition efficiency of primaquine on mild steel corrosion in HCl solution see Table 1 [94, 95]. The inhibitory effects of doxycycline, oxytetracycline hydrochloride, and doxycycline HCl dihydrate were studied for the first time by Von Fraunhofer and Stidham [121].

They discovered that whereas all three antibiotics promote Vitallium corrosion, they prevent titanium and steel corrosion. Similar research has been carried out in various media. In a normal saline solution, oxytetracycline was found to be an effective inhibitor of stainless steel, titanium, and Vitallium [123]. As a result, the chemical composition of the passive layers generated may account for variations in antibiotic corrosion behavior. Thorough research on how doxycycline prevented mild steel corrosion in an HCl solution was carried out. [122]. However, certain sulphonamides (sulfadiazine, sulfaguanidine, sulfamethoxazole, and sulfamethazine) were shown to be ineffective in preventing the corrosion of mild steel in about 1.0 M HCl media. [96]. He

further claimed that because its urea moiety lacks a positive charge, the sulfaguanidine molecule had the lowest inhibitory effectiveness. This is consistent with the findings of theoretical research [97]. It was the first aminoglycoside to be identified and used in human medicine. As seen in Table 1, streptomycin's inhibitory effect on mild steel corrosion behavior in 1 M HCl media was studied. [98].

The first study to show chloramphenicol inhibitory efficiency is carried out in 2009 [124]. Mebendazole, a benzimidazole carbamate prototype, was first used to treat roundworm infestations. The researchers investigated how effectively mebendazole prevented mild steel corrosion in a 1.0 M HCl solution. Table 1 [99]. Furthermore, it was shown that diethylcarbamazine may adsorb on mild steel surfaces in NaCl solution, slowing corrosion advancement. [100]. According to a literature study, the influence of four rhodanine azosulpha medications on the corrosion behavior of stainless steel 304 in 1 M HCl media was investigated see Table 1 [117]. When compared to the other complexes, the molecule with two groups of –OCH3 had the most inhibitory impact because the free electrons on the nitrogen atom were immobilized to a great degree. Other investigations found that when the temperature was raised, the inhibitory effectiveness was considerably lowered. It appears in this situation, especially when the adsorption method is linked to an exothermic activity because it causes a drop in the entropy value. However, DFT simulations were used to evaluate the connection between molecular composition and inhibitory effectiveness of these medicines [118].

They theorized that the three heteroatoms (N, S, and O) in rhodanine fragments might produce a layer of chemical adsorption in rhodanine azosulpha drugs (one nitrogen, two sulfurs, and one oxygen). This claim is backed up by research that shows rhodanine prevents mild steel corrosion in a 0.5 M HCl solution [101]. Other attempts to test tramadol as a mild steel corrosion inhibitor in HCl and H_2SO_4 at concentrations of 0.5 M HCl and 0.25 M H_2SO_4 were unsuccessful [125]. H2 receptor blockers include cimetidine, famotidine, and ranitidine. Famotidine is an H2 receptor antagonist from the third generation. As shown in Table 1, electrochemical tests were performed to illustrate the efficacy of meclizine in preventing mild steel corrosion in 1 M HCl [102]. Other studies have looked at the effects of pheniramine as a mild steel corrosion inhibitor in a 1 M HCl solution. [103]. Undoubtedly, these efficiencies are explained by a common inhibitory mechanism. The effectiveness of fexofenadine in inhibiting the mild steel corrosion in the HCl medium also revealed encouraging findings in Table 1 [104].

The focused study on zinc corrosion and designed creative experiments to determine the function of ziprasidone in chloride and sulfate solutions were carried out [107]. They observed that employing 0.1 M HCl instead of 0.05 M H2SO4 gave them better inhibitory results (87.64 percent). (a whopping 84.91 percent). They were able to get past a drug's zinc corrosion suppression. Because ziprasidone carries a positive charge on the protonated nitrogen of tertiary amines and secondary groups, the negatively charged component of the metal should be electrostatically attracted by this particle (negative charge). Risperidone's inhibitory impact on mild steel corrosion was studied in both 0.5 N HCl and 0.5 N H_2SO_4 media [108]. When investigating the corrosion behavior of mild steel in 0.01 M H2SO4, secnidazole can create a thin layer on the surface by physical adsorption, resulting in the formation of a defensive layer. During this time, scientists established a link between inhibitory efficacy and quantum chemical properties, such as the HOMO and LUMO energies of secnidazole. The tinidazole exhibits excellent properties for mild steel corrosion resistance in HCl media, which confirms the above-mentioned hypothesis [116]. Tinidazole was found to reach inhibition effectiveness of 90.5 percent at a concentration of around 400 parts per million (ppm), and it was observed that the particular mechanism of corrosion inhibition that causes this is still unknown. According to the findings of this study, the nitroimidazole moiety may be converted into an uncharged form of tinidazole in acidic environments with a pH of around 4.5. Tinidazole, on the other hand, has a structure that breaks down into nitroimidazole when it is exposed to more acidic conditions. As a consequence of this, it is difficult to determine whether the inhibition is caused by tinidazole in either its uncharged or charged form or if it is caused by botulinum toxin [105].

