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Chapter

Small Organic Molecule as Corrosion Inhibitors for Mitigating Metal Corrosion

Lakha V. Chopda

Abstract

Metal corrosion constitutes degradation of metals in the presence of favorable corrosive atmosphere. It worsens metal quality. The prevention of metal corrosion is so significant to save metals for their better utility. Corrosion inhibitors are widely used for the mitigation of metal corrosion. Small organic molecules as corrosion inhibitors are showed prominent corrosion inhibitive property because of their unique electron donating capacity to the metal orbitals. The bonding occurred between organic molecules and metals are main aspect to retard the corrosive environment toward metal.

Keywords: metal, corrosion, organic molecule, inhibitor and prevention

1. Introduction

Corrosion is the naturally happening process which transfers metals into their stable form. Metals easily facilitated to the corrosion in the presence of corrosive media (acidic, basic, and brine). In other words, it is the gradual deterioration of metals in the existence of favorable reactive environment. Nowadays, corrosion of metal became global problem as it worsened the quality of metals and directly or indirectly affect economy of any country. The control of corrosion metals using appropriate methodology is so important. Application of corrosion inhibitor for the prevention of corrosion found prominent attention. The suitable concentration of corrosion inhibitor reduced the corrosion rate without altering the concentration of corrosive media [1]. For the control of metal corrosion, various kinds of inhibitors including inorganic compounds, plant extract, and organic molecules are commenced for the mitigation of metal corrosion as illustrated in Figure 1 [2]. Small organic inhibitors are widely applied for the control of metal corrosion as they are easy to prepare compared to complex organic molecules [3]. The best example of small organic molecule as corrosion inhibitor is a BTA [4]. BTA effectively mitigated metal corrosion. The presence of unique functionality in the small organic compounds is strongly react with metal by chemical or physical bonding and preserved metal against harsh corrosive media. Corrosion inhibitors interact with metal at metal/solution interface by forming film on the metal surface and hindered corrosion reaction. The formed protective
film limits corrosive media, oxygen, and water diffusion toward metal surface, so reducing corrosion rate. Any type of corrosion inhibitors can be categorized into cathodic, anodic, or mixed type which depending on their influence in the suppressing cathodic/anodic reaction or both [5]. This chapter includes the application of small organic molecule for the prevention of corrosion of various metals in different corrosive media. This chapter includes the application of small organic molecule for the prevention of corrosion of various metals in different corrosive media.

2. Application of small organic molecule as corrosion inhibitors

Corrosion inhibition activity of small organic molecules such as imidazole (IM), 2-ethylimidazole (EI), thiophene (TH), 2-ethylthiophene (ET), 3-methoxythiophene (MT), pyridine (PY), 4-ethylpyridine (EP), and 4-methoxypyridine (MP) have been assessed for the mild steel (MS) in 1 M HCl [6]. The corrosion inhibition property of inhibitors has been determined by the potentiodynamic polarization (PDP), linear polarization resistance (LPR), and electrochemical impedance spectroscopy (EIS) methods. The parameters such as a decrease in the corrosion current density ($i_{corr}$) values and an increase in the polarization resistance ($R_p$) revealed corrosion inhibition.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Corrosion inhibitor</th>
<th>PDP</th>
<th>LPR</th>
<th>EIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Imidazole (IM)</td>
<td>70.4%</td>
<td>78%</td>
<td>80.1%</td>
</tr>
<tr>
<td>2</td>
<td>2-ethylimidazole (EI)</td>
<td>74.3%</td>
<td>81.1%</td>
<td>84.3%</td>
</tr>
<tr>
<td>3</td>
<td>Thiophene (TH)</td>
<td>59.9%</td>
<td>63.7%</td>
<td>64.2%</td>
</tr>
<tr>
<td>4</td>
<td>2-ethylthiophene (ET)</td>
<td>22.3%</td>
<td>52%</td>
<td>53.4%</td>
</tr>
<tr>
<td>5</td>
<td>3-methoxythiophene (MT)</td>
<td>58.1%</td>
<td>82.6%</td>
<td>82.8%</td>
</tr>
<tr>
<td>6</td>
<td>Pyridine (PY)</td>
<td>74.4%</td>
<td>82.9%</td>
<td>67.6%</td>
</tr>
<tr>
<td>7</td>
<td>4-ethylpyridine (EP)</td>
<td>76.9%</td>
<td>88.7%</td>
<td>85.9%</td>
</tr>
<tr>
<td>8</td>
<td>4-methoxypyridine (MP)</td>
<td>56%</td>
<td>67.5%</td>
<td>71.5%</td>
</tr>
</tbody>
</table>

Table 1.
