Ifeyinwa Calista Ekeke[1,2,]*, Steve Efe[1],
Felix Chigozie Nwadire[3,4]

[1]*Morgan State University, Civil Engineering Department, Baltimore, Maryland, USA,* [2]*Federal University of Technology, Chemical Engineering Department, Owerri, Imo State, Nigeria,* [3]*Michael Okpara University, Chemistry Department, Umudike, Umuahia, Abia State, Nigeria,*[4]*Morgan State University, Chemistry Department, Baltimore, Maryland, USA.*

A review of amino acids used as corrosion inhibitors on iron metal/alloys in aggressive environments

ABSTRACT

Research into the use of safe and environmentally friendly corrosion inhibitors can pave the way for an understanding of their inhibition mechanisms in metallic alloy materials. This review seeks to present and discuss the research work reported in the literature on the use of amino acids and their derivatives as corrosion inhibitors for iron and its alloys in different aggressive solutions. This non-toxic, biodegradable and relatively cheap corrosion inhibitor has shown to be efficient as an inhibitor for metals/alloys in acidic, alkaline and neutral solutions depending on experimental conditions. Electrochemical and surface techniques were among the most often used techniques to evaluate the corrosion inhibition efficiency of amino acids. Highest values of inhibition efficiency can be obtained in the presence of ions as I^- and Br^-. This review presents and discusses most of the contributions made in literature on the use of amino acids and their derivatives as corrosion inhibitors for iron and its alloys.

Keywords*: corrosion inhibitor, iron, metal, alloy, amino acid, computational methods.*

1. INTRODUCTION

Corrosion can be defined as a spontaneous and irreversible weakening of metals or alloys which occurs by electrochemical or chemical reactions with the environment [1]. Corrosion causes enormous wastes of metallic materials which leads to enormous economic losses all over the world. It is a global problem, negatively affecting the growth of both developed and developing countries. Hence, it has drawn much academic and industrial attention [1–5]. Causes of corrosion include acids, bases, brines, oxygen, moisture/water, hydrogen sulfide, bacteria, carbon dioxide, etc. Many techniques of corrosion protection have been developed over time. A flow diagram of the available corrosion protection measures is presented by Verma et al. [2]. Among these, corrosion inhibitors are briefly discussed.

2. BACKGROUND

Corrosion Inhibitors

The use of inhibitors is the most important method for protecting metals from corrosion, and many scientists are conducting research on this topic. New inhibitors are discovered often. In principle, inhibitors prevent the corrosion of metal by interacting with the metal surface via adsorption through donor atoms, π-orbitals, electron density and the electronic structure of the molecule [6–12]. In particular, $–NH_2$ and $–SH$ groups in the structures of inhibitors often act as reaction centres during the adsorption of the inhibitor. In this way, the inhibitors form an adsorbed protective film on the metal surfaces and protect the metals from the attacking acid solution [13–18]. The common corrosion inhibitors such as chromates [19], nitrite [20], and aromatic heterocyclic compounds [21] are environmentally threatening. The replacement of these inhibitors with new environment-friendly materials is crucial. Amino acids are nontoxic, biodegradable, relatively cheap and completely soluble in aqueous media. Much research has been performed as regards the inhibition effect of some amino acids on the corrosion of metals.

Amino acids as Inhibitors

An amino acid is a molecule that possesses at least one carboxyl (-COOH) group and one amino (-NH2) group usually bonded to the same carbon atom (α- or 2-carbon). The other ligands of the α-carbon are -H and R- groups of different sizes, shapes, and chemical properties (side chain) [22]. In physiological terms, there are twenty different amino acids, which are used to build up proteins in all species from bacteria to humans [23].

Amino acids contain heteroatoms (e.g., S, N and O) and eventual conjugated π-electrons system on their molecular structures. This attribute has attracted the attention of researchers to explore their potential abilities to act as green corrosion inhibitors. The first tentative use of amino acid compounds as corrosion inhibitors for metals was reported by [24]. More recent reports such as [25 - 28], on the use of amino acids and even their derivatives have been published.

A thorough examination of literature has revealed that almost all tested amino acids compounds have exhibited the ability to act as ecofriendly inhibitors against metal corrosion in different mediums. However, there is no universal amino acid compound that is applicable to all or most of the metal/solution systems. Hence, the inhibition capability of these compounds depends on their molecular structure, concentration, corrosive medium, nature of the metal surface, hydrodynamic conditions in the system, pH of solution, etc. Whereas an amino acid can act as an effective corrosion inhibitor on a given metal at certain conditions, it can also accelerate the corrosion process at other operating conditions. Current research focuses on the use of newly synthesized derivatives of amino acids with higher corrosion inhibition efficiencies than their corresponding simpler/original compounds as corrosion inhibitors. It also incorporates an explanation of their inhibition mechanisms using quantum chemical calculation and/or simulation by molecular dynamics approach. A list of amino acids which have been researched as green corrosion inhibitors for iron and its alloys is presented in Table 1.

Characterization Techniques

Characterization and determination of corrosion inhibition effectiveness can be conducted in two different ways: experimental methods and Computational methods.

Experimental Methods

Potentiodynamic polarization (PDP) measurement: This method is one of the most used DC electrochemical methods in corrosion measurements. It is based on the evaluation and analysis of the current produced by a variable potential in a working electrode. Here, a wide range of potential is applied to the test electrode. Subsequently, current is generated. The presentation of the potential in the function of current density (I) (or log I) for each measured point results in the polarization curve. The polarization curve can be used to determine the corrosion potential and the corrosion rate of the metal in the given condition (Tafel slope). The advantage of this method is the likelihood of a localized corrosion detection, easy and quick determination of the corrosion rate, efficiency of the corrosion protection, etc. [29].

Cyclic Potentiodynamic Polarization (CPDP). This is also widely used to determine resistance to localized corrosion or degradation rate in a short time [30]. It is performed like a potentiodynamic scan, but with an addition: the voltage is swept across a range but reversed back to the starting potential. This allows a return to the original potential. The surface is likely to be changed by the reactions during the scan, so often the data from the return voltage sweep do not superimpose upon the data from the forward sweep.

Electrochemical Impedance Spectroscopy (EIS) [31]. This technique is used to determine the impedance of a system in terms of the frequency of a variable potential. The analysis of EIS results relies on models with equivalent electrical circuits, with the most recurrent graphical representations of its results being Nyquist plots [32]. EIS shows more information, for example, mechanism and different resistance of the system.

Electrochemical Frequency Modulation (EFM): This is a technique that enables the instantaneous determination of a corrosion rate, without previous knowledge of the Tafel parameters. The EFM approach requires only a small polarizing signal, and measurements can be completed in a short period. A unique advantage of the EFM technique is its ability of innate data validation control using causality factors. It can be used effectively for corrosion rate measurements under various corrosion conditions. [33].

Electrochemical Noise (EN): EN is a method that enables the determination of the phenomenon of metal corrosion at E_{OCP} without the need for any sort of external potential perturbation. Time-dependent statistical treatments of the random current and potential noise signals originating from the corrosion system can be used to calculate the corrosion rate, while corrosion mechanisms can be predicted based on the interpretation of certain spectral patterns obtained from frequency-dependent analysis of the noise signals [34 -39]

Linear polarization resistance (LPR) is a technique used to obtain the corrosion rate by determining the relationship between electrochemical potential and generated currents on charged electrodes [40].

Weight Loss Method (WL): This technique is based on the mass lost by the metal, which is directly monitored to get the corrosion rate. The loss of metal due to corrosion is measured by exposing the metal specimen of known area to the environment for a period of time and calculating the difference in weight before and after exposure [41].

Thermometric method: This is a temperature-based method for corrosion rate calculation. The temperature variation during the reaction of a metal test piece with a definite volume of a corroding solution is ascertained [42]. By the increase in temperature per unit of time, the reaction number (RN) and inhibition efficiency are calculated. [43].

Surface characterization is usually studied by means of spectroscopy and microscopy techniques. Some of these are;

Scanning Electron Microscope (SEM) provides a clear comparison between the metal surface with and without a corrosion inhibitor, as well as other morphological information [44, 45].

Atomic Force Microscope (AFM) obtains information regarding the shape of the metal surface for comparison purposes and topography imaging [46 -49].

X-Ray Photoelectron Spectroscopy (XPS) is recurrently used for oxidation states, stoichiometry, and electronic state determination [50 -53].

Fourier transform infrared (FTIR) spectroscopy is used to obtain information on the functional groups and vibrational modes on the corrosion inhibitors [54].

Ultraviolet–Visible (UV–VIS) spectroscopy helps to explain functional groups, electronic transitions, and optical band gaps.

Computational methods

Computational chemistry methods have been employed by researchers for the purpose of investigating and understanding how the molecular structure of amino acids affects inhibition efficiency. Investigations have been limited to amino acid molecules acting alone in vacuum or in aqueous phase/solution in its neutral, protonated, or unprotonated forms. These methods are briefly described.

Quantum chemical calculation methods:

(i) Semi-empirical methods: These serve as efficient computational tools which can yield fast quantitative estimates for a number of properties. This may be particularly useful for correlating large sets of experimental and theoretical data, for establishing trends in classes of related molecules, and for scanning a computational problem before proceeding with higher-level treatments. However, there is a need to improve semiempirical methods with regard to their accuracy and range of applicability, without compromising their computational efficiency. Examples of semi-empirical methods include MNDO, AM1, PM3, etc. [55].

(ii) Ab initio Methods: The term ab initio indicates that the calculation is from first principles and that no empirical data is used. The simplest type of ab initio electronic structure calculation is the Hartree–Fock (HF), in which the instantaneous Coulombic electron-electron repulsion is not specifically considered, and only its average effect is included in the calculation [55].

(iii) The Density Functional Theory (DFT): This is used in the field of reaction chemistry, in explaining the science of solids and chemistry. It enables an understanding of the structure, properties, reactivity, and dynamics of atoms, molecules and clusters. Large systems involving many atoms or molecules are simulated on a regular basis using this method. [56]. The most important parameter in DFT is the electron density $\rho(r)$, in terms of which all the chemical quantities are expressed [57]. The main objective of DFT is, therefore, to replace the many-body electronic wave function with the electronic density as the basic quantity [58]. The structural parameters calculated through the electronic density ($\rho(r)$ concept) compare well with the parameters calculated by the Schrodinger equation in terms of the single electron wave function (ψ), where the latter can be applied [59]. Examples include B3LYP/6-31+G*, B3LYP/6-311G**, etc.

The inhibition of corrosion is, however, a complex phenomenon, which involves many competitive effects, such as the inhibitor-metal surface bonding (adsorption energy), the solubility of inhibitor, and the complexation of inhibitor with metallic ion in solution, etc. All these factors and others should be taken into consideration if such a phenomenon must be clearly understood. [60 – 67]

Molecular Dynamic (MD) simulation: MD simulation with periodic boundary conditions (which use the Metropolis Monte Carlo statistical method) is used to calculate the adsorption energy and to identify the adsorption configuration (with lower

energy) of several amino acid compounds on metal surfaces. This has been implemented by several authors [68–71]. MD simulation method has the advantage of reduced time consumption compared to quantum chemical methods. Frequently, during MD simulations, the COMPASS (Condensed phase Optimized Molecular Potentials for Atomistic Simulation Studies) ab initio force field is used to calculate the energy of all components of the system.

Quantitative-Structure Activity Relationship (QSAR): Various researchers [72–76] have found a relationship between the inhibition efficiency of amino acids compounds and their reactivity indicators by merging some reactivity indicators obtained from computational methods with statistical tools. This methodology is called Quantitative-Structure Activity Relationship (QSAR) [77 -79].

The main steps of QSAR modeling process are reactivity indictors' selection, data splitting, training, and testing of the model. Frequently, simple and multi-linear regression are used to construct QSAR models [80–81].

Machine Learning Methods: This is a recent trend in recent works on amino acids developed from artificial intelligence. Examples include support vector machine [74] genetic function approximation [70] and artificial neural network [71]. Almost all these studies have been limited to the building of the QSAR models for the prediction of the inhibition efficiency of tested amino acids.

Recently, Taylor et al, 2015 [67] critiqued the investigation of inhibitor efficiencies through QSAR using electronic properties of the molecule because this approach has not taken into consideration factors such as concentration of inhibitor, temperature, solution flow, etc. This leads to the obscurity of these factors in the process of parameter fitting during the training step. Therefore, to build a predictive model for corrosion science and engineering, it is essential to consider the above-named factors. Such an approach is referred to as "Multiphysics Modeling" [67].

3. DISCUSSION

Factors affecting the inhibition ability of amino acid compounds

The efficiency of inhibitors depends on a number of factors and on the interplay between several competitive effects [82]. The major factors which influence the inhibition efficiency (IE) of amino acids include temperature, immersion time, concentration of inhibitor, chemical nature of inhibitor, solution pH, hydrodynamic condition, aerated and deaerated condition, additive, chemical nature of metal and metal/alloy surface state. Few of these factors are discussed here.