2.2 Adsorption Corrosion Inhibitors

The first penicillin to be used in clinical practice. The original penicillin-G structure is used in natural penicillins. The initial member of the category, benzylpenicillin (penicillin G), is still the most effective antibacterial agent against sensitive microorganisms. For severe infections, it is the medication of choice [109]. As a result, penicillin G ($\Delta G_{ads} = 9.65$ kJ mol^{-1}) adsorption onto the surface of mild steel in a corrosive acidic medium has been discovered. Penicillin V has a ΔG_{ads} of 15.91 kJ mol^{-1}, which is much lower than that of the parent molecule. This was ascribed to the aromatic/cyclic structure's inclusion of $–NH_2$ and –C–O, as well as N and S atoms. Penicillin V, on the other hand, is used to treat streptococcal pharyngitis [110]. It can also be utilized to give anaerobic coverage to those who have oral infections. Penicillins have been investigated as a safe and efficient mild steel corrosion inhibitor in a variety of conditions. see Table 2 [111, 112]. It is found that the intensity of surface contact between penicillin and steel continually varies depending on the active sites and the adsorption procedures. Another factor since penicillins is notably affected

Table 2 Drugs act as an adsorption corrosion inhibitor

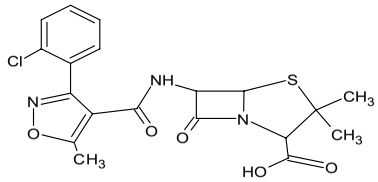
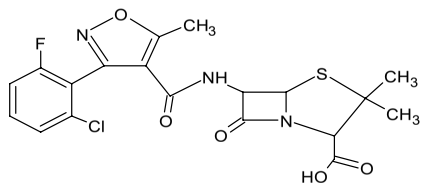
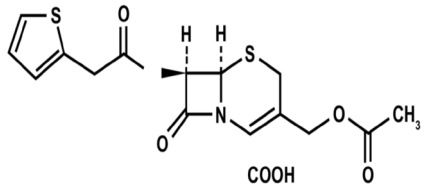
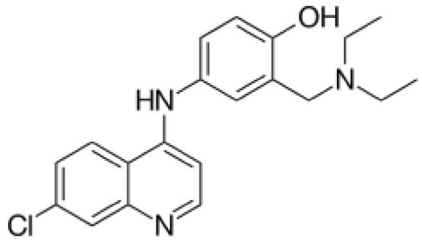
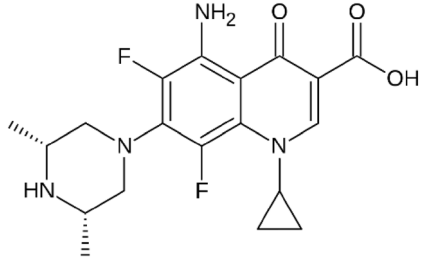
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Adsorption mixed	Cloxacillin		Pneumococcal, streptococcal, and staphylococcal infections	HCl, H_2SO_4, H_3PO_4	Al, Al, Mild steel	[124, 128, 129, 207]
Adsorption mixed	Flucloxacillin (floxacillin)		Cellulitis, impetigo, otitis externa, folliculitis, boil, carbuncle, mastitis, and septicemia are all skin diseases caused by Staphylococcus aureus (SAU)	HCl, H_3PO_4	Al, Al	[128, 129]
Adsorption mixed	Cephalothin		Injection of cephalothin sodium is used to treat bacterial infections in various parts of the body. There is no way for this medicine to cure viral infections such as a cold or the flu	HCl	API 5L X52 steel	[117]
Adsorption mixed	Amodiaquine		To treat malaria, amodiaquine is a kind of aminoquinoline It has been related to severe instances of acute hepatitis that can be deadly, thus it is only advised for use as a therapy and not as malaria prophylactic	HCl	Mild steel	[118]
Adsorption mixed	Sparfloxacin		Infections of the respiratory tract caused by bacteria and sinusitis are treated with Sparfloxacin. Infections caused by bacteria are treated with Sparfloxacin, a fluoroquinolone antibacterial. Sparfloxacin inhibits DNA gyrase, a bacterial topoisomerase, which is responsible for its antibacterial action	HCl	Mild steel	[101]

Table 2 (continued)

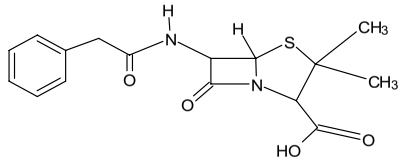
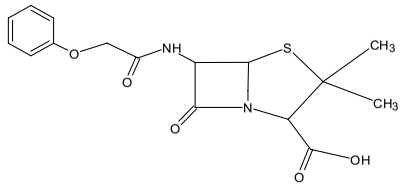
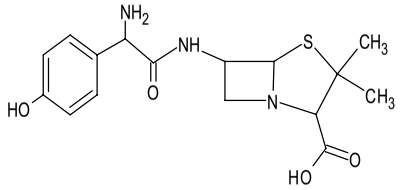
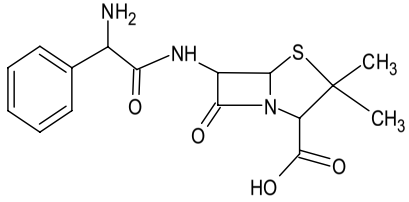
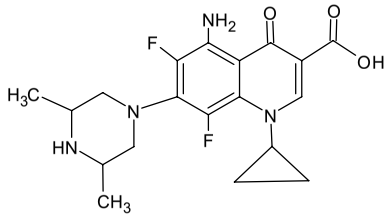
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Adsorption	Penicillin G		Infections such as cellulitis, bacterial endocarditis, meningitis, syphilis, septicemia, and septic arthritis are all examples of infectious diseases	H_2SO_4	Mild steel	[111]
Adsorption	Penicillin V		Rheumatic fever, anthrax, streptococcal skin infections, and spleen problems are among the most common	H_2SO_4	Mild steel	[112]
Adsorption	Amoxycillin		Sinusitis, otitis media, and bronchitis are among the most common ailments	HCl	Al, AA2024, T3 alloy	[128, 210]
Adsorption	Ampicillin		Listeriosis, Haemophilus influenza, otitis media, urinary tract infections, Haemophilus influenzae	HCl, H_2SO_4	Al, Mild steel	[124, 128, 211]
Adsorption	Sparfloxacin		As well as infections of the lower respiratory system and urinary tract, as well as infections of the skin as well as infections of the bones, joints, and prostate	HCl, H_2SO_4	Mild steel	[93, 212, 213]