Corrosion inhibition efficiency of eight heterocycles at 10 mM.
inhibition action of inhibitors. The corrosion inhibition efficiency increased with enhancing of the concentration of inhibitors. The inhibitor EP showed highest corrosion inhibition efficiency. The EP displayed 85.9%, 76.9%, and 88.7% corrosion inhibition efficiency as determined by PDP, LPR, and EIS. The PDP method indicated that corrosion inhibitors behaved as mixed type of inhibitors (control on the anodic and cathodic reaction). The corrosion inhibition efficiency of all eight compounds is displayed in Table 1.

The organic compounds (Z) -4 - ((2-bromobenzylidene) amino) -5-methyl-2-4-dihydro -3H-1,2,4-triazole-3-thione (a) and (Z) -4 - ((3-bromobenzylidene) amino) -5-methyl-2-4-dihydro-3H-1,2,4 -triazole-3-thione (b) have investigated as corrosion inhibitors for MS in 1 M HCl [7]. The PDP method showed that as concentration of both inhibitors increased led to enhance the corrosion inhibition efficiency. The compounds a and b showed 83.66% and 82.84% corrosion inhibition efficiencies at $10^{-3}$ M concentration. The same trend has been observed by EIS method. The increase in the value of charge transfer resistance ($R_s$) and increase in the value of double-layer capacitance ($C_{dl}$) with increased inhibitor concentration proved the corrosion inhibition action of inhibitor. Both inhibitors a and b showed 89.51% and 84.5% corrosion inhibition efficiencies at $10^{-3}$ M concentration. Both inhibitors followed the Langmuir adsorption isotherm and value of free energy ($\Delta G^0$) is negative revealed that adsorption is spontaneous as well inhibitors adsorbed over metal surface by chemisorption. The effect of temperature showed that as temperature increased from 45 to 75°C, it causes a decrease in the corrosion inhibition efficiency. The compound 3-methyl-6-oxo-4-(thiophen-2-yl)-4,5,6,7-tetrahydro-2H-pyrazolo[3,4-b]pyridine-5-carbonitrile (TPP) displayed remarkable corrosion inhibition efficiency for MS in 1 M HCl [8]. The corrosion inhibition action of inhibitor increased as the concentration of inhibitor increased from 50 ppm to 200 ppm. The weight lost method displayed 94.28% corrosion inhibition efficiency at 200 ppm, while 95.75% and 96.83% corrosion inhibition efficacies by inhibitor at same concentration as determined by PDP and EIS methods, respectively. The PDP method showed that inhibitor followed the mixed type of behavior with more control on the cathodic reaction. The Langmuir adsorption isotherm was best fitted, and SEM images indicated that homogeneous adsorption film formed by the inhibitor TPP on the metal surface. The corrosion inhibition action of two Schiff bases such as 3-((phenylimino)methyl)quinoline-2-thiol (PMQ) and 3-((5-methylthiazol-2-ylimino)methyl) quinoline-2-thiol (MMQT) on mild steel surface has investigated by quantum chemical calculation and molecular dynamics (MD) simulation methods [9]. Quantum chemical parameters such as $E_{HOMO}$, $E_{LUMO}$, energy gap ($\Delta E$), dipole moment ($\mu$), electronegativity ($\chi$), global hardness ($\eta$), and fraction of electron transfers have been determined, and parameter such as local reactive sites of molecule have been analyzed by Fukui indices. The adsorption behavior of the inhibitor molecules on Fe (1 1 0) surface has been analyzed using molecular dynamics simulation. The binding strength of the concerned inhibitor molecules on mild steel surface follows the order MMQT-PMQ that was in good agreement with the experimentally determined inhibition efficiencies. Three oxazole derivatives (Compound 1: methyl-4-naphthalen-2-ylmethylene-4H-oxazol-5-one, Compound 2: 4-(2-methyl-5-oxo-oxazol-4-ylidenemethyl)-benzaldehyde, and Compound 3: 4-(2-methyl-5-oxo-oxazol-4-ylidenemethyl)-benzene) were used as corrosion inhibitors for carbon steel (CS) (API5LX60) in 1 N H$_2$SO$_4$. The corrosion inhibition actions of three inhibitors were studied by gravimetric (weight lost) method in the concentration range of 50–200 ppm [10]. The corrosion inhibition efficiency increased with increased in concentration range from 50 to 200 ppm. The highest
