Electrochemical Behaviour of Some Amino Acids as Corrosion Inhibitors for Mild Steel in Sweet Brine

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Abbreviations

Phe	Phenylalanine
Leu	Leucine
Val	Valine
EIS	Electrochemical Impedance Spectroscopy
Rp	Polarization Resistance
SEM	Scanning Electronic Microscope
EDX	Energy Dispersive X-ray
FTIR	Fourier Transform Infrared Spectroscopy

Abstract

The effect of concentration and immersion time of phenylalanine (Phe), leucine (Leu) and valine (Val) for AISI 1018 in sweet brine was studied through Electrochemical Impedance Spectroscopy (EIS), polarization resistance (Rp), Scanning Electronic Microscope (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) as an ecological and biodegradable alternative as corrosion inhibitors. Electrochemical results showed that amino acids are good corrosion inhibitors according to their charge transfer resistance improvement. The effect of immersion time on corrosion behavior was studied through 24 h with amino acids concentration variation of 0, 10, 100 and 250 ppm. The preliminary results demonstrated that the three amino acids adsorb over metal surface following the Langmuir adsorption isotherm model, and tend to agglomerate in bulk within time.

Keywords: Corrosion Inhibitors; Biodegradable; Amino acids; Sweet brine

Abstract

In spite of all developments in new technologies; the search of new oil sources is utmost importance due to the energy growing demand [1]. It comes with new challenges to inhibit corrosion in extraction and transportation systems [2] without neglecting the ecological issue. Recently some researchers such as A.A [3] mentioned that the use of synthetic organic inhibitors in oil and gas industry leads to stricter environmental regulations to their usage; making thus necessitated the research of new natural; inexpensive and environmentally friendly corrosion inhibitors. In this way the presence of functional groups; heteroatoms and multiple bonds make organic compounds a good option as corrosion inhibitors [4], due to this; amino acids have been used as corrosion inhibitors for several metals and alloys in different electrolytes for multiple applications. However; their efficiency depends on many factors; such as inhibitor and oxygen concentration; metal and compound chemical nature; surface

preparation of metal; immersion time; hydrodynamic conditions; temperature; pH and additives [5].

In general; it has been determined that amino acids have higher anticorrosive efficiency in neutral and acidic solutions; due to the protonation of the amino group; adsorbing and blocking the active sites for the corrosion process [6]. Amino acids adsorb over metal surface following different adsorption models. In 2017; H.T.M. Abdel-Fatal et al determined that tryptophan was a good corrosion inhibitor for mild steel in HSO_3NH_2 and HCl acid solutions obeying Temkin adsorption isotherm model. On the other hand [7] determines that the L-histidine as corrosion inhibitor obeys Langmuir adsorption isotherm model.

Additionally it was determined that the concentration is a decisive factor for a corrosion inhibitor; many authors have used amino acids in a wide range of concentrations in order to achieve high corrosion inhibition efficiencies; from tens of ppm (0-99

ppm) [8-10] followed by hundreds of ppm (100-999 ppm)[11-13] to thousands of ppm(+1000 ppm) [14,15]. Due to this; the amino acids: phenylalanine (Phe); leucine (Leu) and valine (Val) (Figure. 1) are proposed as an eco-friendly alternative as corrosion inhibitors for AISI 1018 in a sweet brine for an application in oil industry.

Figure 1: Schematic of inhibitor's molecular structures

Experimental Procedure

Surface Preparation and electrochemical cell

Before the electrochemical tests; the working electrode samples were prepared by abrasion with emery paper to a 2000-grade; a subsequent cleaning with deionized water and acetone and dried at room temperature (25°C)[16]. The electrolyte was a sweet brine composed of a brine solution NACE (NaCl 106.58 g/L; $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ 4.48 g/L and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ 2.96 g/L) and $\text{CO}_2(\text{g})$ until saturation (pH=3.9). The amino acids (Phe;Leu; Val) were reagent grade ($\geq 98\%$) from Sigma Aldrich. Inhibitor concentrations were 0; 10; 100 and 250 ppm.

