

UNIVERSITY OF BELGRADE  
TECHNICAL FACULTY BOR

**52<sup>nd</sup> International October Conference on  
Mining and Metallurgy**



**PROCEEDINGS**

Edited by

**Saša Stojadinović**

and

**Dejan Petrović**

**November 29<sup>th</sup> – 30<sup>th</sup> 2021**

**Bor, Serbia**

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## L-LYSINE AS CORROSION INHIBITOR OF STAINLESS STEEL IN RINGER'S SOLUTION

Milan Radovanović<sup>1</sup>, Ana Simonović<sup>1</sup>, Marija Petrović Mihajlović<sup>1</sup>, Žaklina Tasić<sup>1</sup>, Vladan Nedelkovski<sup>1</sup>, Milan Antonijević<sup>1</sup>

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### Abstract

*The effects of L-Lysine on stainless steel 316L corrosion in Ringer's solution were investigated. The investigation comprised different electrochemical techniques: measurement of open circuit potential and linear potentiodynamic polarization. The results obtained by polarization measurements show that the L-Lysine successfully inhibits the corrosion processes on stainless steel, in Ringer's solution, acting like mixed type inhibitor with a more pronounced influence on cathodic processes. Also, potentiodynamic curves indicate that L-Lysine acts through adsorption onto the steel surface without changing the mechanism of corrosion of steel. Quantum chemical parameters indicate that L-Lysine may be used as a corrosion inhibitor which was confirmed by electrochemical measurements.*

**Keywords:** stainless steel; amino acids; corrosion; Ringer's solution; inhibition.

### 1. INTRODUCTION

Steel is an alloy composed of iron and carbon, which in fact represents primary alloy widely used as a material in structural/civil engineering, because of its properties and cost efficiency. Stainless steel 316L is one of the most used material, especially in medicine, due to high corrosion resistance which is higher than at other steel due to the presence of certain alloying constituents [1]. The most often use of 316L in medicine was for surgical and orthopedic implants. Steel corrodes during utilization as medical implants in human body due to exposure to aggressive ions such as chlorides present in blood plasma. High concentration of chloride ions will cause localized corrosion, while the low concentrations will cause uniform corrosion. Because of their high diffusivity, chloride ions are capable to penetrate through passive layer and cause pitting corrosion on stainless steels. If the concentration of chloride ions in the solution is high enough, accelerated corrosion with the occurrence of deeper and wider pits is to be expected [2]. The most used organic inhibitors are toxic which leads to aspiration to develop so called green inhibitors which are harmless to the environment [3].

Extracts and plant oils are recent years intensively studied as green inhibitors of metal corrosion in different solutions. Obtained results available in the literature show that plant extracts achieved inhibition efficiency which provides promise application of plant extract as potential good corrosion inhibitors [4]. Besides that, amino acids are another very promising group of compounds which already proved as green corrosion inhibitors for different metals and alloys in aggressive environment. Also, amino acids have numerous benefits: low cost of production, high purity, high degree of inhibition efficiency [5].

### 2. EXPERIMENTAL

The experiments were performed in the Ringer's solution without and with addition of different amount of L-Lysine (Lys). Concentration of L-Lysine used during experiments was from  $1 \cdot 10^{-4}$  M up to  $1 \cdot 10^{-2}$  M. The composition of Ringer's solution was shown in Table 1.

Table 1 – Composition of Ringer's solution

Component	Concentration, g/dm <sup>3</sup>
NaCl	8.60
KCl	0.3
CaCl <sub>2</sub>	0.33

Forelectrochemicaltesting of the corrosion behaviorof stainless steel 316Lpotentiostat(IVIUM XRE, IVIUMTechnologies) was used, with the appropriatesoftware. The systemis made up ofthreeelectrodes, stainless steel electrodes working, platinum as theauxiliaryelectrode andstandardcalomel electrode (SCE) as the referenceelectrode. Applied methods were measuring of the open circuit potential for 30 min andpotentiodynamic polarization. The linear potentiodynamic measurements were performed from OCP to -0.5 V vs. SCE in cathodic and to +0.4 V vs. SCE in anodic direction. Applied scan rate was 1 mV/s. All measurements were conducted at room temperature in naturally aerated solutions.

### 3. RESULTS AND DISCUSSION

Variations of OCP over time for stainless steel electrode in Ringer's solution, without and with the addition of different concentrations of L-Lysine are present in Figure 1a.