corrosion inhibition efficiency attained at 200 ppm. At 200 ppm, inhibitors 1, 2, and 3 displayed 90.7%, 78.31%, and 75.66% corrosion inhibition efficiencies, respectively. The inhibitor 1 showed highest corrosion inhibition efficiency. The same trend has been found by the electrical resistance measurement. The inhibitor 1 exhibited highest resistance (2.9 $\Omega$), while inhibitors 2 and 3 displayed 2.8 and 2.3 $\Omega$ value of resistance, respectively. The corrosion prevention of three choline amino acid ionic liquids ([Ch][AA]ILs) was evaluated for mild steel in 1 M HCl in the temperature range of 298–328 K [11]. The result gained from PDP method indicated that [Ch][AA]ILs influenced the cathode and anode reaction. It showed that [Ch][AA]ILs displayed mixed-type inhibitors. Among the evaluated corrosion inhibitors, choline phenylalanine ionic liquids ([Ch][Phe]) showed the highest corrosion efficiency. The values of standard free energy of adsorption ($\Delta G_{ads}$) lied in the range between $-20$ kJ·mol$^{-1}$ and $-40$ kJ·mol$^{-1}$ revealing that inhibitor adsorbed on the metal surface by physical and chemical adsorption mechanism. The inhibitors formed a thick monolayer adsorption layer on the metal surface which effectively preventing metal-corrosive media interaction. The molecular dynamics simulation findings showed that the corrosion inhibitor molecules replaced the solvent water or any other ions pre-adsorbed on the metal surface during the adsorption process and protecting the metal against corrosion. As a cheap natural biomolecule, glucose has proven significant corrosion inhibitor for various metals in the acidic and basic media [12]. The two thiocarbohydrazide-modified glucose derivatives (TBTD-1 and TBTD-2) were synthesized using N-glycosyl linkage. The both inhibitors TBTD-1 and TBTD-2 found to be potential green corrosion inhibitors for the prevention of corrosion of carbon steel pipelines in oil and gas industry. TBTD-1 and TBTD-2 displayed excellent corrosion inhibitive action with an inhibition efficiency of 99.1% for TBTD-1 and 99.4% for TBTD-2. Oleic imidazole (OIM) and mercaptoethanol (ME) are used as corrosion inhibitors for carbon steel in 3.5 wt% NaCl aqueous solution saturated by CO$_2$ at 60°C [13]. Both the WL and the electrochemistry method showed that the synergistic effect between OIM and ME significantly improved the corrosion inhibition performance of the mixture corrosion inhibitors. The inhibition efficiency of the mixture corrosion inhibitors is high up to 96.56% when the ratio of OIM and ME is 3 to 1. The quantum chemical parameters calculated at the B3LYP/6-311++G(d,p) level displayed that OIM can be preferentially adsorbed for its low energy gap, while molecular dynamic simulation results showed that OIM is preferentially adsorbed onto the Fe(110) surface with a adsorption energy of $-1583.7$ kcal·mol$^{-1}$. The adsorbed OIM molecules formed a film with voids and ME molecules fill in the voids forming a bilayer film. The entrapping of inhibitor directly inside the intrinsically conducting polymer (ICP) matrix of polypyrrole (PPy) [14]. The material was coated by using electrodeposited in the presence of $\beta$-cyclodextrine, benzotriazole, and 8-hydroxyquinoline in the deposition of electrolyte-bearing pyrrole and 3-nitrosalicylate as counter-anion. The self-healing performance was investigated by monitoring both the corrosion potential in an electrolyte-filled