Table 2 (continued)

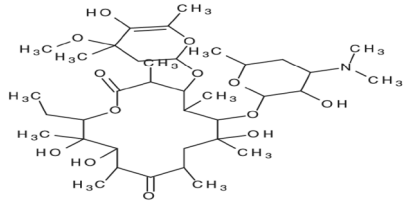
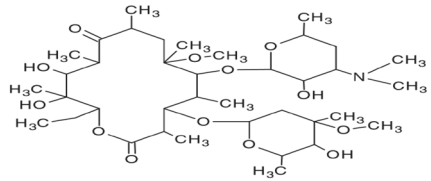
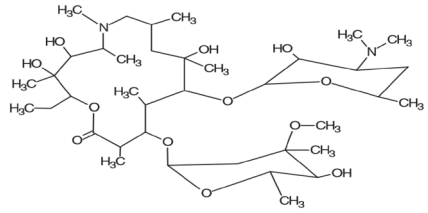
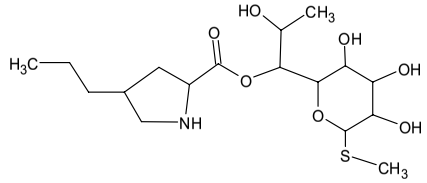
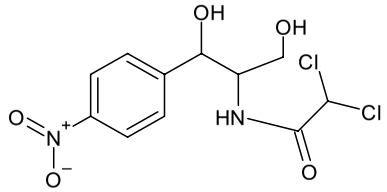
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Adsorption	Erythromycin		Respiratory tract infections, mycoplasma infections, and legionellosis	H_2SO_4	Zn	[214]
Adsorption	Clarithromycin		As well as simple skin and skin structure diseases such as tonsillitis, bronchitis, and pneumonia	H_2SO_4	Zn	[215]
Adsorption	Azithromycin		Nasal polyps and non-gonococcal urinary tract infections (nongonococcal urethritis, cervicitis) are some of the most common ailments	H_2SO_4	Zn	[216]
Adsorption	Lincomycin		Staphylococcus aureus, Streptococcus pneumonia, and other streptococci are sensitive to antibiotics	H_2SO_4	Zn	[217]
Adsorption	Chloramphenicol		Acute bacterial illnesses such as typhoid fever, meningitis, and superficial ocular infections	H_2SO_4	Mild steel	[124]

Table 2 (continued)

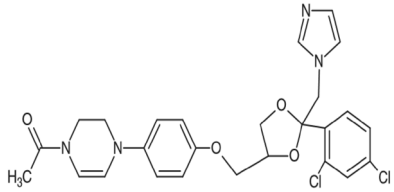
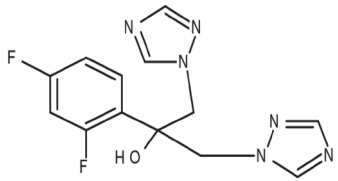
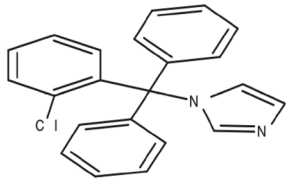
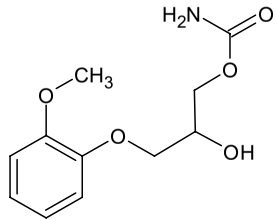
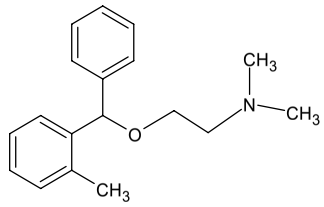
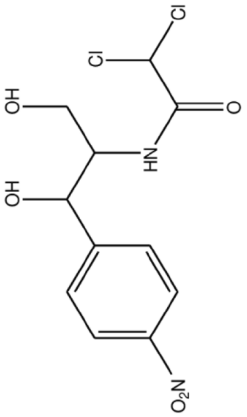
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Adsorption	Ketoconazole		Ringworm, jock itch, athlete's foot, and dandruff are all examples of fungal infections of the skin and mouth	H_2SO_4, HCl	Mild steel, Al	[218–220]
Adsorption	Fluconazole		Yeast infections of the vaginal, oral, and esophageal tracts, as well as pneumonia and cryptococcal meningitis	HCl	Al	[221, 222]
Adsorption	Clotrimazole		As well as local fungal diseases, athlete's foot, jock itch, and tinea corporis,	HCl	Al	[223, 224]
Adsorption	Methocarbamol		Injuries to the muscles can result in muscular discomfort and spasticity	H_2SO_4	Mild steel	[225]
Adsorption	Orphenadrine		Musculoskeletal injury and condition-related pain and discomfort	H_2SO_4	Mild steel	[226]

Table 2 (continued)

Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Adsorption	Chloramphenicol		To treat bacterial infections, chloramphenicol is used as an antimicrobial agent Treatment of conjunctivitis and ear infections are the most prevalent indications for its use. Two types of Chloramphenicol products are available: drops and creams. If you have a doctor's prescription, you can get them from a local drugstore	HCl	Mild steel	[103]

by the pH, because of the rapid breakdown of the unstable lactam ring [113].