Temperature plays a very important role in the IE of an inhibitor. The determination of the optimum temperature for the high IE of an inhibitor is very important in the selection of an inhibitor for a particular application. Table 1 presents such temperatures as investigated by some authors such as Zerfaoui et al., 2004b [83] and Amin et al., 2009a [84]. Immersion time can also play a decisive role in the prevention of corrosion. It has been reported that cysteine displayed a dual effect on the corrosion of galvanized steel [85, 86]; it acted as a corrosion inhibitor at short exposure time and as corrosion accelerator at long immersion time. However, some amino acids have shown an increase in their inhibition performance by increasing exposure time as reported in the case of alanine for nickel [87] and glutamine for mild steel [88]. Such phenomena can be attributed to the instability/stability of adsorbed amino acid film on the metal surface and its affinity to react with metallic ions in the solution. It is also pertinent to ascertain the optimal concentration for the effectiveness of an inhibitor. Some inhibitors perform excellently at very small concentrations [89] while others perform well at higher concentrations [90]. Hydrodynamic conditions (i.e., stagnant, or dynamic solution) can also affect the inhibition performance. Generally, in the presence of inhibitor, two opposite effects for hydrodynamic conditions can be pointed out, which influence its inhibition efficiency. First, the flow can increase mass transport of inhibitor molecules toward the metal surface and raise the inhibition efficiency, as noted in the case of methionine]91] and glutamine [92] for mild steel and aluminum respectively. Secondly, the highest shear stress resulting from flow speed can lead to the desorption of adsorbed inhibitor molecules from the metal surface, which reduces the inhibition efficiency. The same behavior was reported for low alloy steel when a series of amino acids were used. It is pertinent to know that little work appears to have been done on the effect of some of these factors on the inhibition performance of amino acid compounds. More research is, therefore, encouraged in these areas. These factors should also be considered when building predictive models using computational methods.

Recent trends

Recent trends in the use of amino acids as corrosion inhibitors are the cases of Self-Assembly Monolayer (SAM) and Smart Coatings [22]. The Self-Assembled Monolayer (SAM) is prepared by utilizing the strong interaction between the heads of the amphiphiles molecules and the surface of the solid support on one hand, and intermolecular forces (involving van der Waals and hydrophobic forces) between backbone hydrocarbon chains in amphiphiles molecules on the other. The method of formulation involves the submergence of the support into a solution containing the corresponding amphiphiles induces (spontaneous) self-assembly of the amphiphiles components as a monolayer on the support surface. Washing the support removes excess adsorbent, resulting in a strongly immobilized monolayer. The application of the SAM of some amino acids and their related compounds as inhibitors of corrosion has been reported [93 - 95].

The smart coating technology involves the formation of corrosion inhibitors into microcapsules prior to their integration into a protective film. This permits the gradual release of the inhibitor in case the coating got damaged [96 -98]. This technology provides long-term active protection against corrosion of metal surfaces after the coating fails. In addition to corrosion protection and repair, the smart coatings also perform the functions of sensing and warning. A trial application of this on an amino acid as an inhibitor for galvanized steel has been reported [85, 86].

Table 1. Amino acids and their derivatives used as corrosion inhibitors for iron and its alloys

Tabela 1. Aminokiseline i njihovi derivati koji se koriste kao inhibitori korozije za gvožđe i njegove legure.

Inhibitor	Parameter/s studied	Other Details	Results / Findings	Reference
Cysteine cystine, methionine	Concentration	*Alloy* Mild steel *Medium* 1N H_2SO_4 *Methods* WL, PDP	Methionine was the best inhibitor. More than 60% IE was achieved with concentrations of amino acid as low as 10^{-3}M Mixed type inhibitors.	[99]
22 amino acids and four related compounds	Concentration/type of amino acid	*Metal* Iron *Medium* Deaerated 1M HCl *Method* PDP	Amino acid with highest IE (80%) was tryptophan while related compound with highest IE (87%) was 3,5-diiodotyrosine. Both IEs were obtained at 10mM concentration. Longer-chain amino acids showed better inhibition.	[100]
Cystine Parameter studied:	Concentration (0.1, 0.5, 1, 5mM)	*Alloy* Mild steel *Medium* 0.5M H_2SO_4 *Methods* EIS, SEM, AFM	86% maximum IE obtained. IE increased with concentration. Combined physical and chemical adsorption mechanism observed.	[101]
L-methionine	Rotation speed (300, 600, 900, 1500, 2000, 2200rpm)	Alloy Mild steel rotating disk electrode *Medium* 1M H_2SO_4 *Methods* EIS, PDP	IE increased with speed of rotation of electrodes. Maximum IE obtained was 66.5% at the highest speed with the EIS method.	[91]
Glycine, leucine, D-L aspartic, arginine and methionine	Concentration (5 x 10^{-5}, 10^{-4}, 5 x 10^{-4}, 10^{-3}, 5 x 10^{-3}, 10^{-2}, 2 x 10^{-2}M), temperature (30, 40, 50, 60°C) and pH (2.7, 3, 4, 5).	*Metal* Iron *Medium* Citric acid *Methods* WL, EIS, PDP	Methionine gave maximum IE of 90% at 2 × 10^{-2}M concentration, pH 5 and temperature 30°C. IE reduced with temperature increase and pH decrease. All tested amino acids exhibited cathodic inhibition	[83]
Alanine, glycine, and leucine.	Concentration of inhibitor (0.1, 0.01, 0.001, 0.0001M) and conc. of acid	Alloy Steel Medium Different HCl concentrations (0.1M, 0.01M, 0.001M, 0.0001M) Methods WL, PDP	Highest IE of 91.64% obtained with 0.1M leucine in 0.1M HCl	[102]
Methionine methyl ester (MME), methionine ethyl ester (MEE), methionine	Concentration (10^{-5}, 10^{-4}, 10^{-3}, 5 x 10^{-3}, 10^{-2}M) of MEE, temperature (22, 37, 50, 60°C)	Metal Iron Medium 9g/L NaCl Method PDP	Maximum IE of 80% at 10^{-2}M concentration and 37°C. was obtained with MEE. Adsorption was enhanced by sulphur and nitrogen whose electronegativity was enhanced by the ethyl group. Frumkin adsorption isotherm was proposed	[103]

Methionine, cyseine, cystine, glycine, leucine, arginine, serine, glutamic acid, ornithine, lysine, aspartic acid, alanine, valine, aspargine	Concentration	Metal Iron Medium 1M HCl Methods WL, PDP, EIS, DFT/B3LYP, DNP, QSAR (with Genetic Function Algorithm)	Best inhibition efficiencies were obtained with Methionine, cysteine and cystine.	[104]
Methionine ethyl ester	Temperature (30 – 60°C)	Metal Iron Medium Citric chloride Methods PDP, EIS	IE slightly increased with increasing temperature (range 30 – 60°C). Temkin adsorption isotherm.	[105]
Glycine	Concentration (1, 2, 5, 10, 20, 50mM), temperature (20, 30, 40, 50, 60°C).	Alloy Low alloy steel ASTM A213 grade T22 boiler steel Medium 0.5M HCl Methods SEM, PDP, EIS, LP, EFM, EDX ICP-AES	Efficient mixed-type inhibitor with cathodic predominance, Maximum IE of 79.88% obtained with the Tafel polarization. IE increased with concentration of inhibitor but decreased with temperature.	[84]
Tyrosine	Concentration (1, 2, 5, 10, 20, 50mM), temperature (20, 30, 40, 50, 60°C).	Metal Low chromium alloy steel Medium 0.5M HCl Methods SEM, PDP, EIS, EFM, energy dispersive X-rays, WL	Efficient mixed-type inhibitor with cathodic predominance. Maximum IE obtained was 85.23% with the PDP measurement. IE increased with concentration of inhibitor but decreased with temperature	[106]
Methionine methyl ester, glycine methyl ester, leucine methyl ester, phenylaline methyl ester and cysteine methyl ester	Concentration and temperature (20 – 50°C)	Metal Iron Medium 1M HCl Methods PDP, WL	Methionine methyl ester was best inhibitor, (IE – 95% at 10^{-2}M). It was also cathodic. IE increased with temperature. Frumkin adsorption isotherm.	[107]
L-Histidine	Concentration (1 x 10^{-4}, 5 x 10^{-4}, 1 x 10^{-3}, 5 x 10^{-3}, 10^{-2}M).	Alloy Carbon steel Media 0.5M acetic acid and 0.25 M acetate Methods LP, EIS, WL, EDX, SEM, cyclic voltammetry	Maximum IE of 81.6% obtained with 10^{-2}M inhibitor concentration for the WL method	[108]
Tryptophan	Concentration	Alloy Carbon steel Media 0.5M acetic acid and 0.25M acetate Methods LP, WL, SEM, cyclic voltammetry	IE increased with an increase in concentration in the range of 10^{-4} - 10^{-2}mol L^{-1}	[109]
Cysteine	Concentration (10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}M)	Alloy 304L stainless steel Medium Deaerated Molar H$_2$SO$_4$ Methods SEM, EIS, PDP	Cysteine at high concentration (10^{-4} – 10^{-2} mol/L) turned alloy electrochemically active	[110]
Cysteine	Concentration (0.1mM, 0.5mM, 1.0mM and 5.0mM)	Alloy Low carbon steel Medium 0.5M H$_2$SO$_4$ Methods EIS, PDP, SEM	Addition of low conc. (0.1–0.5 mmol L^{-1}) of cysteine, enhanced corrosion while higher concentration ((1.0–5.0 mmol L^{-1}) inhibited corrosion which was enhanced on deaeration of the test solution	[111]

L-Leucine	Concentration (10^{-1}, 10^{-3}, 10^{-5}M) and temperature ((25, 35, 45, 55°C).	Alloy Mild steel Medium $1NH_2SO_4$ Methods OCP, PDP, SEM, IR	Maximum IE - 78% at 0.1M. Mixed-type and passivating inhibitor. IE increased with an increase in concentration but decreased with temperature. Freundlich adsorption isotherm proposed	[112]
cysteine, methionine, cystine, and N-acetylcysteine acids + F^-, Cl^- and Fe^{3+}	Type of ion added	Alloy Mild steel Medium Phosphoric acid (40%) Methods PDP, EIS	The binary mixtures of Cl^- or F^- with cysteine or methionine showed a good anti-corrosion ability (IE > 90%), in contrast to those containing Fe^{3+} ions or ternary mixture ions and an amino acid	[113]
Glutamic acid (Glu-A) ($\pm Zn^{2+}$)		Alloy Carbon steel Medium Natural sea water. Methods WL, AFM	IE increased from 35% at 200ppm of Glu-A to 87% with addition of small amounts of Zn^{2+} (25ppm).	[114]
L-Cysteine (+ triton X-100 (TX), sodium dodecyl sulphate (SDS) and cetyl pyridinum choride (CPC))	Concentration of L-Cysteine (100, 200, 300, 400 and 500ppm) and additives, and temperature (30, 40, 50, 60°C).	Alloy Mild steel Medium 1M HCl Methods WL, PDP, EIS, SEM, FTIR	IE decreased in the order: Cys + TX (97.76%) > Cys + CPC (91.99%) > Cys + SDS (95.09%) > Cys (85.62%) for the WL method. All occurred at 500ppm of Cys and temperature of 30°C. IE increased with concentration but decreased with temperature.	[115]
Derivatives of glycine: 2-(4(dimethylamino) benzylamino) acetic acid hydrochloride (GlyD1), GlyD2 and Glycine (Gly)	Concentration (0.5mM, 1mM, 5mM, 10mM, 50mM) and temperature (5, 15, 25, 35, 45, 55 and 65°C).	Alloy Mild steel Medium $4M H_2SO_4$ Methods PDP, LPR, EIS, ICP-AES,	IE decreased in the order, GlyD1(98%) > GlyD2 (76%) > Gly (64%) at 50mM for the LPR method. IE increased with increase in inhibitor concentration and decreased with temperature. Physisorption of all three inhibitors proposed	[116]
Derivative of Cystine (RSSR), Cysteine (RSH), methionine (CH_3SR), N-Acetylcysteine (ACC) and S-benzylcysteine (BzC)	Concentration	Alloy Mild steel Medium 5% of sulfamic acid at 40°C Methods PR, EIS, PDP	IE followed the order: ACC (97.3%) > RSH (94.3%) > RSSR (92.7%) > BzC (91.7%) > CH_3SR (86.5%) at 1000 µM and with the PR method. Chemisorption proposed.	[117]
Derivative of Glycine: 2-(bis (2-aminoethyl) amino) acetic acid (GlyD) and glycine	Concentration	Alloy Cold-rolled steel Medium 1M HCl Methods PDP, EIS, LPR, ICP-AES, EFM, DFT	IE of derivative (96.02%) was higher than that of glycine alone (75% at 5mM) for the PDP and LPR methods. Higher IE attributed to the presence of extra NH link in derivative through computational study.	[118]
L-Lysine derivatives, SB-1, SB-2, and SB-3	Concentration and temperature (35, 45, 55 and 65°C)	Alloy Mild steel Medium 1M HCl Methods WL, PDP, EIS, SEM, AFM, EDX, quantum chemical calculations	Maximum IE decreased in the order, SB-3 (95.6%) > SB-2 (94.7%) > SB-1 (93.9%) from the WL method all at maximum concentration of 400mg/L. IE decreased with increasing tempe-rature. Strong electron releasing -N(CH3)$_2$ group responsible for high IE of SB-3. Chemical and physical adsorption proposed	[119]
L-tryptophan derivatives designated as S1 and S2		Alloy Mild steel Medium 1M HCl Methods PDP, EIS, SEM-EDX, FTIR, UV-VIS, X-Ray diffraction (XRD), DFT, computational technique	IE of S2 greater than that of S1 due to strong electron-donating ability and presence of additional phenyl rings in the molecule	[120]