defect and the delamination behavior by scanning kelvin probe (SKP). An excellent performance in terms of an extraordinarily significant passivation effect is found. The hollow mesoporous organosilica nanoparticles (HMONs) encapsulated by 2-mercaptobenzothiazole (MBT) corrosion inhibitor are used to prevent the corrosion of Cu in 3.5 wt% NaCl [15]. MBT@HMON was well characterized, and the release kinetics of MBT from HMON under different dithiothreitol (DTT) concentration and pH conditions was studied. The WL and EIS were used to study the controlled release of corrosion inhibitor MBT from HMON by tuning the redox and pH conditions of corrosion
medium. The 1.6 g·L\(^{-1}\) concentration of MBT@HMON was added in the corrosion media which effectively prevented the corrosion of copper alloy. Two modified polyaspartic acid (PASP) derivatives poly(cysteaminoaspartamide) and poly(methionenoaspartamide) were successfully demonstrated corrosion inhibitors for C1018 steel in 3.5% NaCl-saturated CO\(_2\) brine solution by PDP, LPR, and EIS methods [16]. SEM images revealed that uniformed layer of inhibitors formed on the metal surface. Anticorrosion effect of tetracycline drug on carbon steel alloy (ck45) in 1 M HCl using PDP and EIS method was demonstrated [17]. Using 300 ppm concentration of the drug showed 82% and 78% corrosion inhibition efficiencies as determined by PDP and EIS methods, respectively. The PDP measurement showed that tetracycline drug behaved as mixed-type inhibitor. The adsorption of drug molecules on the alloy surface followed the Langmuir adsorption isotherm. \(\Delta G^\text{ads}\) valued suggested that the drug molecules adsorbed on the alloy surface through physisorption mechanism. Additionally, optical microscopy and SEM images also confirmed corrosion inhibition action of drug by the formation of a protective film over the metal surface. Corrosion inhibition performance of imidazole drugs omeprazole (OMP) and its byproducts omeprazole sulfide (OMP-1) and omeprazole sulfonate (OMP-2) on Q235 steel in 1 M HCl was evaluated using WL, PDP, EIS, SEM, and XPS methods as well quantum chemical calculation and molecular dynamics simulation [18]. The obtained results showed that OMP, OMP-1, and OMP-2 are proven to be effective corrosion inhibitors for Q235 steel in 1 M HCl. The inhibition efficiency of above 95% was found at 298 K with 0.2 mM inhibitor concentration. The PDP method was revealed that inhibitors are mixed-type corrosion inhibitors by obeyed Langmuir adsorption isotherm. SEM and XPS studies further confirmed that three inhibitor molecules showed significant corrosion inhibition action by adsorbing on the surface of Q235 steel which formed barrier. Two heteroatom-containing phosphor amides, N-(5-methylisoxazol-3-yl)-P,P-diphenylphosphinic amide (MAPP) and diphenyl (5-methylisoxazol-3-yl)phosphoramidate (PMAP) were found to potent corrosion inhibitors for carbon steel in HCl [19]. The polyaspartic acid (PASP) derivatives modified with benzothiazole compounds (R-ABT: R = H, Me, and OMe) were demonstrated as fluorescent green corrosion inhibitors [20]. The corrosion performance of three inhibitors on carbon steel in cooling water was investigated using the electrochemical test, WL measurement, SEM, AFS, XPS, DFT, and MD simulation. The PDP method indicated that three derivatives are mixed-type inhibitors, and their corrosion inhibition efficiencies trend followed the order as: PASP-OMe-ABT (96.45%) > PASP-Me-ABT (91.38%) > PASP-H-ABT (89.38%). The three inhibitor molecules improved the corrosion of carbon steel surface by physisorption and chemisorption. Pectin obtained from the waste peel and residue of various plants material is used to synthesize environmentally friendly and biodegradable green corrosion