Rini Sowmiya Selva Kumar[1], Raja Sri Siva Kumar[1], Swathi Ramalingam[1], Sheeba Swetha Selvaraj[1], Mariya Selastina Arul Sundar Raj[1], Punitha Pricilla Francis Xavier[1], Simirna Jenifer Ramesh[1], Sathya Priya Murugan[1], Hema Dharshini Selvam[1], Yuva Sri Rathinakumar[1], Anitha Nilavan[1], Susai Rajendran[1,2]*

[1]Corrosion Research Centre, Department of Chemistry, St Antony's College of Arts and Sciences for Women, Amala Annainagar, Thamaraipadi, Dindigul, India, [2]Pondicherry University, Centre for Nanoscience and Technology, Puducherry, India

Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.5937/zasmat2301078K

Zastita Materijala 64 (1)
78 – 85 (2023)

Inhibition of corrosion of L 80 alloy in sodium hydroxide solution (pH=12) by succinic acid

ABSTRACT

Inhibition of corrosion of L80 alloy in sodium hydroxide solution (pH=12) by succinic acid has been evaluated by electrochemical studies such as polarization and AC impedance spectra. The study reveals that succinic acid is able to control corrosion of L80 alloy in NaOH solution (pH = 12). When L 80 alloy is immersed in NaOH solution , the linear polarisation resistance (LPR) increases and the corrosion current (I_{corr}) decreases as revealed by potentiodynamic polarization study. Succinic acid at pH=12 functions as anodic type of inhibitor. When L80 alloy is immersed in NaOH solution , the charge transfer resistance (R_t) increases, impedance increases, phase angle increases and double layer capacitance (C_{dl}) value decreases . These results suggest that a protective film is formed on the metal surface and probably the protective film consists of Fe^{2+} - inhibitor complex (Iron succinate).

Keywords: *corrosion inhibition, L80 alloy, sodium hydroxide solution, electrochemical studies, succinic acid*

1. INTRODUCTION

The corrosion of steel materials in alkaline-saline media is the largest problem in industry. Economical and environmentally friendly corrosion inhibitors are crucial for corrosion protection. Ma et al. have used Nicotinic acid as a novel inhibitor for alkaline cobalt in cobalt interconnect chemical mechanical polishing (CMP) [1]. The effect of structural properties of benzo derivative on the inhibition performance for copper corrosion in alkaline medium has been investigated by Li et al. [2]. Govindaraj et al. have used nano-sized cerium vanadium oxide as corrosion inhibitor. It was observed that the dissolution/solubility of the corrosion inhibitor was more favorable in neutral to alkaline conditions than in acidic conditions [3]. Organic tannic acid (TA) molecules and then inorganic praseodymium (Pr) cations as corrosion inhibitors were successfully loaded by Motamedi et al.[4] into a zeolitic imidazolate framework (ZIF8)-type porous coordination polymer (PCP) decorated on molybdenum disulfide, MoS_2, (MS)-based transition metal dichalcogenides (TMDs) to create novel hybrid mesoporous Pr/TA-ZIF8@MS nanoreservoirs. Abd El-Lateef et al. have studied the effect of two isomer forms thiazole and thiadiazine on the inhibition of acidic chloride-induced steel corrosion [5]. Ruf et al. have used natural product-derived phosphonic acids as corrosion inhibitors for iron and steel. They have been evaluated by chip filter assay, potentiodynamic polarization measurements, electrochemical impedance measurements and gravimetry for corrosion protection of iron and steel in an aqueous environment at slightly alkaline pH [6]. Krishnaveni and Vasanthajothi have investigated on corrosion inhibition behaviour of aqueous extract of leaves of Morinda Tinctoria on Aluminium in sodium hydroxide solution [7]. Chen et al. have made a study on anti-corrosion mechanism of a new double mannich alkaline corrosion inhibitor for acidizing [8]. The corrosion of steel materials in alkaline-saline media is the

[#] Corresponding author: Rini Sowmiya Selva Kumar
E-mail: susairajendran@gmail.com

Paper received: 23. 08. 2022.
Paper accepted: 11. 09. 2022.
Paper is available on the website: www.idk.org.rs/journal

largest problem in industry. Economical and environmentally friendly corrosion inhibitors are crucial for corrosion protection. Berdimurodov et al. have developed a novel cucurbit[6] uril-based [3] rotaxane supramolecular ionic liquid as a green and excellent corrosion inhibitor for the chemical industry [9]. Nambiar et al. have used Derris Indica leaves extract as a green inhibitor for the corrosion of aluminium in alkaline medium [10]. The present work is undertaken to investigate the corrosion resistance of L80 alloy in sodium hydroxide solution at pH 12 in the absence and presence of succinic acid as corrosion inhibitor. Polarisation study and AC impedance spectra(Electrochemical Impedance Spectroscopy - EIS) have been employed for this purpose.