Electrochemical characterization

The electrochemical characterization was carried out using a GillAC potentiostat with a typical three-electrode electrochemical cell composed of an AISI 1018 alloy as working electrode; graphite rod as counter-electrode and a saturated Ag/AgCl reference electrode. Electrochemical Impedance Spectroscopy (EIS) was carried out employing a sinusoidal perturbation signal of ± 10 mV $vs E_{corr}$; within a frequency range of 10^{-2} Hz to 10^4 Hz after rest potential monitoring during 1800 s. After EIS evaluation; a rest potential monitoring was performed during 300 s; then a perturbation of ± 20 mV $vs E_{corr}$ was applied in order to evaluate linear polarization resistance. The experimental data was fitted by ZView 2 software

Morphological Characterization

Samples were immersed in the sweet brine with the optima concentration of each amino acid; during 24 h at room temperature. After immersion; specimens were washed with distilled water and dried in open-air inside a desiccator. The surface was analyzed using a Carl-Zeiss microscope SUPRA 55 VP at 5 kV accelerating voltage; with a 500X secondary electron detector.

Spectroscopic characterization

For Fourier Transform Infrared spectroscopic characterization; electrolyte samples were taken at the beginning

of the tests and after seven days and were analyzed on a Perkin Elmer Spectrum One in the range of 650 to 4000 cm^{-1} .

Results and Discussion

Electrochemical characterization

Electrochemical Impedance Spectroscopy (EIS)

Nyquist plots of AISI 1018 in the sweet brine in absence and presence of Phe during 24 h of immersion can be appreciated in figure 2; which seem to appear as depressed semicircles caused by the heterogeneity of the metal surface [17]. At time $t = 0$ h (Figure. 2a) Phe at 10 ppm presents the higher impedance value (2442 Ωcm^2); this is attributed to the decrease of molecular mobility with the increase of Phe concentration [18]. This tendency persists during the first 12 h (Figure 2b; 2c); and after 24 h of immersion (Figure. 2d) the Phe at 10 ppm remains stable and the other systems achieves similar values; due to oxide formation and amino acid adsorption.

Bode angle plots of AISI 1018 in absence and presence of different concentrations of Phe are shown in figure 3; after 6 h of immersion (Figure. 3a; 3b) can be appreciated only one time constant due to the inhibitor film resistance (R_f); and after 12 and 24 h (Figure. 3c; 3d) there is an arc widening; associated to the presence of a second time constant of the charge transfer resistance (R_{ct})[19]; furthermore; the wide frequency range covered by the phase angle signal provides information on a strong adsorption process over the substrate [20] and the increasing of the phase angle values with the addition of the amino acid means of a formation of a higher protection layer [21].

In order to simulate the response acquired by EIS of all systems; the equivalent circuits in Figure. 4 were used by fitting to the lowest error. Figure 4a shows the circuit used for the first 6 h of immersion and for the 12 and 24 h of immersion the two elements circuit in Figure. 4b was used.

Due to surface heterogeneity [22], a Constant Phase Element (CPE) was used instead of capacitances (C) for a more accurate fitting to EIS results. The CPE is defined in impedance

representation by the following equation:

$$Z_{CPE} = Y_0^{-1}(j\omega)^{-n} \quad (1)$$

where Y_0 is a proportional factor; n is the phase shift. The CPE may represent a resistance ($n = 0$); a capacitor ($n = 1$); or an inductance ($n = -1$). The double layer capacitance (C_{dl}) is represented by;

$$C_{dl} = Y_0(\omega_m'')^{n-1} \quad (2)$$

Figure 2: Nyquist plots for AISI 1018 in a brine solution NACE + CO₂ in absence and presence of Phe after a) 0 h, b) 6 h, c) 12 h and d) 24 h of immersion

Figure 4: Equivalent circuits used for EIS results simulation for a) 0 and 6 h of immersion and b) for 12 and 24 h of immersion

Figure 3: Bode plots of AISI 1018 in a brine solution NACE + CO₂ in absence and presence of Phe after a) 0 h, b) 6 h, c) 12 h and d) 24 h of immersion

Where ω_n is the angular frequency in which the imaginary component of the impedance has a maximum value. Further n can be used as a measurement of the heterogeneity or roughness of the surface[23].

The obtained data from the fitting of the impedance results from AISI 1018 in the sweet brine and the addition of Phe are given in Table 1. As can be seen; with the presence of Phe; the R_{ct} increases; meaning in the formation of a protective film over the surface; in addition the double layer capacitance (C_{dl}) values decrease due to the adsorption of the amino acid on the surface which changes in the dielectric properties of water molecules on the double layer by changing the orientation of the dipole molecules[24]. Besides this; the effect of the addition of Phe can be seen also by the decrease of the corrosion current density (i_{corr}) meaning in a lowering of the corrosion rate (CR; in mm/y).