Cysteine		Alloy Mild steel Medium 0.5M H_2SO_4 PDP, EIS, DFT/B3LYP 6-311++G (d.p)	IE = 96% at 10 mM. Langmuir adsorption isotherm. Chemisorption mechanism. Electrophilic site is the sulphur atom	[121]
Cysteine (Cys) and its derivatives: N-acetyl- L-cysteine (NACYS), N-acetyl-S-benzyl-L- Cys-teine (NASBCYS), and N-acetyl-S-h exyl- L-cysteine (NASHCYS)	Concentration	Alloy Mild steel Medium 1M HCl Methods WL, PDP, DFT, B3LYP 6-31G (d.p), molecular dynamics Fe(1,1,0)	IE: NASBCYS (95.7%) > NACYS (92.5%) > NASHCYS (92.4%) > Cys (90.4%) at 10^{-2}M with the PDP method. Mixed-type inhibitors. E_{HOMO}, ΔE, and molecular volume were good and correlated with experimental results.	[122]
Cysteine (Cys), serine (Ser), amino butyric acid (Abu), threonine (Thr), alanine (Ala), valine (Val), phe-nylalanine (Phe), tryptophan (Trp), and tyrosine (Tyr)		Alloy Mild steel Medium 0.1M H_2SO_4 Methods WL. Computational schemes with statistical analysis	IE ranking: Cys > Ser > Abu, Thr > Ala > Val and Trp > Tyr > Phe.	[123]
Cysteine		Alloy Mild steel Medium 1M HCl and 0.5M H_2SO_4 Methods EIS, PM3, molecular dynamics Fe (0 0 1)	Higher IE (90.4%) obtained in 1M HCl at 0.1M conc. of the inhibitor because of adsorption of Cl⁻. Inhibitor molecules adsorbed on iron surface in a vertical way	[124]
Cysteine	Concentration	Alloy Mild steel Medium 1M HCl and 0.5M H2SO4 Method PDP	IE increased with increasing concentration of L-cysteine in both acids though the higher one was obtained with 1 M HCl.	[125]
Triazolyl bis-amino acid of threonine and phenylalanine	Concentration	Alloy Mild steel Medium 1M HCl Methods WL, PDP, EIS, SEM, DFT/B3LYP 6-31*G	The 1,4-disubstituted triazolyl performed better than the natural amino acids as a result of the triazole ring. IE of one of the tested compounds generally increased with concentration.	[126]
Alanine	Concentration	Alloy Mild steel Medium 1M HCl Methods PDP, EIS, Molecular dynamics Fe (1 1 1)	Maximum IE of 80% obtained at 50mM of inhibitor. Adsorption occurred through the N/O atoms	[127]
Polyaspartic acid (± I⁻)	Concentration and temperature (10, 20, 30, 40°C)	Alloy Mild steel Medium 0.5M H_2SO_4 Methods WL, PDP, EIS, SEM, XPS, FTIR	IE = 88% at 2 g/L of acid alone and 98.8% in the presence of 1mM of I⁻ with the PDP method. IE increased with increase in temperature and concentration Inhibitor was cathodic. XPS analysis revealed a co-adsorption of I⁻ and polyaspartic acid molecules on alloy surface.	[128]
Poly (vinyl alcohol-histidine)	Inhibitor concentration, exposure time, and temperature	Alloy Mild steel Medium 1M HCl Methods WL, PDP, LPR, EIS, SEM, FTIR, UV-VIS, AC conductance measurem-ent using LCZ analyzer, Thermogravimetric analysis (TG/DTG)	IE = 95% at 0.6%wt. Mixed type inhibitor. Temkin adsorption isotherm. Physisorption	[129]

Methionine (± sodium dodecyl sulfate: SDS and cetyltrimethyl ammonium bromide (CTAB)	Concentration (10, 25, 50, 100, 200, 300, 500ppm), temperature (30, 40, 50, 60°C)	Alloy Mild steel Medium 0.1M H$_2$SO$_4$ Methods WL, PDP, SEM, AFM	The synergism between methionine and CTAB is better than that of methionine and SDS. For the WL method, the best IEs were obtained at 300ppm of inhibitors used. IE decreased with temperature increase in all cases. Methionine acted as a mixed-type inhibitor. Physisorption proposed.	[130]
Poly (vinyl alcohol-leucine). (± Br$^-$ and I$^-$)	Concentration (0.06, 0.12, 0.15, 0.18, 0.24, 0.30, 0.36, 0.42, 0.45, 0.48, 0.54 and 0.60%), temperature (30, 40, 50, 60, and 70°C) and immersion time (1, 3, 5, 12, 24hrs)	Alloy Mild steel Medium 1M HCl Methods WL, PDP, EIS, SEM, UV-VIS	Maximum IE = 98.18% at 0.6 wt% in the presence of I$^-$. Synergism effect of inhibitor with Br$^-$ and I$^-$ ions. IE did not change significantly with rise in temperature. Also, IE decreased with prolonged immersion (12 -24hrs).	[131]
Glutamine	Concentration (25, 50, 75 and 100ppm), temperature (35, 45, 55 and 65°C) and immersion time (2, 3, 4 and 6hrs)	Alloy Mild steel Medium 1M HCl Methods DFT/B3LYP 6-31 G* (d.p)	Maximum IE of 96% obtained at an optimum conc. of 100ppm. IE increased with immersion time and concentration but decreased with temperature. Chemisorption proposed. Langmuir adsorption isotherm.	[88]
Decylamides of tyrosine, glycine, alanine and valine.	Concentration (10, 25, 50 and 100ppm), temperature (25, 35, 45, and 60°C).	Alloy Mild steel Medium 1M HCl Methods WL, PDP, XPS, IR	Order of IE of derivatives: tyrosine > glycine > alanine >valine. Flory-Huggins adsorption isotherm obtained. The XPS analyses confirmed the presence of a chemisorbed film of decylamides derivatives on the alloy. IE increased with concentration but decreased with temperature.	[132]
Glutaraldehyde + glycine = (CPI), and glutaraldehyde + methionine = (CP2)	Concentration (0.1, 0.3, 0.5, 0.6, 0.7%, temperature (25, 35, 45 and 65°C) and immersion time (1, 2, 3, 4 and 6hrs)	Alloy Mild steel Medium 2M HCl Methods PDP, WL, IR	CP2 performed better than CP1 for 1 and 2 hrs. of immersion, but the opposite was the case for 3, 4, and 6hrs of immersion. Optimum concentration for IE was 0.6%. IE increased up to 45°C for CP2 and then decreased slowly after 55°C.	[133]
Poly(vinyl alcohol cysteine)	Concentration (0.12, 0.24, 0.36, 0.48 and 0.60wt%, temperature (30, 40, 50, 60 and 70°C) and immersion time (1, 2, 4, 6, 12 and 14hrs).	Alloy Mild steel Medium 1M HCl Methods UV-VIS, PDP, EIS, FTIR, SEM-EDX and WL.	Maximum IE of 94% obtained with inhibitor concentration of 0.6wt% for the WL method. IE increased with immersion time up till 6hrs and then began to reduce. IE also increased with temperature up till 50°C and then reduced on further temperature increase. Inhibitor was mixed type. IE depended on rate of doping of PVA by cysteine. Physisorption proposed.	[134]
1,4-disubstituted 1,2,3-triazolyl bis-amino acid derivatives constituted by ʟ-serine, ʟ-threonine, ʟ-phenylalanine and ʟ-tyrosine	Concentration (1.0 x 10^{-5}, 3.2 x 10^{-5}, 5.6 x 10^{-5}, 1.0 x 10^{-4}, 3.2 x 10^{-4}, 5.6 x 10^{-4}, 1.0 x 10^{-3}M)	Alloy Mild steel Medium 1M HCl Methods WL, PDP, EIS, SEM, AM1	IEs of these derivatives were better than those of their original natural amino acids counterparts. IE generally increased with concentration.	[135]
Thermal polyaspartate (TPASP)		Alloy Mild steel Medium Synthetic salt solution 35ppt (Ph 8) Methods SEM-EDX, EIS, LP, OCP	TPASP is a mild corrosion inhibitor of the mixed type	[136]

Polyaspartic acid (PASP)		Alloy Carbon steel Medium 0.5M H_2SO_4 Methods WL, PDP, EIS, SEM, FTIR	Performed as a good anodic-type inhibitor with maximum IE obtained at 80.33% at10 C. Freundlich adsorption isotherm was proposed	[137]
N,N-Bis (phosphono methyl) glycine + Zn^{2+} ions. (± Tungstate)	Concentration	Alloy Carbon steel Medium 200ppm NaCl (pH 5 – 9) Methods WL, SEM, PDP, EIS, XPS, FTIR	Tungstate exhibited a synergistic effect. Ternary inhibitor formulation performed well in neutral, slightly acidic and slightly alkaline media. Higher IEs were obtained at higher concentrations of the ternary compound. Inhibitor is mixed type. The protective film consisted of iron oxides/hydroxides, zinc hydroxide, heteropolynuclear complex amd WO3	[138]
N,N-Bis(phosph onomethyl) glycine + Zn^{2+} ions. (± Ascorbate ions)	Concentration and pH	Alloy Carbon steel Medium Low chloride environment Methods WL, PDP, EIS, XPS (X-ray photoelectron spectra), SEM, FTIR.	The binary system consisting of 20 ppm of BPMG and 30ppm of Zn^{2+} accelerated corrosion of carbon steel. But the addition of 25ppm of ascorbate to the system gave an IE of 94%. The inhibitor is mixed type and effective between pH of 5 and 11	[139]
Two derivatives: 2-(2-oxo-2-phenothiazin-10-yl) ethylamino)-3- ercaptopropanoic acid (OPEM) and 2-(2-oxo-2-phenothiazin-10-yl) ethylamino) acetic acid (OPEA)	Concentration (20, 50, 100, 150, 200, 250ppm) and temperature (30, 40, 50, 60°C).	Alloy Mild steel Medium 15% HCl Methods WL, PDP, EIS, AM1, SEM.	Maximum IE obtained in the order: OPEM (97.5%) > OPEA (95.8%) at 200ppm and 60°C. IE of both inhibitors increased with increase in concentration and temperature. Both inhibitors are mixed-type. Langmuir adsorption isotherm confirmed.	[140]
N,N-Bis(phosphor nomethyl) glycine ± Zn^{2+}	Concentration of both substances and pH (5 – 8)	Alloy Carbon steel Medium 200ppm NaCl in different pH environment. Methods WL, PDP, EIS, XPS, FTIR, SEM	Inhibitor effective in the pH range 5 – 8. Glycine derivative and Zn^{2+} showed strong synergistic effect. The inhibitor is mixed-type. Formed film contained oxides/hydroxides of iron (III), $Zn(OH)_2$ and [Zn (II) inhibitor] complex.	[141]
Phenylalanine (PA) + Zn2+ ions	Concentration of both substances.	Alloy Carbon steel Medium Well water with pH 8 Methods WL, PDP, EIS, SEM-EDAX	Maximum IE of 90% obtained with 5 ppm of Zn2+ and 150ppm of PA. Inhibitor is anodic.	[142]
Four alkylamides derived from tyrosine and glycine	Concentration (10, 25, 50 and 100ppm) and temperature (25, 35, 45, and 60°C)	Alloy Carbon steel Medium 1M HCl Methods WL, PDP	80% < IE < 90% at >=50 ppm. Inhibitor is mixed type. Dodecyl amine of tyrosine exhibited the higher IE because of its large steric body of the last against glycine. The IE correlated with the length of alkylic chain. IE reduced with temperature increase in all cases.	[143]
Cysteine derivative: methyl ester hydrochloride	Concentration (10^{-2}, 10^{-3}, 10^{-4} and 10^{-5}) and temperature (30, 35, 45 and 55°C)	Alloy Carbon steel Medium 2M H_3PO_4 Methods WL, PDP, EIS	Maximum IE=93% at 10^{-2}M from WL method. IE increased with increasing inhibitor concentration but decreased with increasing temperature, Inhibitor is mixed type. Physisorption proposed.	[144]
Methionine ((± I$^-$)	Concentration of both substances.	Alloy Low carbon steel (SNCLCS) and bulk steel (BLCS) Medium 0.5M H_2SO_4	Synergism effect of I$^-$ ions with methionine. For BLCS, IE = 53% at 5 mM of methionine and 97.7% in the presence of 5mM of KI, and for SNCLCS, the IE = 53% at 5 mM of	[145]