2. EXPERIMENTAL

Electrochemical studies

The corrosion resistance of L80 alloy in sodium hydroxide solution (pH = 12) has been measured by electrochemical studies such as potentiodynamic polarisation study and AC impedance spectra [11-28].

Potentiodynamic polarisation study

A CHI electrochemical work station with impedance model 660A was used for this purpose. A three-electrode cell assembly electrode was used in the present study. L80 alloy was used as working electrode; saturated calomel electrode was used as reference electrode and Platinum electrode was used as counter electrode. From the Polarisation study corrosion parameters such as corrosion potential (E_{corr}) corrosion current (I_{corr}) and Tafel slope values (anodic = b_a and cathodic = b_c) and Linear polarisation resistance (LPR) were calculated. The scan rate (V/S) was 0.01. Hold time at (Efcs) was zero and quit times (s) was two.

AC impedance spectra

AC impedance spectral studies were carried out on a CHI – Electrochemical workstation with impedance, Model 660A. A three – electrode cell assembly was used. The working electrode was L 80 alloy, a saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode.

The real part (Z') and imaginary part (-Z'') of the cell impedance were measured in ohms at various frequencies. Values of the charge transfer resistance (R_t) and the double layer capacitance (C_{dl}), impedance value and phase angle were calculated from Nyquist plots and Bode plots.

Composition of L 80 alloy

L80 alloy is a controlled yield strength material with a hardness testing requirement. L80 is usually used in wells with sour (hydrogen sulfide) environments.

The composition of L80 alloy used in this study is given in Table 1.

Table1. Chemical Composition of L80 alloy

Tabela 1. Hemijski sastav legure L80

	C	Mn	Mo	Cr	Ni	Cu	Ti	P	S	Si	V	Al
Min	-	-	-	-	-	-	-	-	-	-	-	-
Max	0.430	1.900	-	-	0.250	0.350	-	0.030	0.030	0.450		

3. RESULTS AND DISCUSSION

Electrochemical studies such as polarization and AC impedance spectra [11-28] have been employed to evaluate the corrosion protection nature of succinic acid.

Analysis of polarisation curves

Polarisation study has been used to detect the formation of protective film on the metal surface. When a protective film formed on the metal surface, the linear polarisation resistance (LPR) increases and the corrosion current (Icorr) decreases. The potentiodynamic polarisation curves of mild steel immersed in various test solutions are shown in Figure 1. The corrosion parameters namely, corrosion potential (E_{corr}), Tafel slopes (b_c=cathodic; b_a= anodic) linear polarisation resistance (LPR) and the corrosion current (I_{corr}) are given in Table 2. They are compared in Figure 2.

Table 2. Corrosion parameters of L80 alloy immersed in various test solutions obtained by potentiodynamic polarisation study

Tabela 2. Parametri korozije legure L80 uronjene u različite test rastvore dobijene potenciodinamičkom polarizacijom

System	E_{corr} mVvs SCE	b_c mV/decade	b_a mV/decade	LPR Ohmcm^2	I_{corr} A/cm^2
NaOH	-706	225	193	253	1.79 x10^{-4}
NaOH + succinic acid (1000 ppm)	-648	184	229	357	1.24 x 10 $^{-4}$

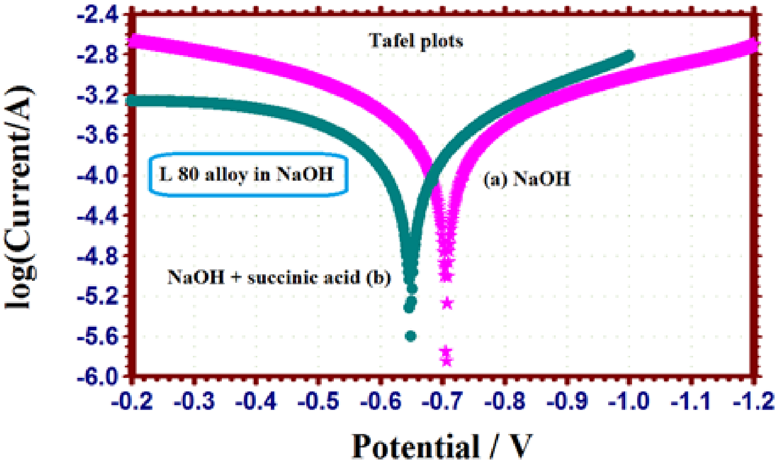

Figure 1. Polarisation curves of L80 alloy immersed in various test solutions (a) NaOH (b) NaOH + Succinic acid