The DFT calculations show that penicillin compounds can physisorbed on mild steel and that the K^+ is responsible for penicillin V's decreased inhibition efficiency (IE) compared to penicillin G because of the highly electropositive charge on potassium ions [114]. The effective attachment of penicillin G to the surface of mild steel is extremely possible due to its lipophilic nature and spatial organization in the H_2SO_4 medium, which was not evident from their theoretical calculations [115, 126, 127]. It is also worth noting that, although being chemically identical to ampicillin (the main difference being the hydroxyl ion of phenyl ring which is linked to the carbon atom in position α of amoxicillin since it has a greater adsorption property than ampicillin, as demonstrated by pharmacological investigations [227, 228]. When it comes to the structure-effect relationship in the middle of the molecular structure and its impact in medicine, as well as its application in corrosion management, some of these concessions are similarly relevant. When comparing the chemical structures of penicillin V and penicillin G, it was discovered that penicillin V has greater effectiveness and is a powerful corrosion inhibitor. Based on the above methods, it is extremely difficult to establish a direct link between medication structure and corrosion inhibitory efficacy. Theoretical estimates on ampicillin in the presence of sulfuric acid for mild steel corrosion [211].

The anti-corrosive properties of cellulose acetate sheets put over AA2024-T3 alloy are improved by doping them with a little amount of amoxicillin of about 2000 ppm [210]. They looked at how chloramphenicol, ampiclox (a medication that includes precise quantities of ampicillin inhibited corrosion of mild steel in 0.1 M H_2SO_4. Chloramphenicol showed the lowest possible efficacy of corrosion inhibitory at a dose of about 0.5 g dm^{-3} (34.33 percent). The importance of adsorption is connected to the computation of the free energy, which explains the kind of adsorption since it demonstrates that it is physical adsorption, while also stating that inhibitory efficacy was unexpected owing to the compounds' low solubility. The computation of the free energy explains the kind of adsorption because it indicates that it is physical adsorption, while also indicating that inhibitory effectiveness was unexpected due to the chemicals' poor solubility. Even if this proximity in inhibitory efficiency of norfloxacin, ofloxacin, and ciprofloxacin cannot be expected, the inventors of the aforementioned investigations suggested. This finding is particularly noteworthy. Fluoroquinolones' benzopyridone nucleus (quinolone) is more sensitive to chemical modification [229].

Furthermore, ofloxacin has a pI of 6.97, making it an amphoteric substance. The substance is completely protonated at a pH of 2.5 [28]. As a result, it is not surprising that a structural alteration might cause these compounds'

adsorption behavior in the H_2SO_4 medium to vary. Table 2 shows that sparfloxacin is considered an aminofluroquinolone derivative that is applied to treat bacterial infections of the respiratory tract, TB, and diabetic foot infections [230]. When compared to other fluoroquinolones derivatives, it has a high bioavailability (92%). The first definitive demonstration of sparfloxacin's inhibitive and adsorption capabilities for mild steel corrosion in HCl solution is produced [231]. It is noticed that the obtained results of these tests show that sparfloxacin has a very high inhibitory effect against mild steel corrosion in acidic conditions. When sulfuric acid was employed to degrade sparfloxacin, the compound's efficiency appeared to be reduced. The amine group in this drug's molecular structure has been found to engage directly with the adjacent CaO, inhibiting the interaction with intramolecular hydrogen bonds and metal ions [232]. The sparfloxacin's poor anti-acid reactivity might be explained when compared to other fluoroquinolones [233].

Macrolide antibiotics are generated by Streptomyces bacteria and are named after the fact that they all have the same chemical structure: a macrocyclic lactone. Erythromycin, the family's prototype, has a range and uses like penicillin [234]. Azithromycin and clarithromycin, two of the group's newest members, are especially beneficial because of their strong lung diffusion and it is an antibiotic used to treat diseases of the respirational expanse, toxoplasmosis, and pediatric infections [235]. Clarithromycin (6-O-methylerythromycin), on the other hand, is commonly applied to care for Helicobacter pylori diseases, which are the source of abdominal abscesses [236–239]. According to their weight loss evaluations, the inhibitory effects of erythromycin at 30 °C were greatest (82.67 percent IE) at 5×10^4 Min 0.01 M H_2SO_4. Temperature and H_2SO_4 concentration increase, on the other hand, have been found to aid zinc weight loss. At 50 °C in 0.03 M H_2SO_4, the lowest IE was 53.01%. Similar IE patterns were found for clarithromycin and azithromycin under the same conditions see Table 2 [215, 216].

Azithromycin, on the other hand, showed the most inhibitory impact, with a 90.55 percent inhibitory effect. Based on the structural changes of the macrolides disclosed at this stage, a preliminary conclusion may be drawn. Erythromycin has a unique structure that includes a 14-membered lactone ring of a macrocyclic connected to two moieties of sugar. In this case, the change makes the molecule more stable in slightly acidic form and precludes the base of erythromycin from degrading into the intermediate of hemiketal, resulting in fewer inhibitory effects compared with erythromycin. The –C–O– group of the aglycone ring is replaced with methyl-substituted nitrogen to produce azithromycin. Additionally, this modification most likely results in a molecule that is more effective against zinc corrosion than erythromycin. Lincosamides are formed up of amino acids and an S-containing octose and are thought to be more easily produced and accessible for medical research [240]. Clindamycin and pirlimycin are two more lincosamide-related compounds [241, 242].