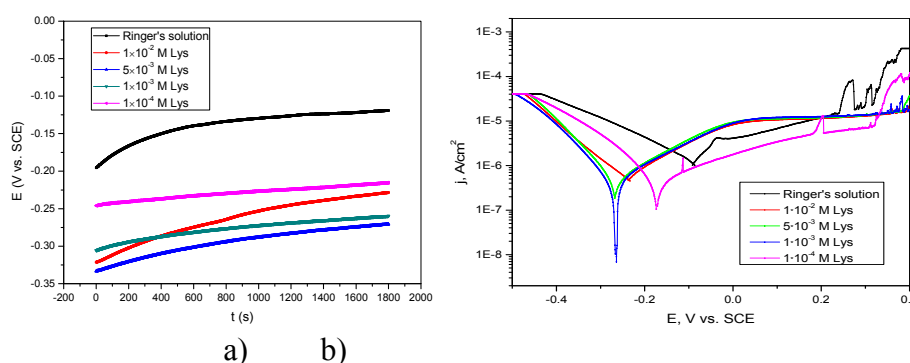


Figure 1 - Open circuit potential (a) and potentiodynamic polarization curves (b) recorded for stainless steel in Ringer's solution without and with the addition of different amount of L-Lysine

In bare Ringer's solution increase of OCP values is related with formation of protective oxide layer on steel surface. In solutions with addition of L-Lysine in whole investigated concentration range OCP values are increased from beginning indicating formation of protective layer in which structure inhibitor molecules are incorporated [6]. Acquired curves presented in Figure 1a reveal that in the presence of L-Lysine OCP values become more negative in comparison with OCP obtained in bare Ringer's solution suggesting that inhibitor molecules are more favourable adsorbed on cathodic active sites [7]. Nevertheless, shift of OCP values is not significant in the presence of inhibitor which indicates that L-Lysine is more likely to act as a mixed-type inhibitor [8].

According to the obtained polarization curves presented in Figure 1b current density decrease in the presence of L-Lysine. A decrease in current density is the most pronounced in the vicinity of corrosion potential and reveal inhibitive action of L-Lysine. Also, L-Lysine shows a stronger influence on decrease of the cathodic current density. The highest tested concentration of L-Lysine decreases anodic current density not only in the vicinity of corrosion potential. Anodic peak obtained in bare Ringer's solution is omitted on polarization curves obtained in Ringer's solution with the addition of L-Lysine due to the formation of protective film on the stainless steel surface [9]. According to the polarization curves (Figure 1b) at higher potentials pitting corrosion occurs. Moreover, electrochemical kinetic parameters were obtained from polarization

curves (Figure 1b) and calculated values were presented in Table 2. Furthermore, inhibition efficiency (IE) of L-Lysine is presented also in Table 2 beside to the kinetic parameters. Inhibition efficiency was calculated according to the equation:

$$IE(\%) = [(j_{\text{corr}} - j_{\text{corr(inh)}}) / j_{\text{corr}}] \times 100$$

where  $j_{\text{corr}}$  and  $j_{\text{corr(inh)}}$  stand for corrosion current density recorded without and with inhibitor, respectively.

Table 2 – Electrochemical parameters of stainless steel 316L obtained using data presented in Figures 1b

Solution	$E_{\text{corr}}$ (V vs. SCE)	$j_{\text{corr}}$ (A/cm <sup>2</sup> )	$b_c$ (mV/dec)	$b_a$ (mV/dec)	IE (%)
Ringer's solution	-0.092	$1.238 \cdot 10^{-6}$	-0.0189	0.0271	/
$1 \cdot 10^{-4}$ M Lys	-0.172	$3.284 \cdot 10^{-7}$	-0.123	0.085	73.5
$1 \cdot 10^{-3}$ M Lys	-0.265	$2.125 \cdot 10^{-7}$	-0.129	0.12	82.8
$5 \cdot 10^{-3}$ M Lys	-0.267	$1.882 \cdot 10^{-7}$	-0.144	0.095	76.7
$1 \cdot 10^{-2}$ M Lys	-0.236	$5.075 \cdot 10^{-7}$	-0.091	0.092	59.0

Considering the results shown in Table 2, it can be concluded that with an increase of L-Lysine concentrations, negative shift of corrosion potential ( $E_{\text{corr}}$ ) values occurs. Decrease of current densities ( $j_{\text{corr}}$ ) in solutions with addition of L-Lysine indicates inhibitory effect of this compound. It is also noticed that with the increase of L-Lysine concentration, inhibition efficiency drops, due to saturation of active sites on the stainless steel surface. A higher concentration of inhibitor means that in solution exist too many molecules of L-Lysine which are in confrontation for available active sites which leads to the decrease in adsorption of inhibitor molecules and to the decrease in inhibition efficiency. According to the values of Tafel slopes, molecules of inhibitor block active sites on the electrode surface due to adsorption without changing the reaction mechanism.