Slika 1. Polarizacione krive legure L80 uronjene u različite testne rastvore (a) NaOH (b) NaOH + ćilibarna kiselina

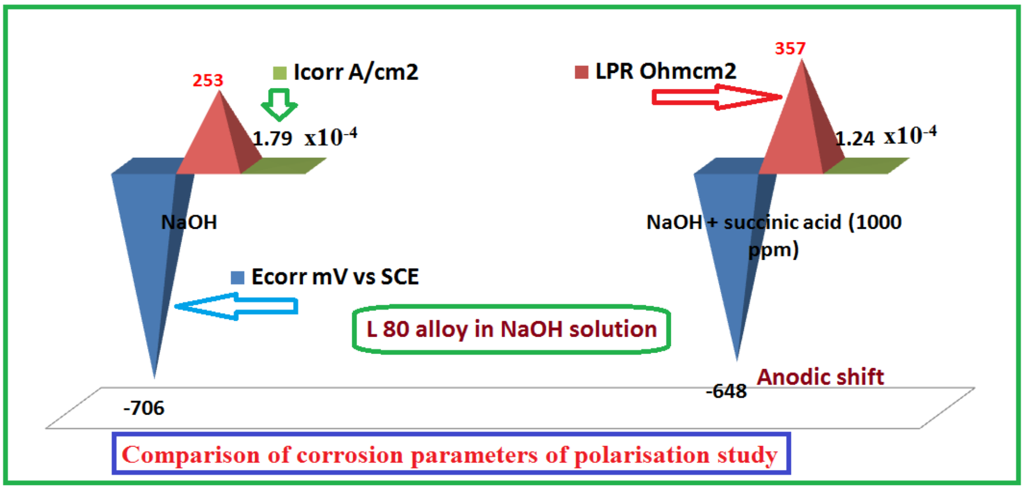

Figure 2. Comparison of corrosion parameters of polarisation study

Slika 2. Poređenje parametara korozije studije polarizacije

Influence of succinic acid on the corrosion resistance of L-80 alloy immersed in sodium hydroxide solution (pH = 12)

When L80 alloy is immersed in sodium hydroxide solution (pH = 12) the corrosion potential is -706 mV vs SCE. The formulation consisting of 1000 ppm of succinic acid shifts the corrosion potential from -706 to -648 mV vs SCE. This indicates that succinic acid at pH=12 functions as anodic type of inhibitor in controlling corrosion of mild steel in sodium hydroxide solution at pH 12. That means the anodic reaction is controlled predominantly. It is also observed that in the presence of succinic acid the LPR value increases from 253 to 357 Ohmcm^2, and the corrosion current decreases from 1.79 x10^{-4} to 1.24 x10^{-4} A/cm^2. In the presence of inhibitor, LPR value increases and corrosion current decreases (Figure 1).

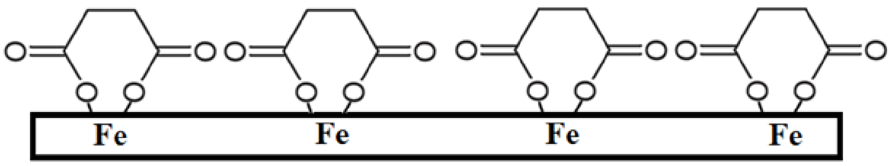

Figure 3. Iron succinate complex

Slika 3. Gvožđe ćilibarni kompleks

These results suggest that a protective film is formed on the metal surface and probably the protective film consists of Fe^{2+} inhibitor complex (Figure 3).

Analysis of AC impedance spectra (Electrochemical Impedance spectra-EIS)

AC impedance spectra have been used to detect the formation of the film formed on the metal surface. If the protective film is formed, the charge transfer resistance (R_t) increases, impedance increases, phase angle increases and double layer capacitance (C_{dl}) value decreases. The AC Impedance spectra of mild steel immersed in various solutions are shown in Figures 4-6. The corrosion parameters are compared in Figure 7 and 8.