At a concentration of 5 104 M, the maximum efficiency (80.32% IE) was attained. They also discovered that the temperature has a considerable effect on the corrosion resistance of lincomycin and the inhibitory effectiveness was dramatically reduced as the temperature was raised. Furthermore, increasing H_2SO_4 concentration showed a substantially detrimental effect on effectiveness. Even though the inventors did not specify the mechanism of lincomycin's inhibitory effect, they did state that physical adsorption was the most common way of inhibition. Lincomycin resembles aminoglycoside antibiotics in structure, making it a potential ligand for Zn and other metallic structures [243]. Because tertiary amine is proven to oxidize gradually in an acidic environment, it is reasonable to assume that the group of this methyl and the pyrrolidine N in lincomycin are primarily accountable for its repressive action [244–246]. The analysis using quantitative structure–activity relationship (QSAR) appears to be a useful method for determining each inhibitor's efficacy. However, chloramphenicol is fundamentally neutral and affected by changes in pH. It is found that over the pH range of 3–9 does not result in considerable variations in solubility. It is difficult to draw firm conclusions about the inhibitory efficacy order of these medicines. However, in the presence of strong acid, chloramphenicol solubility increased ahead of protonation of the faintly alkaline nitrogen in the amide group [247].

The need to determine the present state of chloramphenicol in the H_2SO_4 medium is nowhere more pressing than here, even though it is conspicuously absent from the literature. The most used antifungal medications are classified into two groups based on how they are administered: systemic and topical. Antifungal medicines with systemic administration comprise amphotericin B, griseofulvin, azole compounds and. flucytosine, tolnaftate, clotrimazole, miconazole, ketoconazole, and nystatin are examples of topical antifungal medicines. The imidazoles were the first azoles to be produced for universal therapy of human being fungal infection, being discovered in 1969 [248]. These added new aspects to the investigation of the effects of iodide addition. In the instance of a ketoconazole + iodide combination, the performance of ketoconazole was enhanced by the estimated values of ΔG_{ads}, 13.77 and 19.72 kJ mol^{-1}. In the case of ketoconazole and ketoconazole + I^- combination, correspondingly, supported the physisorption of this medication. It is crucial to note, however, that virtually all medicines are present in aqueous solutions. Evidence from ketoconazole pH stability experiments is a warning remark for interpreting the above-mentioned research. Ketoconazole was observed to be susceptible to specific acid catalysis at low pHs [249].

Fluconazole was the first triazole medication to be created in 1982. Fluconazole has been the preferred prophylactic and main therapy for aggressive monilia disease for the previous 20 years due to its low toxicity profile, excellent pharmacokinetics, and overall effectiveness. The molecular name for fluconazole is (2-(2,4-fluorophenyl)-1,3-bis(1H-1,2,4-triazole-1-yl) propane-2-ol) and studied its inhibitory effect on aluminum in 0.1 M HCl [250]. As the corrosion progressed, physical adsorption of sparfloxacin was seen to be the dominant mode of action [212]. Based on the findings of weight loss tests, maximum inhibitory effectiveness of 97.47% was found at a concentration of 12 104 M sparfloxacin. In the H_2SO_4 medium, however, this drug's inhibitory effectiveness was determined to be 90.79% [213]. The erythromycin (Table 2) inhibits zinc corrosion in H_2SO_4 is existed [214]. The ability of lincomycin to prevent zinc corrosion in sulfuric acid media was described [217]. Several weight loss tests to investigate the impact of ketoconazole on the mild steel corrosion in 0.1 M H_2SO_4 have been conducted see Table 2 [218]. He also wanted to see if adding iodide ions to ketoconazole might have a synergistic impact. While this medication was coupled with I^- ions at 30 °C, the greatest inhibitory effectiveness of 63.7% was obtained. Certainly, this is fertile ground for detecting the increased inhibitory effect that occurs after the use of ketoconazole and iodide ions in combination. In subsequent research, the inhibitory impact of ketoconazole was studied [219]. Differentiating the kind of metal (aluminum) and acid environment, have been provided insight into the inhibitory action of Nizoral (HCl) [220].

They proposed that protonated fluconazole adsorption to positively charged aluminum surfaces could occur at pH 1 via the centers of negative charge such as the O of the OH^-, the N of the rings of triazole, and F^- on the benzene ring which assertion and expanded upon in their future work [221, 221]. The outcomes of this study are in conjunction with prior research on fluconazole acid hydrolysis, which found no degradation [251]. Topical antifungal medications are favored for treating skin infections because they are less prone to induce systemic problems. Clotrimazole is an N-substituted imidazole used to treat cutaneous fungal infections. Decreasing membrane lipid synthesis lowers the integrity of mycological cell membranes [252]. Using of clotrimazole as a corrosion inhibitor for aluminum in HCl utilizing weight loss and semiempirical AM1 techniques was examined [223]. According to experts, the creation of an insoluble stable layer of clotrimazole molecules may have decreased aluminum corrosion. This might support the argument that medicine is a very adsorptive substance [253].

Furthermore, in a separate investigation, these scientists found that their findings were consistent with experimental findings, indicating that clotrimazole had the maximum inhibitory effect while equating to fluconazole [224, 254]. Only dantrolene acts directly on the nerve-muscle junction. Orphenadrine, carisoprodol, chlorzoxazone, chlorphenesin, diazepam, cyclobenzaprine, metaxalone, and methocarbamol, are some of the medicines used as an adjuvant to rest in the treatment of acute muscular spasms [255]. The derivative of mephenesin methocarbamol is a medicinal prescription with an extended combat period and reduced intense poisonousness in animals compared with mephenesin [256]. The inhibitory properties of methocarbamol in H_2SO_4 for mild steel corrosion were investigated see Table 2 [225].