inhibitor. Two corrosion inhibitors of pectin modified by glycine (Gly) and lysine (Lys) were prepared and applied for the control of corrosion of N80 carbon steel in CO\(_2\)-saturated groundwater [21]. The 6.26% and 7.20% of gly and lys were amidated to pectin as confirmed by elemental analysis, FTIR spectroscopy, \(^1\)H NMR, and XRD. Both inhibitors P-Gly (99.01%) and P-Lys (99.36%) showed excellent corrosion inhibition efficiency at 800 mg/L for 120 h. Theoretical calculations done by QC based on DFT and GFN-xTB methods and MD-based RDFs revealed the chemisorption of the inhibitors. N-substituted methyl ethylenediamine derivatives, tetramethylethlenediamine (TDA), pentamethyldiethylenetriamine (PTA), and hexamethylietriethylenetetramine (HTA) are used as corrosion inhibitors for 20# steel in 1 M HCl [22]. The corrosion property of three inhibitors is conducted by WL, PDP,
EIS, and surface analysis techniques. Three methyl ethylenediamine derivatives displayed excellent inhibition properties. The order of inhibition efficiency of these inhibitors was TDA < PTA < HTA. PDP techniques revealed that three inhibitors act as mixed-type inhibitors. The adsorption mechanism of corrosion inhibitors followed the Langmuir isotherm and adsorption followed physisorption and chemisorption. Quantum chemical calculations and MD simulations well supported the experimental results. The excellent corrosion inhibition property of inhibitors was linked to the presence of tertiary amine groups which effectively bound with Fe. The corrosion inhibitor N1-(2-aminoethyl)-N2-(2-(2-(furan-2-yl)-4,5-dihydro-1H-imidazol-1-yl)ethyl)ethane-1,2-diamine (NNED) showed excellent corrosion inhibitive action for carbon steel in 1 M HCl [23]. It exhibited more than 90% corrosion inhibition efficiency at 5 ppm. The adsorption of NNED on the steel surface was spontaneous and followed the Langmuir adsorption isotherm. Xanthium cocklebur corrosion inhibitor effectively suppressed corrosion of carbon steel [24]. It effectively decreased the corrosion current and increased the corrosion potential. The adsorption of inhibitor confirmed the Frumkin adsorption isotherm model. The corrosion inhibition mechanism was attributed to the phenolic hydroxyl oxygen of 1,5-dicafeoylquinic acid hybridizes that formed strong covalent bond with empty 3d orbital of Fe and hydrogen bond formed between hydrogen of hydroxyl with oxygen of hydroxyl presence on the surface of γ-FeOOH (0 1 0). Diaminododecane-functionalized graphene oxide (DAD-GO) and diaminododecane-functionalized graphene oxide (DADD-GO) were demonstrated as corrosion inhibitors for carbon steel corrosion in 15.0% HCl [25]. The inhibition activity enhanced the concentration at room temperature and obtained maximum to 84% for DAD-GO and 78% for DADD-GO at a concentration of 5 ppm for both. The increased temperature contributed to decrease in the corrosion inhibition efficiency. The Langmuir adsorption was followed by the both inhibitors, and corrosion properties of both inhibitors are well supported by AFM, SEM, EDX, and FTIR. All investigated methods revealed that functionalized both GO inhibitors formed protective layer after 24 h of immersion time. 3,5-bis(4-methylphenyl)-4-amino-1,2,4-triazole (MeAT) and 3,5-bis(4-methoxyphenyl)-4-amino-1,2,4-triazole (MxAT) were investigated as corrosion inhibitors for Cu in 1 M HCl [26]. 1,2,4-triazole derivatives are emerged as efficient corrosion inhibitors for Cu in 1 M HCl. The compound MxAT showed highest corrosion inhibition efficiency (87.9%) at 10^{-3} M concentration of MxAT at 303 K. The adsorption of MxAT molecule followed Langmuir adsorption isotherm and founded \( \Delta G_{\text{ads}} \) indicated that adsorption of MxAT is chemisorption. 