The AC impedance parameters, namely charge transfer resistance (R_t), impedance, phase angle and double layer capacitance (Cdl) are given in Table 3. It is observed from Table 3 that when mild steel is immersed in sodium hydroxide solution (pH=12), in the presence of inhibitor (1000ppm of succinic acid) the charge transfer resistance (R_t) increases, impedance increases, phase angle increases and double layer capacitance (C_{dl}) value decreases (Figure 8). These results suggest that a protective film is formed on the metal surface and probably the protective film consists of Fe^{2+} inhibitor complex (Figure 4).

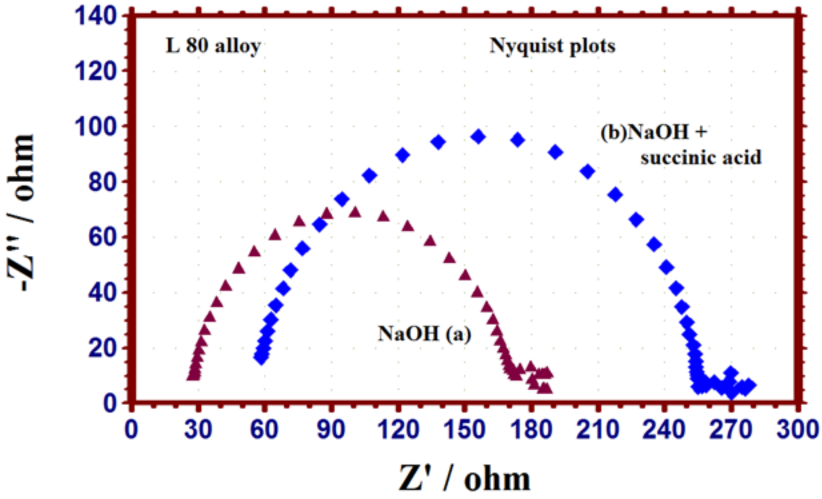

Figure 4. Nyquist plots of L80 alloy immersed in various test solutions. (a) NaOH (b) NaOH + Succinic acid

Slika 4. Nyquist-ovi dijagrami legure L80 uronjeni u različita testna rešenja. (a) NaOH (b) NaOH + ćilibarna kiselina

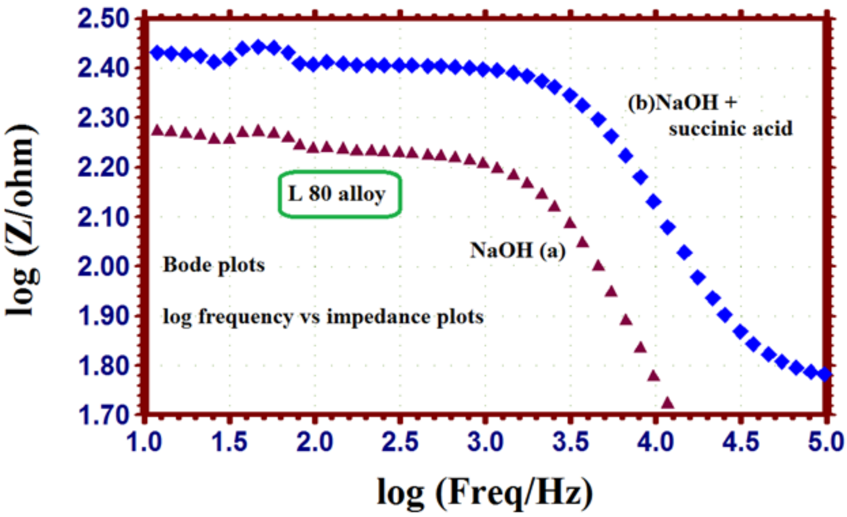

Figure 5. Bode plots (log frequency vs impedance plots) of L80 alloy immersed in various test solutions (a) NaOH (b) NaOH + Succinic acid

Slika 5. Bode-ovi dijagrami (log frekvencije u odnosu na impedansu) legure L80 uronjene u različita testna rešenja (a) NaOH (b) NaOH + ćilibarna kiselina