They claimed that at 303 K, methocarbamol prevents mild steel corrosion considerably, achieving up to 67.12% IE at a recommended concentration of about 2.0×10^3 M. The primary mode of action that begins methocarbamol inhibitory realization is believed to be related to physical adsorption, according to scientists, because increasing the temperature to 60 °C reduces inhibition efficacy. The Gads values, which were determined to be 12.50 kJ mol^{-1} at 30 °C and 15.01 kJ mol^{-1} at 60 °C, tend to endorse this theory. Given that methocarbamol is a chemically steady composite in situations of higher acidity, this is undoubtedly a reasonable assertion [257]. This study reached similar conclusions after using the evolution of hydrogen and thermometrical techniques to investigate the inhibition efficiency and the assets of adsorption of orphenadrine to the corrosion behavior of mild steel in 2.5 M H_2SO_4. see Table 2 [226].

2.3 Cathodic Corrosion Inhibitors

As one may assume, this is most likely connected to earlier results on the inhibitory performance of meclizine and famotidine [258]. The effect of the famotidine medication on the mild steel corrosion in both 0.1 N HCl and H_2SO_4 has been investigated see Table 3 [259]. The effects of etilefrine hydrochloride, maleate, enalapril, and atenolol on the conventional and localized attack of aluminum and 3 alloys of aluminum–silicon in HCl conditions were investigated [260]. This implies that the aromatic ring moiety of the chemical determines the inhibitory effectiveness. According to this viewpoint, a suggested inhibitory mechanism has been established to explain the b-blocker effects on the used inhibitors such as nadolol, timolol, propranolol, and atenolol on corrosion behavior of aluminum in 0.1 M HCl media see Table 3 [261]. Famotidine works as a corrosion inhibitor, greatly decreasing degradation even at low concentrations, according to the corrosion properties they studied. The acidic famotidine isolates seemed to be associated with mild steel corrosion inhibition [262]. Theoretical modeling simulations, which yielded appropriate data for the atenolol particle, provided a more plausible explanation for the two amino acids derivative (L-proline and L-alanine). Similarly, etilefrine HCl is a sympathomimetic amine that has been

Table 3 Drugs act as a cathodic corrosion inhibitor

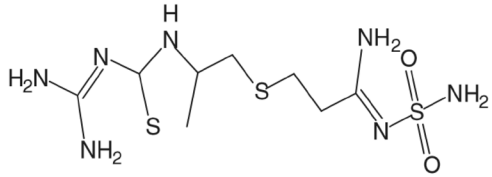
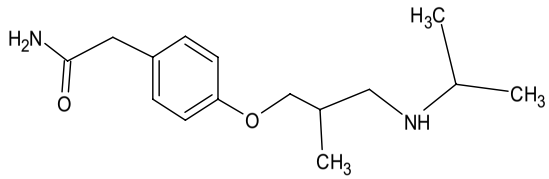
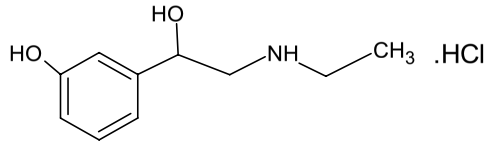
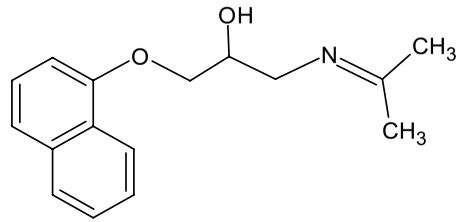
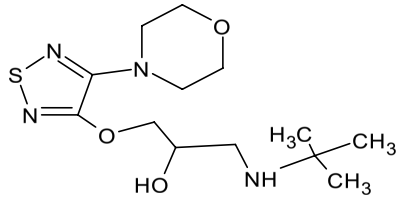
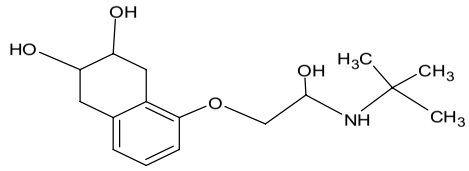
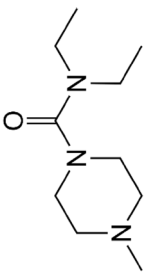
Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Cathodic	Famotidine		Gastroesophageal reflux disease, ulcers, discomfort owing to acid indigestion, and sour stomach are all examples of gastroesophageal reflux	HCl, H_2SO_4	Mild steel	[259, 262]
Cathodic	Atenolol		Acute myocardial infarction, hypertension, angina, supraventricular and ventricular tachycardia, heart failure, migraine headache prophylaxis, and alcohol withdrawal symptoms	HCl	Al, Al-Si alloys	[260, 261]
Cathodic	Etilefrine hydrochloride		An antihypertensive and synaptosomal agent	HCl	Al, Al-Si alloys	[260]
Cathodic	Propranolol		Control of tachycardia/tremor linked with anxiety, hyperthyroidism, or lithium treatment; migraine prophylaxis; cluster headache prophylaxis; tension headache prophylaxis	HCl	Al	[261]
Cathodic	Timolol		Hypertension, glaucoma, and migraine headaches are among the most common medical conditions	HCl	Al	[261]
Cathodic	Nadolol		Hypertension and angina pectoris are two common conditions	HCl	Al	[261]

Table 3 (continued)

Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	References
Cathodic	Diethylcarbamazine		Treatment for some worm infestations involves the use of diethylcarbamazine (DEC)	HCl	Mild steel	[104]

shown to increase cardiac output by influencing the heart's inotropic and chronotropic functions, see Table 3 [263].