3-aminio-1,2,4-triazole-5-thiol (ATAT) inhibited the corrosion of Al [27] in naturally aerated stagnant Arabian Gulf water. The corrosion inhibition action of ATAT was evaluated by EIS, cyclic potentiodynamic polarization (CPP), and potentiostatic current–time (CCT) measurements. EIS method showed that ATAT reduced corrosion of Al by enhancing the solution and polarization resistances, the impedance of the interface, and the maximum degree of phase angle. The other two techniques CPP and CCT revealed the corrosion inhibition property of ATAT by decreased of cathodic, anodic, and corrosion currents and corrosion rate and increased polarization resistance of Al. The pH-sensitive corrosion inhibitor benzotriazole (BTA) was capsulated on the surface of mesoporous silica with metal phenol network. A PH-triggered release of BTA from mesoporous silica as confirmed by UV-vis measurements proved that outstanding protection of Cu [28]. The anticorrosive activities of furfural derivatives prepared by ex situ and in situ are used to prevent the corrosion of mild steel immersed in CO_2-saturated water by WL, PDP, EIS, XPS, and quantum chemical calculation [29]. Furfural thiosemicarbazone
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(prepared by ex situ) showed inhibition efficiency 90.2% for 72 h in immersion. The same molecule, synthesized in situ showed 82.2% corrosion inhibition efficiency for 24 h of immersion, but corrosion inhibition efficiency decreased over the time due to incomplete conversion of the precursors in furfural thiosemicarbazone. The corrosion activity of mild steel in 1 M HCl was evaluated in the presence of (E)-3-(5-bromo-2-hydroxy styryl) quinoxalin-2(1H)-one (FR178) and (E)-3-(5-fluoro-2-hydroxy styryl) quinoxalin-2(1H)-one (FR179) [30]. The organic inhibitors emerged as efficient corrosion inhibitors for mild steel. Increasing concentrations of inhibitors contributed to high inhibition efficiencies that were due to blocking of both sides of metal (anodic and cathodic). The inhibition efficiency found to be 90.9% and 91.5% for both inhibitors FR178 and FR179, respectively, at $10^{-3}$ M. The anticorrosion activities of FR178 and FR179 decreased to 82% and 84%, respectively, at 328 K. PDP and EIS methods showed that both inhibitors are the mixed type. The X-ray, XRD, and SEM-EDS revealed about the formation of protective layer on the metal surface. DFT and molecular dynamics (MD) simulations supported the anticorrosion activity of both inhibitors. Two novel organic aromatic thiophene derivatives, 5-(thiophen-2-yl) - 1H-tetrazole (TET) and thiophene-2-carbaldehyde oxime (OXM), were examined for the corrosion protection of mild steel in 1 M HCl [31]. The two organic inhibitors have significant resistance to the effect of time of immersion and corrosion inhibition efficiency of inhibitors increased with time. The maximum corrosion inhibition efficiency attained 94% and 95% for OXM and TET, respectively, at $10^{-3}$ M. The maximum shift in $E_{corr}$ values found to be 10–17 mV signified thiophene compounds are mixed-type (anodic/cathodic) inhibitors. SEM micrographs confirmed the formation of a protective layer adsorbed on the mild steel surface. The electrophilic/nucleophilic attacks (Fukui indices) on the metal surface are theoretically determined and strong supporter of findings obtained by DFT and MC simulations and electrochemical methods. Ammonium salts DDPC and DDQC showed superior corrosion inhibition property for X65 carbon steel in the sour brine solution at different temperatures [32], and concentration were studied by various methods (WL, electrochemical measurements, and surface analysis (SKP, AFM, SEM, EDs, and ATR-FTIR). The obtained results indicated that corrosion rate decreased with increasing inhibitor concentration, and the inhibition efficiency reached