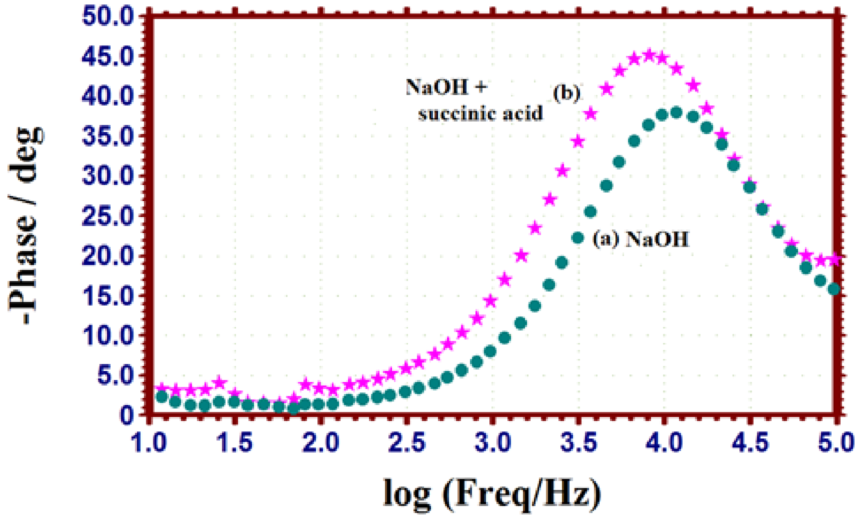

Figure 6. Bode plots (log frequency vs phase angle plots) of L80 alloy immersed in various test solutions. (a) NaOH. (b) NaOH + Succinic acid

Slika 6. Bode-ovi dijagrami (log frekvencije u odnosu na fazni ugao) legure L80 uronjene u različita testna rešenja (a) NaOH. (b) NaOH + ćilibarna kiselina

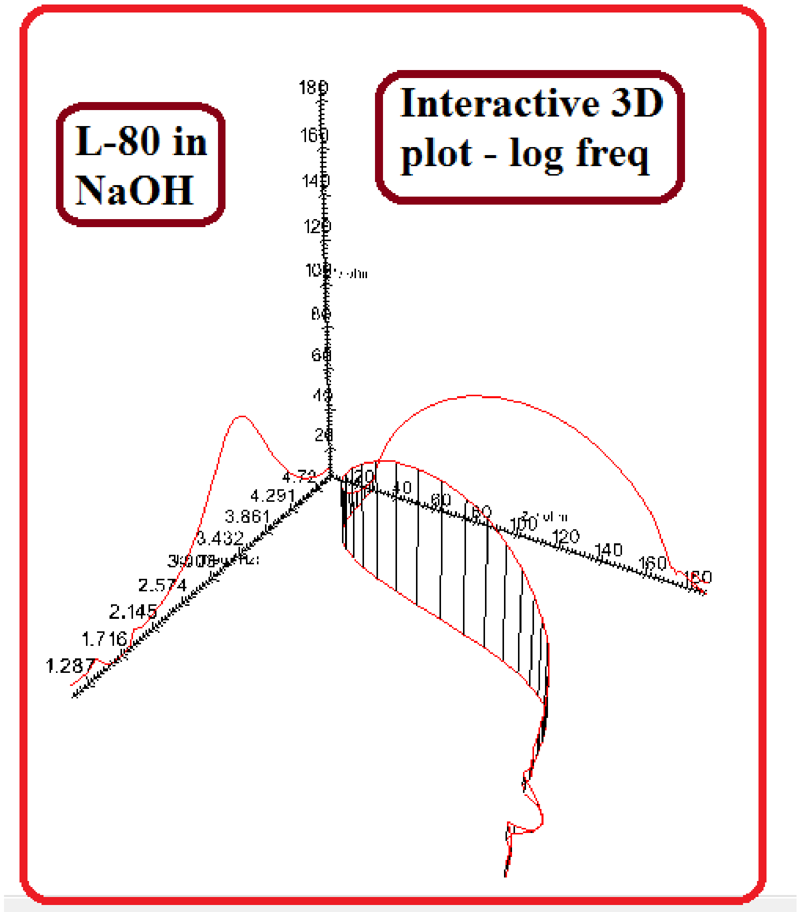

Figure 7. Interactive-3D plot of L80 in NaOH solution

Slika 7. Interaktivni 3D dijagram L80 u rastvoru NaOH

Table 3. Corrosion Parameters of L80 alloy immersed in various test solutions obtained by AC Impedance spectra

Tabela 3. Parametri korozije legure L80 potopljene u različite test rastvore dobijene spektrima AC Impedance

System	R_t Ohmcm^2	C_{dl} F/cm^2	Impedance Log(Z/ohm)	Phase angle°
NaOH	164	3.11×10^{-8}	2.28	38
NaOH + succinic acid (1000 ppm)	276	1.85×10^{-8}	2.49	46