2.4 Anodic Corrosion Inhibitors

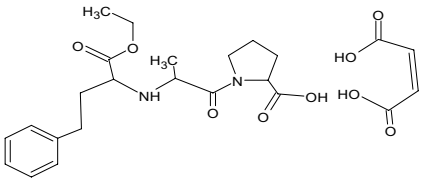
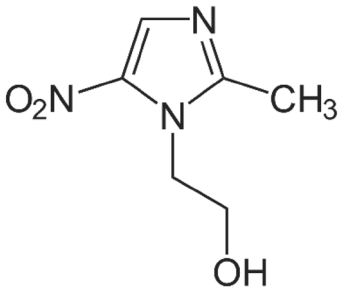
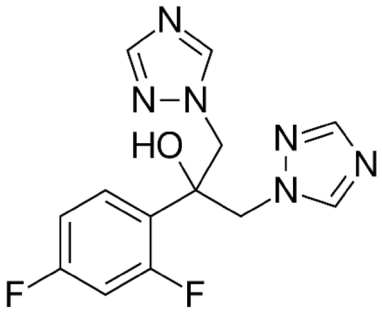
In congestive heart failure, the enalapril maleate is an antihypertensive and a vasodilator. see Table 4 [264]. The inhibitory effect of etilefrine HCl maleate, enalapril, and atenolol reaches its maximum magnitude at an inhibitor concentration of 250 ppm in 1×10^2 M HCl. In the case of enalapril maleate, it is found that the most effective medication, whereas etilefrine hydrochloride was the least effective. The influence of these medications on corrosion inhibition of aluminum and aluminum–silicon alloys was discussed based on adsorption. Dehydration of enalapril maleate results in the formation of diketopiperazine, and hydrolysis results in the formation of the diacid enalaprilat [265]. This raises the long-debated topic of whether diketopiperazine is responsible for the strongest inhibitory impact of enalapril maleate. Atenolol's physicochemical and pharmacological properties are controlled by its alkanolamine and aromatic groups [266].

3 Adsorption Mechanism

The kinetic data of drug sorption onto a composite of metallic structures were fitted into Morris Weber's intraparticle diffusion to assess variations in the concentration of medicines that are considered an adsorbate onto metallic surfaces that are considered a sorbent with tiring time. This was done to determine how the concentration of medicines changes throughout the experiment. The validity of the mechanism based on the intraparticle diffusion process was shown by the linearity of the data in the plot of qt against t 0.5 [267]. The nonlinear plots for the entire concentration range of drug compounds studied, indicate that intraparticle diffusion is not the only rate-limiting step and that other processes may be involved in the adsorption procedure, as well as the low R^2 values for the intraparticle diffusion model presented [268]. The initial adsorption stage is depicted in the first sharp section, where the drug adsorption and/or absorption rate is high due to the large surface area and low competition among active molecules on metallic surfaces [269].

The second section describes the sluggish adsorption phase, which was activated by minor concentration inclines and ultimately led to equilibrium between the drug molecule and the active sites on metallic surfaces. This phase was induced by slight concentration inclines [270]. According to the complexity or criticality of determining whether intraparticle diffusion or film diffusion drives the adsorption progression so it is very important to apply the equation of Boyd kinetic to be used for identifying the adsorption processes

Table 4 Drug acts as an anodic corrosion inhibitor

Inhibitor class	Drug name	Molecular structure	Medical use	Medium	Metal	Ref
Anodic	Enalapril maleate		Diabetes-related hypertension, congestive heart failure, and renal issues	HCl	Al, Al–Si alloys	[259]
Anodic	Metronidazole		Bacterial vaginitis and pelvic inflammation are among the diseases treated with it As well to treating infected insect bites, skin ulcers, and bed sores, it is also used to prevent bacterial and parasitic infections, as well as treating and preventing infections from bacteria and parasites	HCl	Mild steel	[125]
Anodic	Fluconazole		As an antifungal, fluconazole is used to treat fungal infections in the mouth, throat, esophagus lungs bladder, and genital region as well as in the blood	HCl	Mild steel	[122]

[271]. Plotting $-\ln(1q_t/q_e)$ versus t at various launching concentrations to determine the adsorption method, the mechanism of film diffusion follows the Boyd equation [272]. The Boyd plots are linear, but they do not permit passing through the derivation, therefore validating the projection of the film dissemination mechanism onto the adsorption rate [273].

Similarly, when the obtained results were evaluated, the R2 values for the film diffusion model were found to be higher than those for the intraparticle or aperture diffusion models. This suggests that the diffusion of the obtained film normalizes the degree of drug adsorption onto metallic surfaces under the conditions that were investigated [274]. It is impossible to overstate the importance of the adsorption isotherm in the essential connection between adsorbate (drug molecules) and adsorption processes [275]. Furthermore, the adsorbent's adsorption capability was predicted using isotherm analysis, which is an important component in the commercial design of adsorption systems [276]. Isotherm models were used to determine the drug adsorption isotherm parameters on a composite of metallic surfaces [106]. The Langmuir model explains the monolayer adsorption process on a homogeneous adsorbent surface, whereas the Freundlich isotherm assumes that the multilayer adsorption process occurs on a heterogeneous surface [31]. The Freundlich and Langmuir isotherm models in the nonlinear form are widely known and the R^2 values were used to measure the applicability of these two models. The optimal isotherm model was used to determine the highest R^2 values at all examined temperatures [277].