to 98%. The adsorption of inhibitors on the metal surface followed the Langmuir adsorption isotherm. Corrosion inhibition property of inhibitors did not alter at elevated temperatures. Vitamin B$_{12}$ studied as corrosion inhibitor for the mild steel [33]. The PDP and EIS methods were used to assess the corrosion activity of vitamin B$_{12}$. EIS method indicated that in the presence of vitamin B$_{12}$, there is an increase in the $R_{ct}$ (charge transfer resistance) and a decrease in the value of capacitance layer ($C_{dl}$). It showed the formation of a protective layer over the mild steel surface. The surface morphology in the absence and presence of vitamin B$_{12}$ on the mild steel was examined by FE-SEM. The smooth surface has been seen in the presence of inhibitor that revealed the protective behavior of vitamin B$_{12}$. Thiadiazole derivative, 1-phenyl-3-(5-thioxo-4,5-dihydro-1,3,4-thiadiazol-2-yl) thiourea (PTT), was synthesized with 5-amino-1,3,4-thiadiazole-2(3 H)-thione (ATT) [34]. The corrosion inhibitor PTT applied to control the corrosion of N80 carbon steel in supercritical CO$_2$. Corrosion inhibitor PTT showed the excellent corrosion inhibition efficiency (99.58%). DFT calculations confirmed the adsorption of PTT on steel surface by the formation of bonding with the three S atoms of (thione-thiadiazolely)thiourea fragment and with the benzene ring. Compared to ATT, PTT showed the significant improvement in the inhibition performance. It was due to the stronger adsorption of PTT by forming
more S-Fe bonds and the extra C-Fe bonds. Corrosion protective property of coumarin-buta-1,3-diene-conjugated dyes was investigated for steel in acidic environment [35]. The highest corrosion efficiency was estimated to be 97.62% as determined by PDP method. Amino acid-based surfactant sodium cocoyl glycinate (SCG) is studied as a corrosion inhibitor for mild steel 1 M HCl [36]. At 30°C, SCG showed 95.21% inhibition efficiency at 0.2864 mM. The corrosion inhibition efficiency was decreased to 73.21% at 60°C. Thermodynamic and kinetic parameters of MS corrosion and inhibitor adsorption were determined. The Gibbs free energy of adsorption ($\Delta G_{ads}$) was calculated and found to be in the range of $-30$ and $-40$ KJ mol$^{-1}$. It showed the mixed adsorption phenomena (chemisorption and physisorption). Sodium metamizole exhibited corrosion inhibitive action for carbon steel (CS) in 1 M HCl [37]. Corrosion inhibitor displayed 82.87% corrosion inhibition efficiency at 300 ppm and 25°C. The effect of temperature on the CS indicated that corrosion inhibition efficiency decreased at elevated temperature. It showed physisorption of inhibitor on the metal surface as supported by activation energy (80 KJ mol$^{-1}$) and free energy (20 KJ mol$^{-1}$). The adsorption of inhibitor followed Langmuir adsorption model. The PDP method indicated that inhibitor behaved as mixed type. EIS showed a decrease in the values of double-layer capacitance and an increase in the value of the charge transfer resistance with increased concentration of sodium metamizole. Schiff (1Z)-N-[2-(methylthio) phenyl]-2-oxopropane hydrazonoyl chloride (S1) showed anticorrosive property for mild steel in 1 M HCl [38]. Corrosion inhibition efficiency of S1 increased with increasing concentration of inhibitor and decreased with increase in temperature from 25° to 55°C. The maximum inhibition efficiency achieved is 87% at 2.5 × 10$^{-3}$ M concentration at 25°C. Contact angle in the presence and absence of inhibitor was calculated. In the presence of inhibitor S1 showed 75°, while in the absence of inhibitor value of contact angle increased. Corrosion inhibitor followed the Langmuir isotherm. Cefotaxime sodium drug (Cefo) displayed corrosion inhibition property for Al in 