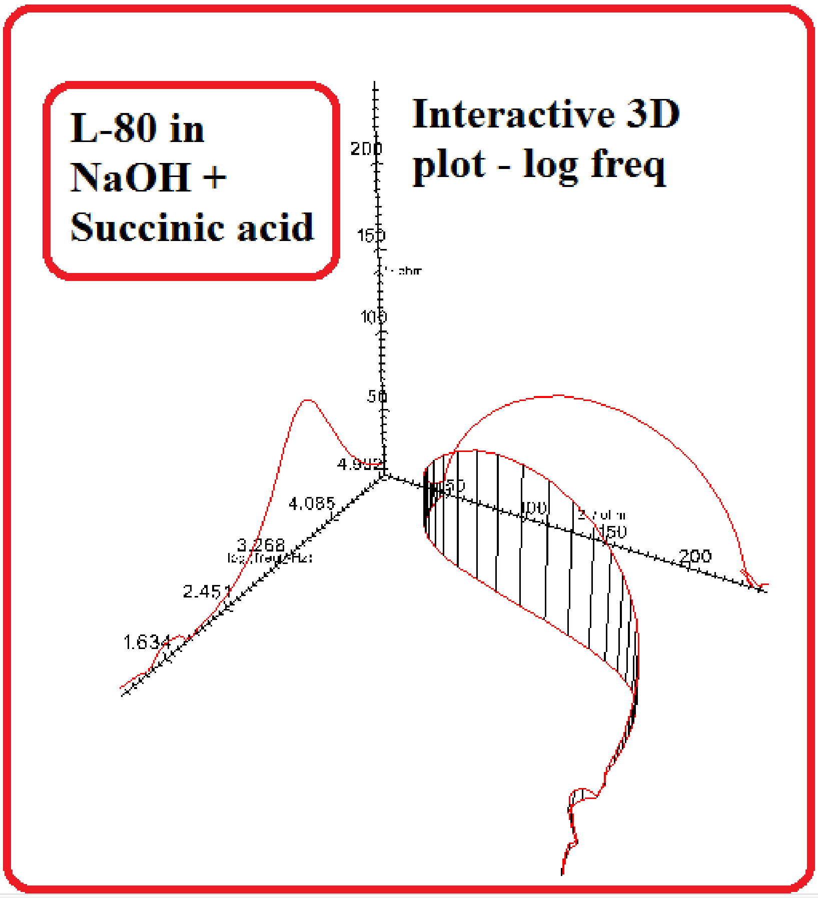

Figure 8. Interactive-3D plot of L80 in NaOH solution + succinic acid

Slika 8. Interaktivni 3D dijagram L80 u rastvoru NaOH + ćilibarna kiselina

4. CONCLUSION

Electrochemical studies such as polarization and AC impedance spectra have been employed to evaluate the corrosion protection nature of succinic acid in controlling corrosion of L 80 alloy in NaOH solution (pH = 12).

- •The study reveals that succinic acid is able to control corrosion of L 80 alloy in NaOH solution (pH = 12).
- •When L80 alloy is immersed in NaOH solution , the linear polarisation resistance (LPR) increases and the corrosion current (I_{corr}) decreases as revealed by potentiodynamic polarization study.
- • Succinic acid at pH=12 functions as anodic type of inhibitor.
- •When L80 alloy is immersed in NaOH solution , the charge transfer resistance (R_t) increases, impedance increases, phase angle increases and double layer capacitance (C_{dl}) value decreases .
- •These results suggest that a protective film is formed on the metal surface and probably the protective film consists of Fe^{2+} inhibitor complex (Iron succinate).

5. REFERENCES

[1] B.Ma, S.Zhang, B.Tan, Y.Wang, X.Sun (2022) Nicotinic acid as a novel inhibitor for alkaline cobalt CMP: Experiment and molecular simulation, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 652,129816.

[2] W.Li, T.Ma, B.Tan, H.Du, X.Wang (2022) The effect of structural properties of benzo derivative on the inhibition performance for copper corrosion in alkaline medium: Experimental and theoretical investigations, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 649, 129531.

[3] Y.Govindaraj, D.Venkatachalam, M.Prabhakar, M.Rohwerder, L. Neelakantan (2022) Nano-sized cerium vanadium oxide as corrosion inhibitor: A microstructural and release study, Electrochimica Acta, 425, 140696.

[4] M.Motamedi, S.Mohammadkhah, M. Ramezanzadeh, H.Eivaz Mohammadloo, B. Ramezanzadeh (2022) Designing Hybrid Mesoporous Pr/Tannate-Inbuilt ZIF8-Decorated MoS2 as Novel Nanoreservoirs toward Smart pH-Triggered Anti-corrosion/Robust Thermomechanical Epoxy Nanocoatings, ACS Applied Materials and Interfaces, 14(27), 31170-31193.