Quantum chemical calculations and molecule geometry optimization were performed using ArgusLab 4.0 [10] PM3-SCF method. The calculated parameters are summarized in Table 3 and they are the values of highest occupied molecular orbital energy ( $E_{\text{HOMO}}$ ), lowest unoccupied molecular orbital energy ( $E_{\text{LUMO}}$ ), energy gap ( $\Delta E = E_{\text{LUMO}} - E_{\text{HOMO}}$ ), dipole moment of inhibitor ( $\mu$ ), ionization potential (I), electron affinity (A), electronegativity ( $\chi$ ), global hardness ( $\eta$ ), maximum number of electrons transferred ( $\Delta N_{\text{max}}$ ) and number of transferred electrons ( $\Delta N$ ). The proposed spatial distribution of HOMO and LUMO is presented in Figure 2.

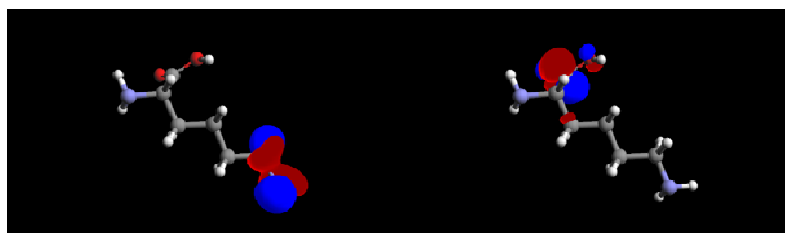


Figure 2 - Distribution of HOMO (left) and LUMO (right) of L-Lysine

Table 2 - Quantum chemical parameters

Parameter	$E_{\text{HOMO}}$ , eV	$E_{\text{LUMO}}$ , eV	$\Delta E$ , eV	$\mu$ , D	$\Delta N$
value	-9.582	0.820	10.402	2.42109886	0.252
Parameter	I, eV	A, eV	$\chi$ , eV	$\eta$ , eV	
value	9.582500204	-0.820332952	4.381083626	5.201416578	

Orbital energy values are indicators of the tendency of L-Lysine molecule to donate (high  $E_{\text{HOMO}}$ ) or accept (low  $E_{\text{LUMO}}$ ) electrons and hence to be adsorbed on the metal surface (small  $\Delta E$ ). Small value of  $\eta$  shows that it reacts with surface more readily and corrosion effect decreases, on the other hand great  $\mu$  facilitates interaction with metal surface. Similar observations are already presented in literature [11]. Parameter  $\Delta N$  also known as electron-donating ability, indicates the tendency of a molecule to donate electrons to the metal surface if  $\Delta N > 0$  [12].

#### 4. CONCLUSION

L-Lysine acts like mixed type inhibitor of stainless steel 316L corrosion in Ringer's solution with more pronounced effect on cathodic processes. Potentiodynamic measurements indicate that L-Lysine forms protective film on steel surface which prevent contact between metal and aggressive ions. Corrosion mechanism of stainless steel is unchanged in the presence of L-Lysine. Quantum chemical parameters indicate that L-Lysine may be used as a corrosion inhibitor which was confirmed by electrochemical measurements.

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#### REFERENCES

- [1] S. L. Assis, S. O. Rogero, R. A. Antunes, A. F. Padilha, I. A. Costa, J. Biomed. Mater. Res. B, 73 B (1) (2005) 109-116.
- [2] M. Talha, Y. Ma, P. Kumar, Y. Lin, A. Singh, Colloid. Surface. B, 176 (2018) 494-506.
- [3] B. El Ibrahimy, A. Jmaiai, L. Bazzi, S. El Isami, Arab. J. Chem., 13 (2020) 740-771.
- [4] C. Verma, E. E. Ebenso, I. Bahadur, M. A. Quraishi, J. Mol. Liq., 266 (2018) 577-590.
- [5] R. T. Loto, J. Mater. Res. Technol., 8 (2019) 484-493.
- [6] O. Kaczerewska, R. Leiva-Garcia, R. Akid, B. Brycki, I. Kowalczyk, T. Pospieszny, J. Mol. Liq., 249 (2018) 1113-1124.
- [7] M. B. Radovanović, Ž. T. Tasić, A. T. Simonović, M. B. PetrovićMihajlović, M. M. Antonijević, ACS Omega, 5 (2020) 12768-12776.
- [8] M. B. Radovanović, Ž. T. Tasić, M. B. PetrovićMihajlović, A. T. Simonović, M. M. Antonijević, Sci. Rep., 9 (2019) 16081.
- [9] S. Bashir, V. Sharma, H. Lgaz, I. Chung, A. Singh, A. Kumar, J. Mol. Liq., 263 (2018) 454-462.
- [10] M.A. Thompson, Planaria Software LLC, Seattle, WA. <http://www.arguslab.com>.
- [11] M. B. PetrovićMihajlović, M. B. Radovanović, Ž. Z. Tasić, M. M. Antonijević, J. Mol. Liq., 225 (2017) 127-136.
- [12] B. El Ibrahimy, A. Soumoue, A. Jmaiai, H. Bourzi, R. Oukhrib, K. El Mouaden, S. El Issami, L. Bazzi, J. Mol. Struct., 1125 (2016) 93-102.

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