In Figure 5 are appreciated the Nyquist plots of Leu; at beginning of the test (Figure 5a) the amino acid provides low corrosion protection in comparison with blank; nearly of 10% of impedance improvement; which enhances within time. After 6 and 12 h of immersion (Figure 5b; 5c) the impedance value of Leu at 250 ppm increases 70% in comparison with AISI 1018 in absence of the Leu. However; after 24 h (figure 5d) the oxide products formed over the surface provide similar protection than that provided by the amino acid.

Figure 6 shows Bode angle plots of the system with variation of concentration and time immersion; during the first 6 h of

immersion (Figure 6a; 6b) can be appreciated only one time constant associated to the film resistance. After 12 and 24 h of immersion time (figure 6c; 6d); the widening in frequency of the phase angle signal implies the apparition of a second time constant associated to the charge transfer resistance. Compared with Phe; the phase angle value in presence of Leu increases to a lesser extent; which is associated with a lower adsorption of the amino acid since it slightly increases the capacitive behavior; which is reflected in the lower impedance values reported in Nyquist diagrams.

The data obtained by fitting the EIS experimental results are shown in Table 2; as can be appreciated; the capacitance of the double layer slightly decreases with the addition of Leu to the system what agrees with the small amount of increment in the diameter of the Nyquist plots compared with the results of the addition of Phe. The Nyquist plots for the addition of Val are shown in Figure 7; where can be appreciated that from time $t = 0$ h (Figure 7a) the corrosion inhibitor effect is evident and proportional to Val concentration; achieving the higher impedance value ($1826 \Omega \text{cm}^2$) at concentration of 250 ppm. This behavior persists during all 24 h of test (Figure 7b; 7c; 7d) providing corrosion protection in the sweet brine. The increase of the phase angle value in the Bode plots (Figure 8) with the addition of the Val implies the formation of the protection layer which matches with the impedance enhancing seen in the Nyquist diagrams. During the first 6 h of immersion in the sweet brine (Figure 8a; 8b) can only

Figure 5: Nyquist plots for AISI 1018 in a brine solution NACE + CO₂ in absence and presence of Leu after a) 0 h, b) 6 h, c) 12 h and d) 24 h of immersion

Table 1: Impedance parameters calculated from EIS diagrams of AISI 1018 in sweet brine as a function of Phe concentration and immersion time

C (ppm)	t (h)	R _f (Ωcm ²)	C _f [x10 ⁻⁴] (F)	R _{ct} (Ωcm ²)	C _{dl} [x10 ⁻⁴] (F)	R _p (Ωcm ²)	i _{corr} [x10 ⁻⁵] (A/cm ²)	CR (mm/y)
0	0	-	-	715	1.23	715	3.64	0.421
	6	-	-	870	1.61	870	2.99	0.346
	12	-	-	1791	1.67	1791	1.45	0.168
	24	1663	1.17	3735	1.23	5398	0.482	0.055
10	0	2442	1.90	-	-	2442	1.06	0.123
	6	3798	1.86	-	-	3798	0.685	0.079
	12	1211	1.07	5325	0.853	6536	0.398	0.046
	24	652.1	0.995	5558	0.928	6210.1	0.419	0.048
100	0	936	1.83	-	-	936	2.78	0.321
	6	2349	2.34	-	-	2349	1.11	0.128
	12	582.8	1.24	3540	0.130	4098.8	0.634	0.073
	24	652.5	1.16	5311	0.171	5963.5	0.436	0.050
250	0	991.2	1.65	-	-	991.2	2.62	0.303
	6	2311	2.40	-	-	2311	1.13	0.130
	12	1073	1.47	3115	1.02	4188	0.621	0.071
	24	1605	1.47	3790	1.28	5395	0.482	0.055

Figure 6: Bode plots of AISI 1018 in a brine solution NACE + CO₂ in absence and presence of Leu after a) 0 h, b) 6 h, c) 12h and d) 24 h of immersion

Table 2: Impedance parameters calculated from EIS diagrams of AISI 1018 in sweet brine as a function of Leucine concentration and immersion time