[5] H.M. Abd El-Lateef, A.R. Sayed, K. Shalabi (2022) Studying the effect of two isomer forms thiazole and thiadiazine on the inhibition of acidic chloride-induced steel corrosion: Empirical and Computer simulation explorations, Journal of Molecular Liquids, 356,119044.

[6] E.Ruf, T.Naundorf, T.Seddig, H.Kipphardt, W. Maison (2022) Natural Product-Derived Phosphonic Acids as Corrosion Inhibitors for Iron and Steel, Molecules, 27(6),1778.

[7] K.Krishnaveni, R.Vasanthajothi (2022) Investigation on corrosion inhibition behaviour of aqueous extract of leaves of Morinda Tinctoria on Aluminium in Sodium hydroxide, Chemical Papers, 76(2), 731-740.

[8] A.Chen, F.Liu, J.Ma, Y.Wu, K.Zhang (2022) Study on Anti-corrosion Mechanism of a New Double Mannich Alkaline Corrosion Inhibitor for Acidizing Xi'an ShiyouDaxueXuebao (ZiranKexue Ban)/Journal of Xi'an Shiyou University, Natural Sciences Edition, 37(1), 114-121

[9] E.Berdimurodov, A.Kholikov, K. Akbarov, M.Rbaa, O. Dagdag (2022) Novel cucurbit[6]uril-based [3]rotaxane supramolecular ionic liquid as a green and excellent corrosion inhibitor for the chemical industry, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 633,127837.

[10] N.K.Nambiar, D.Brindha, P.Punniyakotti, B. R.Venkatraman, S.Angaia (2022) Derris Indica Leaves Extract as a Green Inhibitor for the Corrosion of Aluminium in Alkaline Medium, Engineered Science, 17, 167-175.

[11] S.Rajendran, M.Agasta, R.B.Devi, B.S.Devi, K. Rajam, J.Jeyasundari (2009) Corrosion inhibition by an aqueous extract of Henna leaves (LawsoniaInermis L), Zast. Mater., 50(1), 77–84.

[12] V.Sribharathy, S.Rajendran, P.Rengan, R. Nagalakshmi (2013) Corrosion Inhibition By An Aqueous Extract Of Aleovera (L) Burm F. (Liliaceae), Eur. Chem. Bull., 2, 471–476.

[13] [N.Kavitha, P.Manjula (2014) Corrosion Inhibition of Water Hyacinth Leaves, Zn2+ and TSC on Mild Steel in neutral aqueous medium, Int. J. Nano Corros. Sci. Eng., 1, 31–38.

[14] J.A.Thangakani, S.Rajendran, J.Sathiabama, R.M. Joany, R.J.Rathish, S.S.Prabha (2014) Inhibition Of Corrosion Of Carbon Steel In Aqueous Solution Containing Low Chloride Ion By Glycine – Zn^{2+} System, Int. J. Nano Corros. Sci. Eng., 1, 50–62.

[15] S.Gowri, J.Sathiyabama, S.Rajendran, J.A. Thangakani (2012) Tryptophan as corrosion inhibitor for carbon steel in sea water, J. Chem., Biol. Phys. Sci., 2, 2223-2231.

[16] A.C.C.Mary, S.Rajendran, H.Al-Hashem, R.J.Rathish, T.Umasankareswari, J.Jeyasundari (2015) Corrosion Resistance of Mild Steel in Simulated Produced Water in Presence of Sodium Potassium Tartrate, Int. J. Nano Corr. Sci. Eng., 1, 42-50.

[17] T.A.Onat, D.Yiğit, H.Nazır, M.Güllü, G.Dönmez (2016) Biocorrosion inhibition effect of 2-aminopyrimidine derivatives on SRB, Int. J. Corros. Scale Inhib., 5(3), 273–281. doi: 10.17675/2305-6894-2016-5-3-7.

[18] V.I.Vigdorovich, L.E.Tsygankova, E.D.Tanygina, A.Yu.Tanygin, N.V.Shel (2016) Preservative materials based on vegetable oils for steel protection against atmospheric corrosion. I. Colza oil, Int. J. Corros. Scale Inhib., 5(1), 59–65. doi: 10.17675/2305-6894-2016-5-1-5.

[19] P.N.Devi, J.Sathiyabama, S.Rajendran (2017) Study of surface morphology and inhibition efficiency of mild steel in simulated concrete pore solution by lactic acid–Zn^{2+} system, Int. J. Corros. Scale Inhib., 6(1), 18–31. doi: 10.17675/2305-6894-2017-6-1-2.