		Methods PDP, EIS, AFM, OCP.	methionine and 71% in the presence of 5 mM of KI Inhibitor behaved as mixed type for both alloys	
Serine, cysteine, phenylalanine, aspartate, asparagine, and 70 other organic substances.		Alloy Carbon steel rebar Medium Saturated CaOH solution +NaOH 0.01M (Ph 12.6 +NaCl (0.1, 0.3 and 1M) Method CP	Tested amino acids showed some inhibition effect, but not sufficient for an industrial application.	[146]
Leucine, alanine, methionine, and glutamic acid (Glu-A)	Concentration of inhibitors	Alloy NST-44 mild steel Medium Lime fluid Methods WL, OM	Order of IE of tested amino acids in lime fluid: Alanine > Methionine > Leucine > Glu-A, IE in this medium also increased with concentration.	[147]
Leucine, alanine, methionine, and glutamic acid (Glu-A)	Concentration of inhibitors	Alloy NST-44 mild steel Medium Cassava fluid Methods WL, OM	Order of IE of tested amino acids in cassava fluid: Alanine (50%) > Leucine (46%) > Methionine (45%) > Glu-A (30%).	[148]
Tryptophan		Alloy Low carbon steel Medium 1M HCl Methods WL, PDP, Molecular dynamic Fe (1 1 0). DFT/B3LYP 6-311*G (d.p)	Maximum IE = 91% at 10^{-2} M. Cathodic inhibitor. Physisorption and chemisorption mechanism. Tryptophan molecules assumed a nearly flat orientation with Fe (1 1 0) surface.	[89]
Tryptophan, tyrosine and serine	Concentration (0.01, 0.02, 0.04 and 0.06M), temperature (30, 40, 50, and 60 ± 1 °C), stirring velocities (400, 800, 1,200, and 1,600 rpm)	Alloy Low alloy steel Medium 0.2M ammoniated citric scid Methods PDP, EIS, EFM, OM	Order of maximum IE = Tryptophan (86%) > Tyrosine (83%) > serine (82%) at 0.06M. Physisorption proposed. IE decreased with incre-ase in solution stirring speed due to removal of layers of inhibitor on alloy surface. IE also increased with incre-ase in concentration but decreased with increase in temperature.	[90]
Serine	Concentration (1, 2, 5, 10, 20, 50mM) and temperature (10, 20, 30, 40, 50, 60°C).	Alloy Low alloy ASTM A213 Medium 0.5M HCl Methods PDP, EFM, XPS	Inhibitor is cathodic. XPS confirmed film formation of inhibitor. Physical adsorption proposed. Temkin adsorption isotherm confirmed. IE increased with increase in Serine concentration, while it decreased with temperature increase.	[149]
Methionine, alanine and glycine, Citrulline and hydroxyproline		Alloy 16/14 austenitic stain/ess steel Medium HCl Methods PDP, PR	There is more passivation at wide potential range in the presence of the amino acids	[150]
Aspartic acid	pH of corrosive media	Alloy Steel (UNS G10180) Media Solutions with different pH values (8 -12) Methods WL, EIS with RDE	At a pH less than ~9.5 to 10, aspartic acid appeared to speed up corrosion, while at pH above those, it inhibited corrosion	[151]
Tryptophan	Concentration (0.005, 0.01, 0.02, 0.04M), temperature (25, 40, 50, 60°C) and immersion time	Alloy Low alloy steel Medium 0.6 M HSO_3NH_2 Methods WL, EIS and EFM	Inhibitor performed very well. IE increased with concentration increase but decreased with temperature increase.	[152]

Tryptophan	Concentration (0.005, 0.01, 0.02, 0.04M), temperature (25, 40, 50, 60°C) and immersion time	Alloy Low alloy steel (ASTM A213 grade T22) Media 0.6 M HSO_3NH_2 and 0.6 M HCl Methods WL, EIS and EFM	Inhibitor performed better in 0.6 M HCl (IE =94.46%) than in 0,6M HSO_3NH_2 (IE=91.58%) from the EFM method. The adsorption can occur via adsorbed $SO_3NH_2^-$ and Cl^- anions at the surface of the alloy. IE increased with increase in concentration but decreased with increase in temperature and immersion time.	[153]
Methionine	Concentration of inhibitor (0.25, 0.50, 0.75 and 1.0g/L)	Alloy Low alloy steel (39 and 44) Medium 1M H_2SO_4 + 1mM NaCl Method PDP	IE = 74% for Steel 39 and 81% for steel 44 at 1 g/L of methionine. Inhibitor is mixed type. IE increased with increase in concentration	[154]
Polyaspartic acid (PASP)	pH	Alloy Steel Medium $CaSO_4$ + $MgCl_2$ + $NaHCO_3$+ Na SO_4 solutions and deionized water (pH 3.5 -12) Methods WL, EIS, RCE	At low to neutral pH values, PASP increased the corrosion rate and at high pH values, it functioned as an inhibitor. At lower pH values, Fe-PASP complexes were stable, while at higher pH values, no such complexes were predicted.	[155]
Cysteine	Concentration (0.1, 0.5, 1.0, 2.0 and 5.0g/L)	Alloy Steel 08-kp Medium 0.5M H_2SO_4 Methods WL, PDP, SEM	Maximum IE of 66% obtained at 5g/L concentration of inhibitor. Inhibition functioned as mixed type	[156]
L-arginine	Concentration (100, 300, 700, 900mgL)	Alloy Steel Medium 1M HCl Methods WL, PDP, EIS, EFM	Maximum IE of 70.53% obtained with 900ng/L of inhibitor (from EIS measurements)	[157]
L-arginine	Concentration (100, 300, 700, 900mgL)	Alloy Steel Medium 3.5% NaCl Methods PDP, EIS, EFM, DFT	Maximum IE of 88.20% obtained with 900mg/L of inhibitor (from EIS measurements). MD simulations revealed shape of adsorption on Fe (1 1 1).	[158]
Serine, threonine, glutamine		Alloy Cold-rolled steel Medium 1M HCl Methods WL, PDP, EFM, AFM, SEM, computational schemes	IE of Glu was better than those of serine and threonine. Temkin adsorption isotherm was confirmed. IE increased with an increase in total negative charge values of the molecules. R^2 = 0.96 with 3LYP/6-311 G(d,p) was found as the best model among models generated by the Genetic Function Algorithm	[159, 160]
Tyrosine, polyacrylic acid and yeast	Concentration (5ppm) and temperature (25, 35, 45, 55°C)	Alloy Stainless steel (S41000) Medium Synthetic seawater Methods PDP, EIS	Yeast performed better as an inhibitor than others	[161]
4,6-diamino-2-pyrimidinethiol (4D2P)	Concentration (0.5, 1.0, 5.0, 10mM) and immersion time (1, 24, 72, 120hrs)	Alloy Mild steel Medium 0.1M HCl Methods LPR, PDP, EIS, SEM, DFT with 6-311++G (d, p)	Maximum IE of 97.2% obtained with the 10mM concentration at 72hrs of immersion.	[6]
Polyaspartic acid-glycine derivative	Concentration (50, 100, 150, 200 250ppm)	Alloy Carbon steel Medium Sea water Methods PDP, EIS, SEM, EDX, H NMR	Maximum IE (83.8%) obtained at 250ppm of inhibitor	[162]

Methionine, cysteine, serine, arginine, glutamine and asparagine		Alloy Carbon steel Medium 0.5M H_2SO_4 Methods PDP, EIS, DFT/BLYP 3.5 DNP, molecular dynamics on Fe (1 0 0)	Order of IE; = Methionine > Cysteine > Serine> Arginine > Glutamine > asparagine at 10^{-2}M.	[163]
Cysteine (± imidazoline derivative (IM)		Alloy Carbon steel Medium CO_2-saturated brine solution Methods PDP, OCP, EIS, WL, XPS, contact angle	Order of IE (at 50ppm cysteine): cysteine (91.8%) < cysteine + IM (96.7%). Inhibitor exhibited mixed type inhibition.	[164]
Tetra-n-butyl Ammonium methioninate	Concentration (1.33 x 1^{-5}M, 1.33 x 10^{-4}M, 2.66 x 10^{-4}M, 7.97 x 10^{-4}M, 1.59 x 10^{-3}M	Alloy Mild steel Medium 1M HCl Methods PDP, SEM-EDX, OCP, DFT/B3LYP 6-311++G**	Maximum IE of 95.1% obtained with 1.59 x 10^{-3}M. Mixed type inhibitor with prevalent anodic inhibition. Freundlich adsorption isotherm confirmed.	[165]
Leucine, phenylalanine and methionine derivatives		Alloy Carbon steel Medium 1M HCl Methods PDP, EIS, MINDO, FTIR, H, C NMR and elemental analysis	Phenylalanine-based derivative exhibited highest IE of 94.14% with 10^{-3}M concentration Inhibitor is mixed type. Langmuir adsorption isotherm proposed.	[166]
l- Lysine (Lys) and l- Arginine (Arg)		Alloy 316L Stainless Steel Medium 0.5 M NaCl, pH 6.0 Methods FTIR, SERS, SEM	Lysine and Arginine showed excellent inhibition properties and effectively restrained the corrosion of 316 stainless steel. Addition of Iodide ion increased their inhibition efficiency. In all, Arginine performed as a better inhibitor than lysine	[167]
Glutamic acid, (Glu), Glutamine (Gln), Cerium Glutamate (Ce-Glu), Cerium Glutamine (Ce-Gln)	Concentration (25-200ppm) and temperature (25 and 55°C)	Alloy Mild Steel Medium 0.5 M HCl Methods PDP, EIS, SEM, UV-VIS, FTIR	The efficiency of inhibition was found to be Ce-Gln > Gln and Ce-Glu > Glu	[168]
L-Amino Acids		Alloy Mild Steel Medium Gas phase Methods Monte Carlo Simulations	Inhibitors were studied based on different side chain lengths. The efficiency of inhibitions was in the following order: Glu (acidic) < Gln (polar) < Trp (nonpolar) < Arg (basic)	[169]
Cysteamine-modified Polyaspartic acid (PASP-S) and Polyaspartic acid (PASP)	Concentration (10, 20, 50, 100mg/L) and temperature (25, 35, 45°C)	Alloy Mild steel Medium 0.5 M H_2SO_4 Methods WL, PDP, EIS, DFT, XPS	Maximum IE of 93.9% obtained with the WL method using 100mg/L PASP-S. IE reduced with temperature but increased with concentration	[170]
Phenylalanine (Pl) Aspartic Acid (P2)	Concentration	Alloy Mild Steel Medium 1M HCl Methods UV-VIS SEM, EIS, PDP	Adsorption increased with increase in concentration of both P1 and P2. P2 gave highest adsorption of 89% as compared to P1 that gave maximum adsorption of 87%	[171]
Amino acids.	Concentration (1-1000 × 10^{-6}mol/l) and temperature (25–40°C)	Alloy Carbon steel Medium H_3PO_4 Methods galvanostatic techniques	Increases in the amino acid concentrations inhibited the electroplating process by 83.33% in the case of L-methionine at 25°C.	[172]

Cysteine-doped Polyvinylpyrro lidone (PVPC)	Concentration (25, 100, 300, 500, and 700 ppm)	Alloy Mild steel Medium 1M HCl Methods WL, FTIR, XRD, SEM/EDX	Maximum IE of 97% obtained at 700 ppm	[173]
L-histidine (LHD), 1-phenylthiourea (PT), LHD+PT, phenylcarbam othioyl)histidine (PT-HD)	Concentration (0.05, 0.1, 0.2, 0.4Mm), temperature of 60°C	Alloy Carbon steel Medium CO_2-saturated formation water Methods WL, EIS, PDP, SEM, AFM, ATR-AFM, quantum chemical calculation, GFN-xTB calculations	Inhibition efficiency decreased in the order: PT-HD (99.3%) > LHD + PT (99.2%) > PT (97%) > LHD (70.9%) at concentration of 0.4mM with the EIS method	[174]
L-histidine + thiourea, L-cysteine + thiourea)		Alloy N80 carbon steel Medium CO_2-containing environment Methods EIS, PDP, OCP, SEM, AFM, XPS, theoretical calculations	Maximum IE of 99.4% obtained with ʟ-histidine + thiourea and 99.3% obtained with ʟ-cysteine + thiourea using the PDP method	[175]
Benzotriazole (BZT), 5- methyl-1H-benzotriazole (5MBZT), and 3-amino-5-methylthio-1H-1, 2,4, triazole (3AMT)	Type of metal, molecular structure, and immersion time	Alloy/Metal C1020 steel and copper Medium 2% HCl Methods EIS, PDP, LPR, theoretical simulations	For C1020 steel, order of IE using EIS data was 5MBZT (91.8%) > BZT (78.1%) > 3AMT (24.8%) after 24hrs of immersion	[176]
Tryptophan, histidine	Concentration (100,200, 300, 400, 500ppm), temperature (20, 30, 40, 50°C)	Metal SABIC iron Medium 0.5M HCl Methods PDP, EIS, mass loss, SEM, DFT, MC simulation	Maximum IE of 92.09% for tryptophan and 89.37% for histidine at a concentration of 500 ppm and 30°C using the PDP method. IE increased with concentration but reduced with temperature (using the mass loss method)	[177]
Thiazolidine-2,4-diones (TZD) and its amino derivative 2-aminothiazolidin-4-one (AT).	Concentration (1 x 10^{-6}, 5 x 10^{-6}, 1 x 10^{-5}, 5 x 10^{-5}, 1 x 10^{-4}, 5 x 10^{-4}, 1 x 10^{-3}, 5 x 10^{-3} and temperature (30, 40, 50, 60°C).	Alloy Mild steel Medium 5% HCl Methods WL, OCP, PDP, EIS, FTIR, UV–VIS, XPS, SEM-EDS, AFM	Maximum IEs of 98.0% and 99.7%, obtained with TZD and AT respectively at a concentration of 5 × 10^{-4} M at 60 °C. IE increased with temperature and concentration.	[178]
2 Indoline compounds designated as FTTI and FTMI	Concentration (5, 10, 15, 20, 25, 30, 35, 40, 45, 50µML^{-1}) and temperature (30, 40, 50, 60°C)	Alloy oil well/ tubing steel Medium 15% HCl Methods WL, OCP, PDP, EIS, SEM-EDX, AFM, XPS, DFT, MD Simulation	IEs of 99.08% and 97.75% obtained for the two compounds respectively at 30°C and concentration of 50 µML^{-1}. IE remained nearly constant at elevated temperatures due to predominant chemisorption of the inhibitors upon the metallic substrate	[179]
Protein and its amino acids, isolated from tofu pulp,	Concentration (40, 60, 80, 100, 120ppm)	Alloy Carbon steel Medium brackish water media Method EIS	IE % of isolated protein in fraction 3 was found to be 92% at 80 ppm.	[180]
Two new thiazoles designated as APNT and APT		Alloy Mild steel Medium 1M HCl WL, DFT	IE values of 98.1% and 94.74% were recorded as results of inhibition of the mild by the inhibiting compounds APNT and ATP respectively	[181]