C (ppm)	t (h)	R _f (Ωcm ²)	C _f [x10 ⁻⁴] (F)	R _{ct} (Ωcm ²)	C _{dl} [x10 ⁻⁴] (F)	R _p (Ωcm ²)	i _{corr} [x10 ⁻⁵] (A/cm ²)	CR (mm/y)
0	0	-	-	715	1.23	715	3.64	0.421
	6	-	-	870	1.61	870	2.99	0.346
	12	-	-	1791	1.67	1791	1.45	0.168
	24	1663	1.17	3735	1.23	5398	0.482	0.055
10	0	540.2	1.43	-	-	540.2	4.81	0.557
	6	830.8	1.77	-	-	830.8	3.13	0.362
	12	666.2	1.29	1090	1.49	1756.2	1.48	0.171
	24	801.2	1.11	4708	1.03	5509.2	0.472	0.054
100	0	779.9	1.22	-	-	779.9	3.33	0.386
	6	1019	1.47	-	-	1019	2.55	0.295
	12	890.8	1.16	1003	1.50	1893.8	1.37	0.159
	24	583	0.893	4982	0.912	5565	0.467	0.054
250	0	593.7	1.69	178.4	4.83	772.1	3.36	0.390
	6	692.3	1.67	662.8	2.04	1355.1	1.92	0.222
	12	745.7	1.44	2346	1.70	3091.7	0.840	0.097
	24	874.9	1.47	3381	1.41	4255.9	0.611	0.071

Figure 7: Nyquist plots for AISI 1018 in a brine solution NACE + CO₂ in absence and presence of Val after a) 0 h, b) 6 h, c) 12 h and d) 24 h of immersion

Figure 8: Bode plots of AISI 1018 in a brine solution NACE + CO₂ in absence and presence of Val after a) 0 h, b) 6 h, c) 12h and d) 24 h of immersion

be appreciated one well defined time constant associated with the amino acid film resistance (R_f) and after 12 and 24 h of immersion; the widening of the phase angle signal implies a second time constant associated to the charge transfer resistance (R_{ct}). In Table 3 can be seen the data obtained by the fitting of the impedance results; with presence of Val; the double layer capacitance decreases; which implies its adsorption by the changing of the electrical permittivity of the film.

The difference in the concentration when the higher inhibitory effect is achieved by each amino acid is associated to the different molecular structure [25,26]; since the three amino acids interacts with the metal surface by the interaction of the lone-pair electron of the heteroatoms [27], the presence of an aromatic ring in the Phe provides it of a higher electronic density; so that π -electrons of the benzene ring have donor-acceptor interactions with the vacant d-orbital of the metal surface [28,29].

Polarization Resistance (R_p)

The effect of immersion time on the AISI 1018 resistance in the sweet brine is shown in Figure 9; in case of Phe (Figure 9a); can be appreciated a superior corrosion inhibition at concentration of 10 ppm. In addition; the R_p values increases initially followed by a subsequent leveling after 12 h; indicating a gradual reaction of the molecule with the metal surface followed by a surface saturation of simultaneous adsorption-desorption phenomenon [30].

With Leu addition (Figure 9b); the system resistance hardly increases compared with blank; meaning in a slightly protection; agreeing with what was observed in the impedance results. Finally; with Val (Figure 9c) can be seen a superior corrosion protection with a gradual enhancing within immersion time; due to the formation of the amino acid film over the substrate surface.

Figure 9: Variation of linear polarization resistance with immersion time with different concentrations of a) Phe, b) Leu and c) Val

Amino acids inhibition efficiency

Polarization resistance was taken for amino acids Inhibition Efficiency ($I.E.$) calculations as follows:

$$I.E. = \left(\frac{R_{p_{inh}} - R_{p_0}}{R_{p_{inh}}} \right) \cdot 100 \quad (3)$$

where R_{p_0} and $R_{p_{inh}}$ are the polarization resistances in absence and presence of corrosion inhibitor; respectively [31] and results are shown in Figure 10. As immersion time increases; the polarization resistance also increases due to further amino

acid adsorption; and consequently the inhibition efficiency increases up to 89; 87 and 93 % for Phe; Leu and Val; respectively. It should be noted that in case of Phe; the $I.E.$ achieves 89% since the first 12 h of immersion; and remains constant for 12 more hours; in comparison with Leu and Val which reach their highest efficiency after 24 h.