The fact that the Freundlich model fits the isotherm data better than before suggests that drug adsorption onto the heterogeneous surface of the metallic surface may involve multilayer adsorption. This finding lends weight to the hypothesis that physisorption is the relevant process. According to Giles's classification of adsorption isotherm, the L-shaped curve that is produced when drugs are adsorbed onto metallic surfaces shows that drug molecules are probably adsorbed in a flat region on metallic surfaces since there is less competition from soluble molecules [278]. Furthermore, the Freundlich exponential factor (n) was found to be larger than (1) for all investigated temperatures, indicating a favorable adsorption process. For example, at 30, 40, and

50 °C, the Langmuir monolayer adsorption capacities were 756.97, 982.47, and 994.06 mg g^{-1}, respectively, which is highly promising when compared to other composites for drug adsorption. Using the Gibbs and Van't Hoff equations, experimental data for drug adsorption on metallic surfaces at various temperatures was used to calculate thermodynamic parameters such as Gibbs free energy (ΔG), enthalpy variation (ΔH), and entropy variation (ΔS). The intercept and slope of plot $\ln K_o$ versus 1/T were used to calculate the values of ΔS and DH. Gibbs's free energy (ΔG) values at various temperatures were all negative and decreased as the temperature rose, suggesting that the drug adsorption on metallic surfaces was spontaneous [279].

The presence of an exothermic reaction was established by the negative ΔH value of drug adsorption on metallic surfaces (8.897 kJ mol^{-1}). The ΔH value was less than 84 kJ mol^{-1}, indicating that the physisorption adsorption process was taking place. The entropy (ΔS) value was likewise negative (9.802 J mol^{-1}. K), which explains why there was less randomness at the solid/solution interface during adsorption. This study revealed the proposed metallic surfaces composite's excellent reusability without noticeable reduction in drug molecule capacity, making corrosion protection for the metallic surface's rehabilitation more sustainable and cost-effective, and safe for the natural environment [280].

4 Conclusion

The research looked at several medications that are used as corrosion inhibitors to protect metals from corroding. The objective of this study was to provide evidence for a standardized recommendation manual that contained all available information on the efficacy of corrosion inhibition for diverse medications. The subsequent assumptions in this study are made for the person who reads consideration founded on the given data. The corrosion technologists are endeavoring to include ecological elements into corrosion inhibitor selection methods as soon as possible in response to a rising knowledge of the necessity to shield the natural environment. The environmental friendliness of some medicines is a major factor in their selection as corrosion inhibitors. We can identify whether a medication is biodegradable, lipophilic, hydrophilic, polar, or non-polar persistent based on molecular weights, and structure, such as polarity, activity, and salt forms. Even though most of the drugs investigated are biodegradable and hydrophilic, it should be noted that not all pharmaceuticals are easily recyclable, and their transition outcomes may be as if not more, detrimental to the environment.

As a result, further research is needed before these, or any other medicines can be categorically linked to the environmentally beneficial and corrosion inhibitor categorization. Pharmaceutical residues, as previously stated, have very little to no chance of having a major detrimental influence on marine ecology right away. Pharmaceutical contaminants, on the other hand, are presently being studied for their possible hazardous consequences. This fact should be considered when determining whether a medication is suitable for use as a green corrosion inhibitor. As previously indicated, medicine compatibility with the environment is important, but it is not needed for corrosion inhibition.

According to a review of the literature, the efficacy of corrosion inhibitors is determined by their molecular structure, chemical content, and affinities of the metal surfaces. Organic compounds that may donate electrons to the metal surface's vacant d orbitals to form coordination and/or covalent bonds, as well as absorb available electrons from the metallic surface utilizing their anti-bond orbitals to create response linkage, are effective and potent corrosion inhibitors for metals and its alloys. Multiplexes including heteroatoms such as N, O, S, and P, as well as five-membered or six-membered aromatic rings, might be inferred to be the most effective corrosion inhibitors.

The medicines reported in this paper comprise spontaneous cores that resemble O, N, and/or S fragments with unique electron pairs, as well as five or six aromatic rings and delocalized p-electron processes that can aid in adsorption on metallic surfaces. They also have higher molecular weights, making them more likely to efficiently cover the more external surfaces of the metal (due to adsorption), preventing corrosion. Penicillins, cephalosporins, and other medicines with a similar skeleton are typically classified together, as in this overview. In certain cases, this classification is useful since the compounds involved are physiologically active and have the same way of engagement, such as penicillin's antibacterial activity. It must be informed that not all chemically similar compounds have an identical natural impact.

For illustration, steroids, have a comparable tetracyclic arrangement but produce entirely dissimilar physiological influences. Various classes of structurally related medicines, such as penicillins, cephalosporins, and sulfonamides, are covered in this work. These are some examples of chemicals that have a similar structure and action mechanism. The fact that most sulfonamides are used as antibacterial, even though a handful have entirely different therapeutic functions, is a compromise. The specific processes regulating drug corrosion inhibition on various metals are yet unknown. Several groups have conducted extensive studies, but none of the theories have enough experimental support to be recognized as the real inhibitory mechanism.

There is still a need for more research, both theoretical and experimental. The medicines have a high adsorption ability for spreading on metallic surfaces, according to this

phenomenon the adsorption was shown to be significantly dependent on the starting concentration, contact duration, pH of the original solution, and temperature. The nonlinear approach was used to evaluate the adsorption kinetic and equilibrium data for various process parameters since its obtained findings revealed that both the Freundlich and Langmuir models well matched the obtained experimental data, although the error functions indicated that the Freundlich isotherm was superior. To summarize, pharmaceuticals are effective, high-potential adsorption for corrosion resistance and can be employed as corrosion inhibitors.

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Data Availability Data will be available on reasonable request.

Declarations

Conflict of interest There is no conflict of interest.

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