Methionine (MTI)	Concentration (500, 1000, 1500, 2000ppm), temperature (40, 60, 80°C), and speed of rotation	Alloy carbon steel 1018 Medium 5.0 mol/L MEA Methods WL, EIS, PDP, OCP	IEs of up to 83.56% and 74.96% were obtained under static and dynamic conditions, respectively. IE increased with MTI concentration and solution temperature but decreased with rotational speed.	[182]
Ortho-, meta- and para-aminobenzoic acid (ABA)		Alloy Mild steel Medium HCl solution Methods Computational methods	IE occurred in the order (OABA > MABA > PABA).	[183]
L-valine + additives (salts, both inorganic (potassium iodide, KI) and organic (Sodium benzoate, SB), and non-ionic sugar based surfactant (N-decyl-N′ -glucosylethy-lenediamine, SS)	Concentration (100, 200, 300, 350, 400ppm), temperature (30, 40, 50, and 60 ◦C) and immersion time extending from 1 to 7 days.	Alloy Mild steel Medium 5% HCl Methods EIS, PDP, FTIR, SEM-EDX	The inhibition effect of the additives in 5% HCl is in the following order: Val + SS > Val + SB > Val + KI > Val + KI. The IE of Val and Val + additives increased with temperature rise from 30 ◦C to 60 ◦C. However, increases in the exposure period within the first three days resulted in IE increases, but thereafter it decreased.	[184]
D-cysteine	Concentration (2.5mM, 5mM) and time of immersion (1, 3, 7days)	Alloy 304 stainless steel Medium Sterile and *Pseudomonas aeruginosa*-inoculated culture media Methods XPS, SEM	The biofilm inhibition effect of D-cysteine greatly reduced the destructive effect of the adhered P. aeruginosa cells on the passive film of the stainless steel, thus inhibiting the microbiologically influenced corrosion of the stainless steel.	[185]
l-histidine based ionic liquid (LHIL)		Alloy Mild steel Medium 1M HCl Methods FTIR, UV-VIS, XPS, H-NMR and high-resolution mass spectrometry, PDP, EIS, localized electrochemical strategies, Theoretical calculations	Maximum IE attained was 98.8%	[186]

4. CONCLUSIONS

From the literature scan, amino acids have shown high efficacy as corrosion inhibitors for metals in acidic solutions. Much of the research focused on the synthesis of the derivatives of the amino acid compounds. Some experimental results indicated that the inhibition efficiency of some amino acids increases with increasing pH values. Computational modeling employed in some of the studies provided useful insights into the interactions between the metal and the studied amino acids including the inhibition mechanisms of the compound.

The efficiency of those compounds has been found to be greatly influenced by many factors, such as temperature, concentration of inhibitor, immersion time, pH, hydrodynamic conditions, etc. Highest values of inhibition efficiency were obtained in the presence of I⁻ ions and Br⁻ ions. Mechanism of inhibition by amino acid is found to be principally due to adsorption of the hetero-atoms/groups and π-electrons (polar groups) to the metal/alloy surface.

Further research should consider experimental studies and computational modeling to evaluate the effect of amino acid and its derivative compounds on other metals/alloys such as stainless steel, bronze, zinc, etc. with a larger scale of application. In addition, when developing a predictive model for Corrosion Science and Engineering, such factors as concentration of inhibitor, temperature, solution flow, solution pH, inhibitor-metal surface bonding, solubility of inhibitor, etc. must be put into consideration. These factors should also be considered during experimental investigations.

ABBREVIATIONS

HPLC - high-performance liquid chromatography.

ATR-FTIR – Attenuated total refraction FTIR.

LP – Linear polarization

PR – Polarisation resistance

OCP – Open circuit potential.

IR – Infrared spectroscopy

EDX – Energy Dispersive X-ray spectroscopy.

SEM-EDS – Scanning electron microscopy – energy dispersive spectroscopy

SEM-EDAX - Scanning electron microscopy – energy dispersive spectroscopy

OM – Optical microscopy.

RCE - Rotating cylinder electrode

RDE – Rotating disk electrode

SERS - Surface-enhanced Raman spectroscopy.

GC – Gas Chromatography.

MC – Mass spectroscopy.

XRD - X-ray diffractometer.

MC - Monte Carlo.

QM - quantum mechanics

GFN-xTB: Geometries; F: Frequencies; N: Noncovalent interactions) tight-binding based electronic structure.

H, NMR - Hydrogen-nuclear Magnetic Resonance.

C, NMR – Carbon Nuclear Magnetic Resonance

MNDO - Modified Neglect of Diatomic Overlap.

ICP-AES - inductively coupled plasma atomic emission spectroscopy

DNP - double numerical with polarization

PM3 - Parameterized Model number 3.

AM1 - Austin Model 1

5. REFERENCES

[1] R.Revie, H.Uhling, (2007) Corrosion and Corrosion Control, fourth edition, Wiley, p.1–3.

[2] C.Verma, E.Ebenso, M.Quraishi (2017) Ionic liquids as green and sustainable corrosion inhibitors for metals and alloys: An overview, Journal of Molecular Liquids, 233, 403 – 414.

[3] S.Masadeh (2015) The effect of added carbon black to concrete mix on corrosion of steel in concrete, Journal of Minerals and Materials Characterization and Engineering, 3, 271–276.

[4] A.Winkleman, E.Svedberg, E.Schafrik, D.Duquette (2011) Preventing corrosion from wearing our future away, Advanced Materials and Processes, 169, 26–31.

[5] Y.Panchenko, A.M.arshakov (2016) Long-term prediction of metal corrosion losses in atmosphere using a power-linear function, Corrosion Science, 109, 217–229.

[6] R.Yıldız (2015) An electrochemical and theoretical evaluation of 4,6-diamino-2- pyrimidinethiol as a corrosion inhibitor for mild steel in HCl solutions, Corrosion Science, 90, 544 - 553.

[7] K.Emregül, M.Hayvali (2004) Studies on the effect of vanillin and protocatechualdehyde on the corrosion of steel in hydrochloric acid, Materials Chemistry and Physics, 83, 209–216.

[8] A.Döner, E.Sahin, G.Kardas, O.Serindag (2013) Investigation of corrosion inhibition effect of 3-[(2-hydroxy-benzylidene)amino]-2-thioxo-thiazolidin4-one on corrosion of mild steel in the acidic medium, Corrosion Science, 66, 278–284.

[9] R.Solmaz (2010) Investigation of the inhibition effect of 5-((E)-4-phenylbuta-1,3-dienylideneamino) - 1,3,4-thiadiazole-2-thiol Schiff base on mild steel corrosion in hydrochloric acid, Corrosion Science, 52, 3321–3330.

[10] R.Solmaz (2014) Investigation of corrosion inhibition mechanism and stability of Vitamin B1 on mild steel in 0.5 M HCl solution, Corrosion Science, 81, 75–84.

[11] A.Döner, A.Yüce, G.Kardas (2013) Inhibition effect of rhodanine-N-acetic acid on copper corrosion in acidic media, Industrial and Engineering Chemistry Research, 52, 9709–9718.

[12] R.Solmaz, E.Sahin, A.Döner, G.Kardas (2011) The investigation of synergistic inhibition effect of rhodanine and iodide ion on the corrosion of copper in sulphuric acid solution, Corrosion Science, 53, 3231–3240.

[13] K.Emregül, O.Atakol (2003) Corrosion inhibition of mild steel with Schiff base compounds in 1 M HCl, Materials Chemistry and Physics, 82, 188–193.

[14] A.Döner, G.Kardas (2011) N-Aminorhodanine as an effective corrosion inhibitor for mild steel in 0.5 M H2SO4, Corrosion Science, 53, 4223–4232.

[15] R.Solmaz, G.Kardas, B.Yazıcı, M.Erbil (2008) Adsorption and corrosion inhibitive properties of 2-amino-5-mercapto-1,3,4-thiadiazole on mild steel in hydrochloric acid media, Colloids and Surfaces A, 312, 7–17.

[16] B.Mert, M.Mert, G.Kardas, B.Yazıcı (2011) Experimental and theoretical investigation of 3-amino-1,2,4-triazole-5-thiol as a corrosion inhibitor for carbon steel in HCl medium, Corrosion Science, 53, 4265–4272.

[17] M.Özcan, F.Karadagˇ, I.Dehri (2008) Interfacial behavior of cysteine between mild steel and sulfuric acid as corrosion inhibitor, Acta Physico-Chimica Sinica, 24, 1387–1392.

[18] R.Yıldız, T.Dogˇan, I.Dehri, (2008) Evaluation of corrosion inhibition of mild steel in 0.1 M HCl by 4-amino-3-hydroxynaphthalene-1-sulphonic acid, Corrosion Science, 85, 215–221.

[19] A.Baral, R.Engelken (2002) Chromium-based regulations and greening in metal finishing industries in the USA, Environmental Science & Policy, 5, 121–133.

[20] J.Gaidis (2004) Chemistry of corrosion inhibitors, Cement & Concrete Composites, 26, 181–189.

[21] E.Stupnisek-Lisac, A.Loncaric Bozic, I.Cafuk (1998) Low-toxicity copper corrosion inhibitors, Corrosion, 54 (9), 713–720.

[22] B.El Ibrahimi, A.Jmiai, L.Bazzi, S.El Issami (2020) Amino acids and their derivatives as corrosion inhibitors for metals and alloys, Arabian Journal of Chemistry, 13, 740 – 771.

[23] M.Kilberg, D.Ha¨ussinger (1992) Mammalian Amino Acid Transport, Springer, Science & Business Media.

[24] H Mihara, Y.Hayakawa, D.Kagaku (1969) Effects of oxycarbonic acids on corrosion of aluminum in alkaline medium, Journal of The Electrochemical Society, Japan 37.

[25] G.El-Hafez, W.Badawy (2013) The use of Cysteine, N-acetyl cysteine and Methionine as environmentally friendly corrosion inhibitors for Cu–10Al–5Ni alloy in neutral chloride solutions, Electrochimica Acta, 108, 860–866.

[26] D.Zhang, B.Xie, L.Gao, H.Joo, K.Lee (2011c) Inhibition of copper corrosion in acidic chloride solution by methionine combined with cetrimonium bromide/cetylpyridinium bromide, Journal of Applied Electrochemistry, 41, 491–498.

[27] M.Mobin, M.Parveen, M.Rafiquee (2017) Synergistic effect of sodium dodecyl sulfate and cetyltrimethyl ammonium bromide on the corrosion inhibition behavior of L-Methionine on mild steel in acidic medium, Arabian Journal of Chemistry, 10, S1364–S1372.

[28] E. Kowsari, S.Armanb, M.Shahini, H.Zandi, A. Ehsani, R.Naderif, A.PourghasemiHanza, M. Mehdipour (2016) In situ synthesis, electrochemical and quantum chemical analysis of an amino acid-derived ionic liquid inhibitor for corrosion protection of mild steel in 1 M HCl solution, Corrosion Science, 112, 73–85.

[29] J.Telegdi, A.Shaban, G. Vastag (2018) Biocorrosion- steel, book Encyclopedia of Interfacial Chemistry, Surface Science and Electrochemistry, 28 – 42.

[30] S.Esmailzadeh, M.Aliofkhazraei, H.Sarlak (2018) Interpretation of Cyclic Potentiodynamic Polarization Test Results for Study of Corrosion Behavior of Metals: A Review, Protection of Metals and Physical Chemistry of Surfaces, 54(5), 976–989.

[31] A.Vaamonde, J.de Damborenea, J.González (2000) Ciencia e Ingeniería de la Superficie de los Materiales Metalicos (Textos Universitarios), Editorial CSIC- CSIC Press: Madrid, Spain.