Adsorption isotherms and thermodynamics

The usual mechanism in which organic corrosion inhibitors provide anticorrosive protection is by their adsorption over the metal surface; insulating it from the aggressive electrolyte and preventing the substrate dissolution [32]. For a further analysis

of adsorption processes carried out in the system; the implementation of adsorption isotherms provides information about the nature of the interactions between the corrosion inhibitor molecule and the metal surface [33]. The adsorption process is influenced by many factors; as the metal charge; chemical nature of metal and organic compound or charge distribution on the molecule [34]. When considering adsorption isotherms; it is conventional to adopt the term surface coverage (θ); which defines the saturation of a particular adsorbate on a given surface [35]. It can be calculated by the following equation:

$$\theta = 0.01 \left(\frac{Rp_{inh} - Rp_0}{Rp_{inh}} \right) \quad (4)$$

Figure 10: Efficiencies of the different concentration of a)Phe, b) Leu and c) Val for AISI 1018 in a sweet brine in continuous immersion

where the value of θ must be in the interval of 0-1. When $\theta = 0$; implicates the lack of surface coverage of the corrosion inhibitor and at the case of $\theta = 1$ implies the total coverage of substrate surface [36]. There are several adsorption isotherms models used for thermodynamic analysis; some of them are: Langmuir; Temkin; Freundlich; Frumkin; Fory-Huggins or Bockris-Swinkels (Abd El Rehim et al; 2016). The three amino acids systems adjusted more accurately to Langmuir's model; given by the following equation:

$$\frac{C}{\theta} = \frac{1}{K_{ads}} + C \quad (5)$$

where C is the corrosion inhibitor concentration (mol/L) and K_{ads} is the adsorption constant [37]. In order to determinate the adsorption model; it is important to calculate the Gibbs free energy of adsorption (ΔG_{ads}^0) which is related with the adsorption constant (K_{ads}) by the following equation:

$$\Delta G_{ads}^0 = -RT \ln K_{ads} \quad (6)$$

where R is the ideal gas constant and T is the absolute temperature (K).

If the Gibbs free energy gets negative values; a spontaneous process is happening (Cleveland and Morris; 2014). When there is a physical interaction (physisorption) between amino acids and metal surface then $\Delta G_{ads} < -20$ kJ/mol; for a chemical interaction (chemisorption) $\Delta G_{ads} > -40$ kJ/mol; and for values of -20 kJ/mol $< [\Delta G]_{ads} < -40$ kJ/mol there is a combined process of physisorption and chemisorption [38].

In Figure 11 can be appreciated the adsorption isotherms of the three amino acids (Phe; Leu and Val) and in table 4 is shown the thermodynamic data calculated from them. It can be seen that for Phe; at all immersion times the ΔG_{ads} values are near -40 kJ/mol meaning a chemisorption in comparison with Leu and Val

Figure 11: Adsorption model adopted from the experimental results according to the theoretical model of Langmuir

Table 3: Impedance parameters calculated from EIS diagrams of AISI 1018 in sweet brine as a function of Valine concentration and immersion time

C (ppm)	t (h)	R_f (Ωcm^2)	$C_f \times 10^{-4}$ (F)	R_{ct} (Ωcm^2)	$C_{dl} \times 10^{-4}$ (F)	R_p (Ωcm^2)	$i_{corr} \times 10^{-5}$ (A/cm ²)	v_{corr} (mm/y)
0	0	-	-	715	1.23	715	3.64	0.421
	6	-	-	870	1.61	870	2.99	0.346
	12	-	-	1791	1.67	1791	1.45	0.168
	24	1663	1.17	3735	1.23	5398	0.482	0.055
10	0	993.5	1.23	-	-	993.5	1.99	0.231
	6	551.4	1.17	549.8	0.967	1101.2	2.36	0.273
	12	491.3	1.11	1282	1.11	1773.3	1.46	0.169
	24	604.5	0.939	5404	1.06	6008.5	0.432	0.050
100	0	855.3	1.37	-	-	855.3	3.04	0.352
	6	237.4	0.869	895.5	1.14	1132.9	2.29	0.265
	12	216.9	0.840	1723	2.41	1939.9	1.34	0.155
	24	360.8	0.786	5233	1.16	5593.8	0.464	0.053
250	0	1826	0.702	-	-	1826	1.42	0.165
	6	3515	0.551	-	-	3515	0.739	0.085
	12	1269	1.09	4164	1.08	5433	0.478	0.055
	24	7239	0.521	2890	0.916	10129	0.256	0.029

where ΔG_{ads} are in the range of -20 and -40 kJ/mol meaning in a combined process; which implies a weaker interaction with the metal surface; agreeing with results seen in the electrochemical characterization.