[20] L.G.Knyazeva, L.E.Tsygankova, A.V.Dorokhov, N.A.Kur'yato (2021) Protective efficiency of oil compositions with Cortec VpCI-368D, Int. J. Corros. Scale Inhib., 10(2), 551-561. doi: 10.17675/2305-6894-2021-10-2-4.

[21] M.Cenoui, I.Himer, R.Touir, M.EbnTouhami, A. Dermaj, N.Hajjaji, H. El Kafssaoui (2010) Influence of molybdate ions on the inhibition of corrosion and scale of ordinary steel in cooling water system by new organic compound, Zast.Materijala, 51(1),3-10.

[22] N.Antony, H.B.Sherine, S.Rajendran (2010) Investigation of the inhibiting effect of nano film by sodium meta silicate- Zn^{2+} system on the corrosion of carbon steel in neutral chloride solution, Zast. Materijala,51(1), 11-18.

[23] S.S.Rajendran, T.S.Muthumegala, M. Pandiarajan, P.Nithya Devi, A.Krishnaveni, J.Jeyasundari, B.Narayana Samy, N.Hajara Beevi (2011)

Corrosion resistance of SS316 L in simulated concrete pore solution in presence of trisodium citrate, Zast. Materijala, 52(1), 85-89.

[24] A.S.Fouda, G.Y.Elewady, A.EL-Askalany, K.Shalabi (2010) Inhibition of aluminum corrosion in hydrochloric acid media by three Schiff base compounds, Zast. Materijala, 51(2), 205-219.

[25] S.Rajendran, V.Sribharathy, A.Krishnaveni, J.Jeyasundari, J. Sathiyabama, T.S.Muthumegala, M. Manivannan (2011) Inhibition effect of self assembled films formed by adipic acid molecules on carbon steel surface, Zast. Materijala, 52, 163-172.

[26] P.Satyabama, N.Narendran, K.Bavithra Devi, Th.R.U.Sankareswari , A.Nilavan , S. Rajendran, C.Lacnjevac (2022) Electrochemical studies on the corrosion behaviour of Aluminium in an alkaline medium, Zast. Materijala, 63 (3), 230 - 237.

[27] Th.Umamathi, R.Parimalam, V.Prathipa, A.J. Vanitha, K.Muneeswari, B. Mahalakshmi, S. Rajendran, A. Nilavan (2022) Influence of urea and glucose on corrosion resistance of Gold 21K alloy in the presence of artificial sweat, Zast. Materijala, 63 (3), 341 - 352.

[28] K.Kavipriya, M. L.Lavanya, K. Bhuvaneswari, V.Velkannan, N. Anitha, S.Rajendran, C.Lacnjevac (2022) Influence of a paint coating on the corrosion of hull plates, made of mild steel in natural seawater, Zast. Materijala, 63(3), 353 - 362.

IZVOD

INHIBICIJA KOROZIJE LEGURE L 80 U RASTVORU NATRIJUM HIDROKSIDA (pH=12) ĆILIBARNOM KISELINOM

Inhibicija korozije legure L80 u rastvoru natrijum hidroksida (pH=12) ćilibarnom kiselinom je procenjena elektrohemijskim studijama kao što su spektri polarizacije i AC impedanse. Studija otkriva da je ćilibarna kiselina u stanju da kontroliše koroziju legure L80 u rastvoru NaOH (pH = 12). Kada se legura L80 potopi u rastvor NaOH, otpor linearne polarizacije (LPR) se povećava, a struja korozije (Icorr) opada, što je otkriveno istraživanjem potenciodinamičke polarizacije. Ćilibarna kiselina pri pH=12 funkcioniše kao anodni tip inhibitora. Kada se legura L 80 potopi u rastvor NaOH, otpor prenosa naelektrisanja (Rt) se povećava, impedansa raste, fazni ugao se povećava i vrednos11t kapacitivnosti dvoslojnog sloja (Cdl) opada. Ovi rezultati sugerišu da se na površini metala formira zaštitni film i verovatno se zaštitni film sastoji od Fe 2+ -inhibitornog kompleksa.

Ključne reči: *inhibicija korozije, legura L80, rastvor natrijum hidroksida, elektrohemijska ispitivanja, ćilibarna kiselina.*

Naučni rad
Rad primljen: 23. 08. 2022.
Rad prihvaćen: 11. 09. 2022.
Rad je dostupan na sajtu: www.idk.org.rs/casopis