0.1 M NaOH [39]. The corrosion inhibition efficacy increases with increasing concentrations of up to 300 ppm while decreasing with increase in temperature. The maximum inhibition efficiency of Cefo was 71.8% at 300 mg/L. Cefo adsorption on the Al surface is a mixed and spontaneous process that obeyed Freundlich adsorption isotherm. XPS and FESEM/EDAX proved the presence of protective layers on the Al surface. Two bi-pyrazole-carbohydrazides, 1,1’-(propane-1,3-diyl)bis(5-methyl-1H-pyrazole-3-carbohydrazide) (P2PZ) and 1,1’-(oxy bis (ethane−2,1-diyl)) bis (5-methyl-1H-pyrazole-3-carbohydrazide) (O2PZ) were evaluated as corrosion inhibitors for mild steel (MS) in 1.0 M HCl [40]. The corrosion inhibition efficiency achieved to 95% and 84% at 308 K and 10−3 mol/L of P2PZ and O2PZ, respectively. Corrosion inhibition efficiency increased with increase in concentration and decreased with increase in temperature. PDP method showed that P2PZ and O2PZ acted as mixed-type inhibitors and followed the Langmuir adsorption isotherm. The free energy of adsorption ($\Delta G_{ads}$) values are found to be in the range of $-39.94$ to $-37.36$ KJ mol$^{-1}$. It confirmed the physicochemical adsorption process. SEM images indicated the formation of a protective layer on the surface of the metal in the presence of both inhibitors. Dopamine-modified polyaspartic acid (PASP-Dop) showed corrosion protective action toward mild steel [41]. Corrosion inhibition efficiency of PASP-Dop was estimated to be 90.9% at 298 K in 0.5 M H$_2$SO$_4$ using 100 ppm concentration of inhibitor. The corrosion inhibition efficiency of inhibitor did not alter at elevated temperature. 2-mercaptopbenzothiazole (MBT) showed corrosion inhibition action for Zn in 1 M HCl [42]. PDP and EIS showed an increase in charge transfer resistance ($R_{ct}$) and a decrease in
corrosion current density (Icorr). The values of Rct found to be 156.8, 225.8, 420.7, and 753.5 Ω cm² at 0, 100, 300 and 500 ppm MBT, and value of Icorr decreased as increase in the concentration of inhibitor. The order of Icorr is as follows: 500 ppm (89 μA cm⁻²) < 300 ppm (230 μA cm⁻²) < 100 ppm (340 μA cm⁻²) < 0 ppm (955 μA cm⁻²). Two xanthone derivatives, namely 12-(4-chlorophenyl)-9,9-dimethyl-8,9,10,12-tetrahydro-11H-benzo[a]xanthen-11-one (BX-Cl) and 9,9-dimethyl-12-(4-nitrophenyl)-8,9,10,12-tetrahydro-11H-benzo[a]xanthen-11-one (BX-NO₂), were studied as corrosion inhibitor for P110 steel in 15% HCl [43]. The corrosion inhibition of BX-Cl and BX-NO₂ was improved in the presence of KI. WL method showed that corrosion inhibition efficiency increased from 62.10% to 92.21% for BX-Cl and 47.36 to 84.21% for BX-NO₂ as concentration increased from 50 to 200 mg/L. The corrosion inhibition efficiency of BX-Cl and BX-NO₂ decreased with increase in temperature. EIS method indicated that Rct values increased upon increasing the amount of BX-Cl and BX-NO₂ and reached to maximum value to 644.8 Ω cm². PDP confirmed the reduction in the Icorr value from 630 to 54 μA/cm².

3. Conclusion and future prospective

Corrosion of metal is the ambitious problem. The corrosion of metal can be controlled by using appropriate method. Corrosion inhibitors somewhat mitigated the metal corrosion. Small organic molecules played a significant role as corrosion inhibitors. The benefit to utilize small organic molecules is that they are easy to prepare (no multiple steps are involved) and exhibited good corrosion activity similar to complex molecules. There are numerous small molecules available. The future direction in this filed is to apply small organic molecules which are most economical, less hazardous, and readily available from the natural sources and can show good anticorrosive property as well.
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