Morphological Characterization

Scanning Electronic Microscopy (SEM)

In Figure 12 can be appreciated the surface morphology images of the polished AISI 1018 steel sample (figure 12a); and the steel sample after 24 h of immersion in the aggressive

electrolyte with 10 ppm of Phe (Figure 12b); 100 ppm of Leu (Figure 12c) and 250 ppm of Val (Figure 12d). It can be observed that the polished line of the sample can still be seen after the 24 h immersion in the presence of the three amino acids; meaning that organic molecules adsorbed in those areas forming a protecting layer and inhibiting the metal dissolution; the agglomerations seen in images are associated to corrosion products and NaCl incrustations due to the presence of Na and Cl signals in EDX images [39,40]. The cluster presence in substrate surface validates electrochemical results; since the system with

Figure 12: SEM and EDX images of (a) polished substrate and with (b) phenylalanine, (c) leucine and (d) valine after 24 h immersion in the sweet brine

Figure 13: Transmission spectra of brine solution NACE + CO₂ in absence and presence of amino acids a) at beginning of tests and b) after seven days

Table 4: Thermodynamic data calculated from Langmuir's adsorption model adjustments of AISI 1018 in a sweet brine with Phe, Leu and Val

Amino acid	t (h)	K_{ads}	ΔG_{ads} (kJ/mol)	m	R^2	Adsorption type
Phe	0	1.09E7	-39.61	3.626	0.9795	Chemisorption
	6	1.20E7	-39.84	1.456	1	Chemisorption
	12	2.16E7	-41.28	1.208	0.9999	Chemisorption
	24	1.06E7	-39.54	1.154	0.9999	Chemisorption
Leu	0	3.77E4	-25.76	14.24	0.9995	Combined
	6	8.01E4	-27.70	1.843	0.8954	Combined
	12	4.63E5	-31.89	1.265	0.9782	Combined
	24	2.72E6	-36.21	1.207	0.9992	Combined
Val	0	3.42E4	-25.52	1.319	0.4268	Combined
	6	8.92E4	-27.86	1.096	0.4930	Combined
	12	2.95E5	-30.78	1.102	0.9433	Combined
	24	1.91E6	-33.35	1.068	0.9982	Combined

Phe present the less agglomeration areas; followed by the system with Leu and finally with Val [41,42].

Spectroscopic characterization

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectrum of the Sweet Brine (SB) with the different amino acids is shown in Figure 13a. The width peak observed in the range of 3000-3500 cm^{-1} is attributed to the O-H stretching vibrations (ν_1); the sharp peak in 1640 cm^{-1} is attributed to the O-H bending vibrations (ν_2) and at 2100 cm^{-1} is the combination band ($\nu_1 + \nu_2$) [43]. As can be seen; it is basically the water FTIR spectrum due to the fact that characteristic bond of amino acids was not detected due to their low concentration in the solution. In figure 13b can be appreciated the spectrum of the same solutions after seven days; where agglomerations could be distinguished. The most intense peak is attributed to the O-H stretching vibrations [44]; the peak in the range of 1700-1500 cm^{-1} is associated to the C=O and C-N stretching vibrations [45-48]; the last related to the peptide bond which suggests that amino acid molecules tend to agglomerate within time; diminishing their efficiency as corrosion inhibitors.

Conclusion

In order to contribute the necessitated development of new natural; inexpensive and environmentally friendly corrosion inhibitors; this research work determinate the following results:

From the electrochemical results; it was determinate that the proposed amino acids are a good ecological alternative as corrosion inhibitors for AISI 1018 in sweet brine due to the system corrosion resistance increasing.

It was determinate that the amino acids form a monolayer on metal surface due to the systems fit the Langmuir's adsorption isotherms. It was also concluded that Phe needs lower concentration to inhibit corrosion due to its molecular structure;

which provides it of a higher electronic density by the aromatic ring; improving the interaction between amino acid and metal surface; inducing chemisorption. In comparison with Leu and Val where the absence of the benzene ring leads to weaker bonds with the iron in surface; having a combination of physical and chemical interactions.

The amino acids presence prevents the metal dissolution; as can be seen in the SEM images; where the areas where the polished lines are still visible were where the inhibitor was adsorbed and protected the substrate.

The inhibition efficiency of the amino acids would decrease within time due to desorption process and due to their agglomeration in solution bulk; which could be seen in FTIR by the appearance of the C-N vibrational band associated to the peptide bond between amino acids.

Authors' contributions

León-González carried out the electrochemical studies of amino acids and participated in electrochemical; thermodynamic; morphological and spectroscopic analysis and drafted the manuscript.

Onofre-Bustamante and Rodríguez-Gómez participated in electrochemical and morphological analysis; design of the study; project administration; funding acquisition and supervision.

Espinoza-Vázquez participated in electrochemical; thermodynamic and spectroscopic analysis for amino acids and supervision. All the authors read and approved the final manuscript.

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