[32] M.Orazem, B.Tribollet (2017) Electrochemical Impedance Spectroscopy, John Wiley & Sons: Hoboken, NJ, USA.

[33] R.Bosch, J.Hubrecht, W.Bogaerts, B.Syrett (2001) Electrochemical Frequency Modulation: A New Electrochemical Technique for Online Corrosion Monitoring, Corrosion 57 (01), Paper Number: NACE-01010060

[34] M.Amin, S.Abd El-Rehim, E.El-Sherbini, O.Hazzazi (2009) Polyacrylic Acid as a Corrosion Inhibitor for Aluminium in Weakly Alkaline Solutions. Part I: Weight Loss, Polarization, Impedance EFM and EDX Studies, Corrosion Science, 51, 658-667.

[35] I.Obot, I.Onyeachu, A.Zeino, S.Umoren (2019) Electrochemical noise (EN) technique: review of recent practical applications to corrosion electrochemistry research, Journal of Adhesion Science and Technology, 33:13, 1453-1496,

[36] R.Cottis (2001) Interpretation of electrochemical noise data. Corrosion, 57, 265–285.

[37] R.Kelly, M.Inman, J.Hudson (1996) Electrochemical noise measurement for corrosion applications. West Conshohocken USA: ASTM, 1277, 101–113.

[38] D.Skoog, F.Holler, S.Crouch (2007) Principles of instrumental analysis, 7th ed. Boston (MA): Cengage.

[39] G.Bell, G.Edgemon, S.Reid (1998) NACE International Corrosion Conference, 22–27; San Diego (CA), USA.

[40] F.Mansfeld (2009) Fundamental aspects of the polarization resistance technique—the early days, Journal of Solid-State Electrochemistry, 13, 515–520.

[41] R.Govindasamy, S.Ayappan (2015) Study of Corrosion Inhibition Properties of Novel Semicarbazones on Mild Steel in Acidic Solutions, Journal of Chilean Chemical Society, 60(1).

[42] A.Shams, E.L. Din, R.Arain (1998) Thermometric, gravimetric, and potentiometric study of corrosion of iron under conditions of reaction $Fe + 2Fe^{3+} = 3Fe^{2+}$, British Corrosion Journal, 33 (3), 189-196.

[43] R.Kushwah, R.Pathak (2020) Open Circuit Potential, Polarization and Thermometric Study of Guar Gum as Corrosion Inhibitor on Mild Steel by in Acidic Media, Asian Journal of Chemical Sciences, 8(2): 55-60.

[44] A.Saxena, K.Thakur, N.Bhardwaj (2020) Electrochemical studies and surface examination of low carbon steel by applying the extract of *Musa acuminata*, Surfaces and Interfaces, 18, 100436.

[45] G.Vengatesh, M.Sundaravadivelu (2019) Non-toxic bisacodyl as an effective corrosion inhibitor for mild steel in 1 M HCl: Thermodynamic, electrochemical, SEM, EDX, AFM, FT-IR, DFT and molecular dynamics simulation studies, Journal of Molecular Liquids, 287, 110906.

[46] R.Haldhar, D.Prasad, A.Saxena (2018) *Armoracia rusticana* as sustainable and eco-friendly corrosion inhibitor for mild steel in 0.5 M sulphuric acid: Experimental and theoretical investigations, Journal of Environmental Chemical Engineering, 6(4), 5230–5238.

[47] M.Finšgar (2020) Electrochemical, 3D topography, XPS, and ToF-SIMS analyses of 4-methyl-2-phenylimidazole as a corrosion inhibitor for brass, Corrosion Science, 169, 108632.

[48] X.Li, S.Deng, H.Fu (2009) Synergistic inhibition effect of red tetrazolium and uracil on the corrosion of cold rolled steel in H_3PO_4 solution: Weight loss, electrochemical, and AFM approaches, Materials Chemistry and Physics, 115(2-3), 815–824.

[49] R.Haldhar, D.Prasad, A.Saxena (2018) Myristica fragrans extract as an eco-friendly corrosion inhibitor for mild steel in 0.5 M H_2SO_4 solution, Journal of Environmental Chemical Engineering, 6(2), 2290–2301.

[50] A.Singh, K.Ansari, D.Chauhan, M.Quraishi, S.Kaya (2020) Anti-corrosion investigation of pyrimidine derivatives as green and sustainable corrosion inhibitor for N80 steel in highly corrosive environment: Experimental and AFM/XPS study, Sustainable Chemistry and Pharmacy, 16, 100257.

[51] M. Bouanis, M. Tourabi, A. Nyassi, A. Zarrouk, C. Jama, F. Bentiss (2016) Corrosion inhibition performance of 2,5-bis(4-dimethylaminophenyl)-1,3,4-oxadiazole for carbon steel in HCl solution: Gravimetric, electrochemical and XPS studies, Applied Surface Science, 389, 952–966.

[52] M.Luna, T.Le Manh, R.Sierra, J.Flores, L.Rojas, E.Estrada (2019) Study of corrosion behavior of API 5L X52 steel in sulfuric acid in the presence of ionic liquid 1-ethyl 3-methylimidazolium thiocyanate as corrosion inhibitor, Journal of Molecular Liquids, 289, 111106.

[53] H.Zarrok, A.Zarrouk, B.Hammouti, R.Salghi, C.Jama, F.Bentiss (2012) Corrosion control of carbon steel in phosphoric acid by purpald–Weight loss, electrochemical and XPS studies, Corrosion Science, 64, 243–252.

[54] A.Miralrio, A.Vázquez (2020) Plant Extracts as Green Corrosion Inhibitors for Different Metal Surfaces and Corrosive Media: A Review, Processes, 8, 942,

[55] G.Gece (2008) The use of quantum chemical methods in corrosion inhibitor studies, Corrosion Science, 50 (11), 2981-2992.

[56] I.Obot, D.Macdonald, Z.Gasem (2015) Density functional theory (DFT) as a powerful tool for designing new organic corrosion inhibitors. Part 1: An overview, Corrosion Science, 99, 1-30.

[57] C.Lee, W.Yang, R.G.Parr (1998) Development of the Colle-Salvetti correlation-energy formula into a functional of the electron density, Physical Review B, 37, 785–789.

[58] F.Jensen (2007) Introduction to Computational Chemistry, John Wiley & Sons, Chichester.

[59] R.Parr, W.Yang (1989) Density Functional Theory of Atoms and Molecules, Oxford University Press, Oxford.

[60] L.Guo, W.Dong, S.Zhang (2014) Theoretical challenges in understanding the inhibition mechanism of copper corrosion in acid media in the presence of three triazole derivatives, Royal Society of Chemistry Advances, 4, 41956–41967.

[61] D.Gustincic, A.Kokalj (2015) A DFT study of adsorption of imidazole, triazole, and tetrazole on oxidized copper surfaces: $Cu_2O(111)$ and $Cu_2O(111)$-w/o-Cu^{CUS}, Physical Chemistry Chemical Physics, 17, 28602–28615.

[62] A.Kokalj (2010) Is the analysis of molecular electronic structure of corrosion inhibitors sufficient to predict the trend of their inhibition performance, Electrochimica Acta, 56, 745–755.

[63] N.Kovacevic´, A.Kokalj (2011) Analysis of molecular electronic structure of imidazole- and benzimidazole-based inhibitors: a simple recipe for qualitative estimation of chemical hardness, Corrosion Science, 53, 909–921.

[64] N.Kovacevic, A.Kokalj (2013a) Chemistry of the interaction between azole type corrosion inhibitor molecules and metal surfaces, Materials Chemistry and Physics, 137(1), 331–339.

[65] N.Kovacevic´, A.Kokalj (2013b) The relation between adsorption bonding and corrosion inhibition of azole molecules on copper, Corrosion Science, 73, 7–17.

[66] N.Kovacevic, I.Milosev, A.Kokalj (2015) The roles of mercapto, benzene, and methyl groups in the corrosion inhibition of imidazoles on copper: II. Inhibitor–copper bonding. Corrosion Science, 98, 457–470.

[67] C.Taylor, A.Chandra, J.Vera, N.Sridhar (2015) A multi-physics perspective on mechanistic models for chemical corrosion inhibitor performance, Journal of the Electrochemical Society, 162, C369–C375.

[68] M.M.Kabanda, I.B.Obot, E.E.Ebenso (2013) Computational study of some amino acid derivatives as potential corrosion inhibitors for different metal surfaces and in different media, International Journal of Electrochemical Science, 8, 10839–10850.

[69] S.Kaya, B.Tu¨zu¨n, C.Kaya, I.Obot (2016) Determination of corrosion inhibition effects of amino acids: quantum chemical and molecular dynamic simulation study, Journal of the Taiwan Institute of Chemical Engineers, 58, 528–535.

[70] K.Khaled, A.El-Sherik (2013) Using molecular dynamics simulations and genetic function approximation to model corrosion inhibition of iron in chloride solutions, International Journal of Electrochemical Science, 8, 10022–10043.

[71] K.Khaled, A.Sherik (2013) Using neural networks for corrosion inhibition efficiency prediction during corrosion of steel in chloride solutions, International Journal of Electrochemical Science, 8, 9918–9935.

[72] G.Gece, S.Bilgic, O.Tu¨rksen (2010) Quantum chemical studies of some amino acids on the corrosion of cobalt in sulfuric acid solution, Materials and Corrosion, 61, 141–146.

[73] A.Al-Fakih, Z.Y.Algamal, M.Lee, H.Abdallah, H.Maarof, M.Aziz (2016) Quantitative structure–activity relationship model for prediction study of corrosion inhibition efficiency using two-stage sparse multiple linear regression, Journal of Chemometrics, 30, 361– 368.

[74] H.Zhao, X.Zhang, L.Ji, H.Hu, Q.Li (2014) Quantitative structure–activity relationship model for amino acids as corrosion inhibitors based on the support vector machine and molecular design, Corrosion Science.

[75] N.Eddy, F.Awe, C.Gimba, N.Ibisi, E.Ebenso (2011b) QSAR, experimental and computational chemistry simulation studies on the inhibition potentials of some amino acids for the corrosion of mild steel in 0.1 M HCl, International Journal of Electrochemical Science, 6, 931–957.

[76] N.Eddy, U.Ibok, B.Ita (2011c) QSAR and quantum chemical studies on the inhibition potentials of

some amino acids for the corrosion of mild steel in H_2SO_4, Journal of Computational Methods in Sciences and Engineering, 11, 25–43.

[77] C.Selassie (2003) History of Quantitative Structure-Activity Relationships. In: Abraham, D.J. (Ed.), Burger's Medicinal Chemistry and Drug Discovery, John Wiley & Sons, Inc.

[78] P.Liu, W.Long (2009) Current mathematical methods used in QSAR/QSPR studies, International Journal of Molecular Sciences, 10, 1978–1998,

[79] L.Carlsen (2009) The interplay between QSAR/QSPR studies and partial order ranking and formal concept analyses, International Journal of Molecular Sciences, 10, 1628-1657.

[80] M.A. Amin, O.A. Hazzazi, F.Kandemirli, M. Saracoglu (2012) Inhibition performance and adsorptive behavior of three amino acids on cold-rolled steel in 1.0 M HCl-chemical, electrochemical, and morphological studies, Corrosion, 68, 688–698.

[81] G.Gece, S.Bilgic¸ (2010) A theoretical study on the inhibition efficiencies of some amino acids as corrosion inhibitors of nickel, Corrosion Science, 52, 3435–3443.

[82] L.Sheir, R.Jarman, G.Burstein (1994) Corrosion, Butterworth-Heinemann, Great Britain.

[83] M.Zerfaoui, H.Oudda, B.Hammouti, S.Kertit, M. Benkaddour (2004) Inhibition of corrosion of iron in citric acid media by amino acids, Progress in Organic Coatings, 51, 134–138.

[84] M.Amin, S.Rehim, H.Abdel-Fatah (2009a) Electrochemical frequency modulation and inductively coupled plasma atomic emission spectroscopy methods for monitoring corrosion rates and inhibition of low alloy steel corrosion in HCl solutions and a test for validity of the Tafel extrapolation method, Corrosion Science, 51, 882–894.

[85] V.Shkirskiy (2015) Corrosion Inhibition of Galvanized Steel by LDH - Inhibitor Hybrids: Mechanisms of Inhibitor Release and Corrosion Reaction, Universite Pierre et Marie Curie.

[86] V.Shkirskiy, P.Keil, H.Hintze-Brueningb, F.Leroux, F.Brisset, K.Oglea, P.Volovitch, (2015) The effects of ʟ-cysteine on the inhibition and accelerated dissolution processes of zinc metal, Corrosion. Science, 100, 101–112

[87] E.Hamed, S.El-REhim, M.El-Shahat, A.Shaltot (2012) Corrosion inhibition of nickel in H_2SO_4 solution by Alanine, Material Science and Engineering B, 177, 441–448.

[88] A.Singh, E.Ebenso (2013) Use of glutamine as a new and effective corrosion inhibitor for mild steel in 1 M HCl solution, International Journal of Electrochemical Science, 8, 12874–12883.

[89] J.Fu, S.Li, I.Cao, Y.Wang, I.Yan, L.Lu (2010b) ʟ-tryptophan as green corrosion inhibitor for low carbon steel in hydrochloric acid solution, Journal of Materials Science, 45, 979–986.

[90] H.Abdel-Fatah, H.Abdel-Samad, A.Hassan, H.El-Sehiety (2014) Effect of variation of the structure of amino acids on inhibition of the corrosion of low-alloy steel in ammoniated citric acid solutions, Research on Chemical Intermediates, 40, 1675–1690.

[91] H.Ashassi-Sorkhabi, E.Asghari (2008) Effect of hydrodynamic conditions on the inhibition performance of ʟ-Methionine as a ''green'' inhibitor, Electrochimica Acta, 54, 162–167.

[92] H.Ashassi-Sorkhabi, E.Asghari (2010) Electrochemical corrosion behavior of Al7075 rotating disc electrode in neutral solution containing ʟ-Glutamine as a green inhibitor, Journal of Applied Electrochemistry, 40, 631–637.

[93] M. Migahed, E.Azzam, S.Morsy (2009) Electrochemical behaviour of carbon steel in acid chloride solution in the presence of dodecyl cysteine hydrochloride self-assembled on gold nanoparticles, Corrosion Science, 51, 1636–1644.

[94] D.Zhang, X.He, Q. Cai, L.Gao, G.Kim (2009b) Arginine self-assembled monolayers against copper corrosion and synergistic effect of iodide ion, Journal of Applied Electrochemistry, 39, 1193–1198.

[95] D.Zhang, H.Zeng, L.Zhang, P.Liu, L.Gao (2014a) Influence of oxygen and oxidant on corrosion inhibition of cysteine self-assembled membranes for copper, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 445, 105–110.

[96] W.Feng, S.Patel M.Young, J.Zunino, M.Xanthos (2007) Smart polymeric coatings—recent advances, Advances in Polymer Technology, 26, 1–13.

[97] M.Kendig, M.Hon, I.Warren (2003) 'Smart' corrosion inhibiting coatings, Progress in Organic Coatings, 47, 183–189.

[98] W.Li, L.Calle (2007) A smart coating for the early detection and inhibition of corrosion, In: The Smart Coatings 2007 Conference, p. 191.

[99] R.Abd-El-Nabey, N.Khalil, A.Mohamed (1985) Inhibition by amino acids of the corrosion of steel in acid, Surf. Technol. 24, 383– 389

[100] V.Hluchan, B.Wheeler, N.Hackerman (1988) Amino acids as corrosion inhibitors in hydrochloric acid solutions, Materials Corrosion, 39, 512–517.

[101] M.Ozcan (2008) AC impedance measurement of Cystine adsorption at mild steel/sulfuric acid interface as corrosion inhibitor, Journal of Solid State Electrochemistry, 12, 1653–1661.

[102] H.Ashassi-Sorkhabi, M.Majidi, K.Seyyedi (2004) Investigation of inhibition effect of some amino acids against steel corrosion in HCl solution, Applied Surface Science 225, 176–185.

[103] D.Bouzidi, A.Chetouani, B.Hammouti, S.Taleb, M.Taleb, S.AlDeyab (2012) Electrochemical corrosion behaviour of iron rotating disc electrode in physiological medium containing amino acids and amino esters as an inhibitor, International Journal of Electrochemical Science, 7, 2334–2348

[104] A.Aouniti, K.Khaled, B.Hammouti (2013) Correlation between inhibition efficiency and chemical structure of some amino acids on the corrosion of Armco iron in molar HCl, International Journal of Electrochemical Science, 8, 5925–5943.

[105] M.Zerfaoui, H.Oudda, B.Hammouti, M.Benkaddour, S. Kertit, M. Zertoubi, M.Azzi, M.Taleb (2002) Electrochemical studies of the corrosion inhibition of methionine ethyl ester on iron in citric-chloride solution, Revue de Métallurgie, Paris J. 99, 1105–1110.

[106] M.Amin, S.Abd El Rehim, M.El-Naggar, H.Abdel-Fatah (2009b) Assessment of EFM as a new nondestructive technique for monitoring the corrosion inhibition of low chromium alloy steel in 0.5 M HCl by Tyrosine, Journal of Materials Science, 44, 6258–6272.

[107] B.Hammouti, A.Aouniti, M.Taleb, M.Brighli, S.Kertit (1995) L-methionine methyl-ester hydrochloride as a corrosion-inhibitor of iron in acid chloride solution, Corrosion, 51, 411–416.

[108] M.Bobina, A.Kellenberger, J.Millet, C.Muntean, N.Vaszilcsin (2013a) Corrosion resistance of carbon steel in weak acid solutions in the presence of L-Histidine as corrosion inhibitor, Corrosion Science, 69, 389–395.

[109] M.Bobina, N.Vaszilcsin, C.Muntean (2013b) Influence of Tryptophan on the corrosion process of carbon steel in aqueous weak acid solutions, Revista de Chimie,-Bucharest 64, 83–88.

[110] A.Silva, S.Agostinho, O.Barcia, G.Cordeiro, E.D'Elia (2006) The effect of cysteine on the corrosion of 304L stainless steel in sulphuric acid, Corrosion Science, 48, 3668–3674.

[111] E.Oguzie, Y.Li, F.Wang (2007b) Effect of 2-amino-3- mercaptopropanoic acid (Cysteine) on the corrosion behaviour of low carbon steel in sulphuric acid, Electrochimica Acta, 53, 909–914.

[112] P.Singh, K.Bhrara, G.Singh (2008) Adsorption and kinetic studies of L-Leucine as an inhibitor on mild steel in acidic media, Applied Surface Science, 254, 5927–5935.

[113] M.Morad (2005) Effect of amino acids containing sulfur on the corrosion of mild steel in phosphoric acid solutions containing Cl⁻, F⁻ and Fe^{3+} ions: behavior under polarization conditions, Journal of Applied Electrochemistry, 35, 889–895.

[114] S.Gowri, J.Sathiyabama, S.Rajendran, Z.Kennedy, S.Devi (2013) Corrosion inhibition of carbon steel in sea water by Glutamic acid-Zn^{2+} system, Chemical Science Transactions, 2, 275–281.

[115] M.Mobin, S.Zehra, M.Parveen (2016) l-Cysteine as corrosion inhibitor for mild steel in 1 M HCl and synergistic effect of anionic, cationic and non-ionic surfactants, Journal of Molecular Liquids, 216, 598–607.

[116] M.Amin, M.Ibrahim (2011) Corrosion and corrosion control of mild steel in concentrated H_2SO_4 solutions by a newly synthesized Glycine derivative, Corrosion Science, 53, 873–885.

[117] M.Morad (2008) Corrosion inhibition of mild steel in sulfamic acid solution by S-containing amino acids, Journal of Applied Electrochemistry, 38, 1509–1518.

[118] M.Amin, K.Khaled, S.Fadl-Allah (2010a) Testing validity of the Tafel extrapolation method for monitoring corrosion of cold rolled steel in HCl solutions – experimental and theoretical studies, Corrosion Science, 52, 140–151.

[119] N.Gupta, C.Verma, M.Quraishi, A.Mukherjee (2016) Schiff's bases derived from l-lysine and aromatic aldehydes as green corrosion inhibitors for mild steel: experimental and theoretical studies, Journal of Molecular Liquids, 215, 47–57.

[120] S.Vikneshvaran, S.Velmathi (2017) Adsorption of L-Tryptophan-derived chiral Schiff bases on stainless steel surface for the prevention of corrosion in acidic environment: experimental, theoretical and surface studies, Surface and Interface Analysis, 6, 134–142.

[121] M.Özcan, F.Karadağ, I.Dehri (2008) Interfacial Behavior of Cysteine between Mild Steel and Sulfuric Acid as Corrosion Inhibitor, Acta Physico-Chimica Sinica, 24(8), 1387-1392,

[122] J.Fu, S.Li, Y.Wang, X.Liu, L.Lu (2011) Computational and electrochemical studies on the inhibition of corrosion of mild steel by L-cysteine and its derivatives, Journal of Materials Science, 46, 3550– 3559.

[123] N.Eddy (2011) Experimental and theoretical studies on some amino acids and their potential activity as inhibitors for the corrosion of mild steel, part 2, Journal of Advanced Research, 2, 35–47.

[124] H.Cang, Z.Fei, W.Shi, Q.Xu (2012a) Experimental and theoretical study for corrosion inhibition of mild steel by L-Cysteine, International Journal of Electrochemical Science, 7, 10121–10131.

[125] H.Cang, W.Shi, Y.Lu, J.Shao, Q.Xu (2012b) Cysteine as inhibitor on the corrosion of mild steel in sulphuric acid and hydrochloric acid solutions, Asian Journal of Chemistry, 24, 3675–3678.

[126] Q.Deng, H.Shi, N.Ding, B.Chen, X.He, G.Liu, Y.Tang, Y.Long, G.Chen (2012a) Novel triazolyl bis-amino acid derivatives readily synthesized via click chemistry as potential corrosion inhibitors for mild steel in HCl, Corrosion Science. 57, 220–227.

[127] K.Khaled, N.Abdelshafi, A.El-Maghraby, A.Aouniti, N.AlMobarak, B.Hammouti (2012) Alanine as corrosion inhibitor for iron in acid medium: a molecular level study, International Journal of Electrochemical Science, 7, 12706–12719.

[128] B.Qian, J.Wang, M.Zheng, B.Hou (2013) Synergistic effect of polyaspartic acid and iodide ion on corrosion inhibition of mild steel in H_2SO_4, Corrosion Science, 75, 184–192.

[129] A.Rahiman, S.Subhashini (2013) A novel water-soluble, conducting polymer composite for mild steel acid corrosion inhibition, Journal of Applied Polymer Science, 127, 3084–3092.

[130] M.Mobin, M.Parveen, M.Rafiquee (2017) Synergistic effect of sodium dodecyl sulfate and

cetyltrimethyl ammonium bromide on the corrosion inhibition behavior of L-methionine on mild steel in acidic medium, Arabian Journal of Chemistry, 10 (Supplement 1), S1364–S1372.

[131] A.Rahiman, S.Subhashini, R.Rajalakshmi (2013) Water soluble conducting polymer composite of polyvinyl alcohol and leucine: an effective acid corrosion inhibitor for mild steel, Werkst Korros, 64, 74–82.

[132] O.Olivares, N.Likhanova, B.Go´mez, J.Navarrete, M.Llanos-Serrano, E.Arce, J.Hallen (2006b) Electrochemical and XPS studies of decylamides of α-amino acids adsorption on carbon steel in acidic environment, Applied Surface Science, 252, 2894–2909.

[133] S.Rajappa, T.Venkatesha (2002) New condensation products as corrosion inhibitors for mild steel in hydrochloric acid medium, Indian Journal of Engineering and Material Sciences, 9, 213–217.

[134] A.Rahiman, S.Subhashini 2017 Corrosion inhibition, adsorption and thermodynamic properties of poly(vinyl alcohol-cysteine) in molar HCl, Arabian Journal of Chemistry, 10, S3358–S3366.

[135] Q.Deng, H.Xiao-Peng, S.Hong-Wei, C.Bao-Qin (2012b) Concise Cu-I-catalyzed azidealkyne 1,3-dipolar cycloaddition reaction ligation remarkably enhances the corrosion inhibitive potency of natural amino acids for mild steel in HCl, Industrial and Engineering Chemistry Research, 51, 7160–7169.

[136] B.Little, C.Sikes (1991) Corrosion inhibition by thermal Polyaspartate. ACS Symp. Ser. 444, 263–279.

[137] R.Cui, N.Gu, C Li (2011) Polyaspartic acid as a green corrosion inhibitor for carbon steel, Materials and Corrosion, 62, 362–369.

[138] R.Appa, R.Venkateswara, R.Srinivasa, B.Sreedhar (2010) Tungstate as a synergist to phosphonate-based formulation for corrosion control of carbon steel in nearly neutral aqueous environment, Journal of Chemical Sciences, 122, 639–649.

[139] R.Appa, R.Srinivasa, M.Venkateswara (2008) Environmentally friendly ternary inhibitor formulation based on N, N-bis (phosphonomethyl) glycine, Corrosion Engineering Science and Technology, 43, 46–53.

[140] M.Yadav, S.Kumar, L.Gope (2014) Experimental and theoretical study on amino acid derivatives as eco-friendly corrosion inhibitor on mild steel in hydrochloric acid solution, Journal of Adhesion Science and Technology, 28, 1072–1089.

[141] R.Appa, R.Venkateswara, R.Srinivasa, B.Sreedhar (2011) Synergistic effect of N, N-bis (phosphonomethyl) glycine and zinc ions in corrosion control of carbon steel in cooling water systems, Chemical Engineering Communications, 198, 1505–1529.

[142] A.Raja, S.Rajendran, P.Satyabama (2013) Inhibition of corrosion of carbon steel in well water by DL-phenylalanineL Zn^{2+} system, Journal of Chemistry, 8.

[143] O.Olivares-Xometl, N.Likhanova, M.Dominguez-Aguilar, E.Arce, H.Dorantesc, P.Arellanes-Lozada (2008) Synthesis and corrosion inhibition of alpha-amino acids alkylamides for mild steel in acidic environment, Materials Chemistry and Physics, 110, 344–351.

[144] H.Zarrok, A.Zarrouk, R.Salghi, B.Hammouti, M. Elbakri, M.Ebn Touhami, F.Bentiss, H. Oudda (2013) Study of a Cysteine derivative as a corrosion inhibitor for carbon steel in phosphoric acid solution, Research on Chemical Intermediates, 40, 801–815

[145] E.Oguzie, Y.Li, F.Wang (2007c) Effect of surface nanocrystallization on corrosion and corrosion inhibition of low carbon steel: Synergistic effect of Methionine and iodide ion, Electrochimica Acta, 52, 6988–6996.

[146] M.Ormellese, L.Lazzari, S.Goidanich, G.Fumagalli, A.Brenna (2009) A study of organic substances as inhibitors for chloride-induced corrosion in concrete, Corrosion Science, 51, 2959–2968.

[147] M.Alagbe, L.Umoru, A.Afonja, O.Olorunniwo (2006) Effects of different amino-acid derivatives on the inhibition of NST-44 mild steel corrosion in lime fluid, Journal of Applied Sciences, 6, 1142–1147.

[148] M.Alagbe, I.Umoru, A.Afonja, O.Olorunniwo (2009) Investigation of the effect of different amino -acid derivatives on the inhibition of NST-44 carbon steel corrosion in cassava fluid, Anti-Corrosion Methods and Materials, 56, 43–50.

[149] M.Amin, A.Gaber, Q.Mohsen (2011) Monitoring corrosion and corrosion control of low alloy ASTM A213 grade T22 boiler steel in HCl solutions, Arabian Journal of Chemistry, 4, 223–229.

[150] L.Madkour, M.Ghoneim (1997) Inhibition of the corrosion of 16/14 austenitic stainless steel by oxygen and nitrogen containing compounds, Bulletin of Electrochemistry, 13(1), 1–7.

[151] D.Kalota, D.Silverman (1994) Behavior of aspartic-acid as a corrosion-inhibitor for steel, Corrosion, 50, 138–145.

[152] H.Abdel-Fatah, S. Rashwan, S.Wahaab, A.Hassan (2016) Effect of Tryptophan on the corrosion behavior of low alloy steel in sulfamic acid, Arabian Journal of Chemistry, 9, S1069–S1076.

[153] H.Abdel-Fatah, M.Kamel, A.Hassan, S.Rashwan, S.Wahaab, H. El-Sehiety (2017) Adsorption and inhibitive properties of Tryptophan on low alloy steel corrosion in acidic media, Arabian Journal of Chemistry, 10, S1164–S1171.

[154] A.Jano, A.Lame (Galo), E.Kokalari(Teli) (2014) The inhibition effects of Methionine on mild steel in acidic media, Analele Stiintifice ale Universitatii Ovidius Constanta-Seria Matematica, 25, 39–42.

[155] D.Silverman, D.Kalota, F.Stover, (1995) Effect of pH on corrosion inhibition of steel by polyaspartic acid, Corrosion, 51, 818–825.

[156] D.Tkalenko, G.Venkatesvaran, Y.Vishevskaya, S.Keny, M.Byk, K.Muthe (2010) Inhibitory effect of Cysteine in acid media, Protection of Metals and Physical Chemistry of Surfaces, 46, 609–614.

[157] K.Khaled, N.Abdel-Shafi (2013) Chemical and electrochemical investigations of ʟ-Arginine as corrosion inhibitor for steel in hydrochloric acid solutions, International Journal of Electrochemical Science, 8, 1409–1421.

[158] K.Khaled, S.Al-Mhyawi (2013) Electrochemical and density function theory investigations of ʟ-Arginine as corrosion inhibitor for steel in 3.5% NaCl, International Journal of Electrochemical Science, 8, 4055–4072.

[159] M.Amin, O.Hazzazi, F.Kandemirli, M.Saracoglu (2012) Inhibition performance and adsorptive behavior of three amino acids on cold-rolled steel in 1.0 M HCl-chemical, electrochemical, and morphological studies, Corrosion, 68, 688–698.

[160] F.Kandemirli, M.Saracoglu, M.Amin, M. Basaran, C.Vurdu (2014) The quantum chemical calculations of serine, threonine and glutamine, International Journal of Electrochemical Science, 9, 3819–3827.

[161] K.Emran, S.Hamdona, A.Balawi (2013) Investigation of the corrosion resistance of some safely additives and mixed salts - scales on S41000 stainless steel surface in synthetic seawater, International Journal of Electrochemical Science, 8, 8126–8137.

[162] M.Migahed, S.Rashwan, M.Kamel, R.Habib (2016) Synthesis, characterization of polyaspartic acid-glycine adduct and evaluation of their performance as scale and corrosion inhibitor in desalination water plants, Journal of Molecular Liquids, 224, 849–858.

[163] G.Mendonca, S.Costa, V.Freire, P.Casciano, A.Correia (2017) Lima-Neto Pd understanding the corrosion inhibition of carbon steel and copper in sulphuric acid medium by amino acids using electrochemical techniques allied to molecular modelling methods, Corrosion Science, 115, 41–55.

[164] C.Zhang, H.Duan, J.Zhao (2016) Synergistic inhibition effect of imidazoline derivative and ʟ-cysteine on carbon steel corrosion in a CO2-saturated brine solution, Corrosion Science, 112, 160–169.

[165] E.Kowsari, S.Armanb, M.Shahini, H.Zandi, A.Ehsani, R.Naderif, A. PourghasemiHanza, M.Mehdipour (2016) In situ synthesis, electrochemical and quantum chemical analysis of an amino acid-derived ionic liquid inhibitor for corrosion protection of mild steel in 1 M HCl solution, Corrosion Science, 112, 73–85.

[166] A.Al-Sabagh, N.Nasser, O.El-Azabawy, A.Tabey (2016) Corrosion inhibition behavior of new synthesized nonionic surfactants based on amino acid on carbon steel in acid media, Journal of Molecular Liquids, 219, 1078–1088.

[167] R.Zhao, Q.Yu, L.Niu (2022) Corrosion Inhibition of Amino acids for 316L Stainless Steel and Synergistic effect of I⁻ Ions: Experimental and Theoretical Studies, Journal of Material and Corrosion, 73, 31-44

[168] X.Liu, P.Okafor, X.Pan, D.Njoku, K.Uwakwe, Y.Zheng (2020) Corrosion inhibition and adsorption properties of cerium-amino acid complexes on mild steel in acidic media: Experimental and DFT studies, Journal of Adhesion Science and Technology, 34(19), 2047-2074,

[169] A.Kasprzhitskii, G.Lazorenko, T.Nazdracheva, V.Yavna (2021) Comparative Computational Study of ʟ-Amino Acids as Green Corrosion Inhibitors for Mild Steel, Computation, 9(1).

[170] C.Chaia, Y.Xua, D.Lia, X.Zhaoa, Y.Xua, L.Zhanga, Y.Wua (2019) Cysteamine modified polyaspartic acid as a new class of green corrosion inhibitor for mild steel in sulfuric acid medium: Synthesis, electrochemical, surface study and theoretical calculation, Progress in organic coatings, 129, 159 – 170.

[171] M.Oubaaqa, M.Ouakki , M.Rbaa , A.Abousalem , M.Maatallah , F.Benhiba , A.Jarid M.Touhami, A.Zarrouk (2021) Insight into the corrosion inhibition of new amino-acids as efficient inhibitors for mild steel in HCl solution: Experimental studies and theoretical calculations, Journal of Molecular Liquids, 334, 116520.

[172] A.Moustafa, H.Abdel-Rahman, D.Mabrouk, A.Omar (2022) Mass transfer role in electropolishing of carbon steel in H_3PO_4 containing amino acids: Electrochemical, computational, SEM/EDX, and stylus profilometer investigation, Alexandria Engineering Journal, 61(8), 6305-6327.

[173] C.Nsakabwebwe, M.Makhatha, G.Tsoeunyane, A.Baruwa (2022) Corrosion Inhibition Efficiency of Polyvinylpyrrolidone-Cysteine on Mild Steel in 1.0 M HCl Solution, Journal of Bio- and Tribo-Corrosion, 8(2),48

[174] Q.Zhang, Z.Jiang, Y.Li, X.Wang, W.Xiong, H.Liu, G.Zhang (2022) In-depth insight into the inhibition mechanism of the modified and combined amino acids corrosion inhibitors: "intramolecular synergism" vs. "intermolecular synergism, Chemical Engineering Journal, 437, 135439.

[175] Q.Zhang, Y.Li, Y.Lei, X.Wang, H.Liu, G.Zhang (2022) Comparison of the synergistic inhibition mechanism of two eco-friendly amino acids combined corrosion inhibitors for carbon steel pipelines in oil and gas production, Applied Surface Science, 583, 152559.

[176] N.Wazzan, I.Obot, T.Fagieh (2022) The role of some triazoles on the corrosion inhibition of C1020 steel and copper in a desalination descaling solution Desalination, 527, 115551.

[177] M.Abdallah, K.Soliman, R.Alfattani, A.Fawzy, M.Ibrahim (2022) Insight of corrosion mitigation performance of SABIC iron in 0.5 M HCl solution by tryptophan and histidine: Experimental and computational approaches, international Journal of Hydrogen Energy, 47(25), 12782-12797.

[178] K.Alamry, R.Aslam, A.Khan, M.Hussein, N. Tashkandi (2022) Evaluation of corrosion inhibition performance of thiazolidine-2,4-diones and its amino derivative: Gravimetric, electrochemical, spectroscopic, and surface morphological studies, Process Safety and Environmental Protection, 159, 178-197.

[179] T.Sarkar, M.Yadav, I.Obot (2022) Mechanistic evaluation of adsorption and corrosion inhibition capabilities of novel indoline compounds for oil well/tubing steel in 15% HCl, Chemical Engineering Journal, 431, 133481

[180] M.Zunita, D.Wahyuningrum, I.Wenten, R.Boopathy (2022) Carbon steel corrosion inhibition activity of tofu associated proteins, Bioresource Technology Reports, 17, 100973.

[181] A.Alamiery, A.Mohamad, A.Kadhum, M.Takriff (2022) Comparative data on corrosion protection of mild steel in HCl using two new thiazoles, Data in Brief, 40, 107838.

[182] B.Udayappan, A.Veawab (2022) Performance analysis of methionine as an environmentally friendly corrosion inhibitor for carbon steel in the amine based carbon capture process, International Journal of Greenhouse Gas Control, 114, 103565.

[183] A.Imjjad, K.Abbiche, M.Mellaoui, A.Jmiai, N.El Baraka, A.Taleb, I.Bazzi, S.El Issami, M.Hilali R.Said, M.Hochlaf (2022) Corrosion inhibition of mild steel by aminobenzoic acid isomers in hydrochloric acid solution: Efficiency and adsorption mechanisms, Applied Surface Science, 576, 151780.

[184] M.Mobin, M.Parveen, H.Aslam (2022) Effect of different additives, temperature, and immersion time on the inhibition behavior of L-valine for mild steel corrosion in 5% HCl solution, Journal of Physics and Chemistry of Solids, 161, 110422.

[185] H.Qian, W.Chang, W.Liu, T.Cui, Z.Li, D.Guo, C.Kwok, L.Tam, D.Zhang (2022) Investigation of microbiologically influenced corrosion inhibition of 304 stainless steel by D-cysteine in the presence of Pseudomonas aeruginosa, Bioelectrochemistry, 143, 107953.

[186] J.Wang, C.Liu, B.Qian (2022) A novel l-histidine based ionic liquid (LHIL) as an efficient corrosion inhibitor for mild steel, Royal Society of Chemistry Advances, 12(5), 2947-2958

IZVOD

PREGLED AMINOKISELINA KOJE SE KORISTE KAO INHIBITORI KOROZIJE NA METALU/LEGURAMA GVOŽĐA U AGRESIVNIM SREDINAMA

Istraživanje upotrebe bezbednih i ekološki prihvatljivih inhibitora korozije može utrti put za razumevanje njihovih mehanizama inhibicije za materijale od metalnih legura. Ovaj pregled ima za cilj da predstavi i prodiskutuje istraživački rad objavljen u literaturi o upotrebi aminokiselina i njihovih derivata kao inhibitora korozije gvožđa i njegovih legura u različitim agresivnim rastvorima. Ovaj netoksičan, biorazgradiv i relativno jeftin inhibitor korozije pokazao se efikasnim kao inhibitor metala/legura u kiselim, alkalnim i neutralnim rastvorima u zavisnosti od eksperimentalnih uslova. Elektrohemijske i površinske tehnike bile su među najčešće korišćenim tehnikama za procenu efikasnosti inhibicije korozije aminokiselina. Najveće vrednosti efikasnosti inhibicije mogu se dobiti u prisustvu jona kao I- i Br-. Ovaj pregled predstavlja i razmatra većinu doprinosa u literaturi o upotrebi aminokiselina i njihovih derivata kao inhibitora korozije gvožđa i njegovih legura.

Ključne reči: *inhibitor korozije, gvožđe, metal, legura, amino kiselina, računske metode*