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Investigating the Oxidative Degradation of Amoxicillin on Pt-RuO_2 Electrodes: Insights into Surface Stability and Halide Effects

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Abstract: This study investigated the electrochemical oxidation of amoxicillin using a platinum-ruthenium oxide (Pt-RuO_2) electrode in various supporting electrolytes: $KClO_4$, $HClO_4$, H_2SO_4, and NaOH. The Pt-RuO_2 electrode exhibited a robust electrochemical response across all tested media, with higher catalytic activity observed in acidic environments. A surface inhibition effect was observed with increasing amoxicillin concentration, limiting the availability of active sites on the electrode. Additionally, the pH of the medium impacted the reduction peaks, with a consistent decline in intensity correlating with increased acidity. Chloride ions (Cl^-) further improved the oxidation peak, indicating a catalytic role in the oxidation process. These findings provide insights into optimizing the electrochemical degradation of amoxicillin and highlight the importance of medium composition in influencing electrode performance. Chronoamperometry confirmed the formation of an inhibitory surface layer. These results underscore the role of medium composition in optimizing electrochemical degradation efficiency.

Keywords: Electrochemical oxidation, pharmaceuticals, DSA, surface inhibition, chloride ions.

1. Introduction

The discovery and widespread use of antibiotics, including amoxicillin (AMX), have greatly improved public health by effectively treating common bacterial infections such as skin, respiratory, and urinary tract infections [1,2]. However, a significant portion of administered AMX is excreted in an unmetabolized form, which leads to environmental contamination of water resources [3,4]. This contamination poses substantial toxicological risks to aquatic ecosystems and, through bioaccumulation, to humans [5].

The persistence of AMX in the environment also promotes the spread of antibiotic-resistant bacteria, a serious concern for public health, as these resistances can transfer from animals to humans [5,6]. Recognizing these risks, the European Union has added AMX to its watch list of emerging contaminants due to its ecological impact potential [7].

To monitor AMX presence, various analytical methods, such as high-performance liquid chromatography and electrochemical techniques, have been developed to detect this molecule at trace levels in water samples [8,9]. Electrochemical methods, in particular, provide cost, speed, and sensitivity advantages for in situ analysis [10]. Recent advancements in electrode modification, using nanocarbon materials like graphene, graphite, and carbon nanotubes, have enhanced the electrochemical signals for AMX, offering a promising solution for accurate analysis [11,12]. Combining these nanomaterials with metallic nanoparticles (such as gold and palladium) further improves electrode sensitivity and stability, enabling reliable detection even in complex matrices like milk and urine [9,13,14].

Despite these advancements, conventional wastewater treatment methods remain ineffective at entirely removing AMX [15]. This highlights the need for novel treatment approaches, such as advanced oxidation processes and adsorption, and the development of electrochemical solutions using nanomaterials to mitigate the impact of AMX on the environment and human health [16].

In addition to electrode modifications [17], halide ions, particularly chloride ions (Cl^-), have gained attention in electrochemical oxidation processes [18]. Halide ions can enhance the electrochemical oxidation of organic pollutants by forming reactive intermediates, such as active chlorine or hypochlorite ions, which can effectively degrade pharmaceutical compounds like AMX [19,20]. Chloride ions are beneficial due to their widespread availability, low cost, and ability to form

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strong oxidants that accelerate the degradation of antibiotics, making them a valuable tool in environmental remediation efforts [21]. However, controlling the concentration of chloride ions is critical, as excessive levels may lead to undesirable byproduct formation and electrode corrosion [22].

Given these considerations, this study aims to investigate the electrochemical oxidation of AMX on a Pt-RuO_2 electrode across different supporting media, chloride ion concentrations, and pH levels. These investigations will provide insight into optimizing electrochemical conditions for AMX degradation and highlight the potential of halide ions as catalytic agents in the electrochemical treatment of pharmaceutical contaminants.

2. Materials and methods

2.1. Reagents and chemicals

Amoxicillin tablets made by Bailly-Creat were obtained from a pharmacy in Abidjan using its commercial formula. The tablets were crushed before use. H_2SO_4, $HClO_4$, $KClO_4$, and NaCl were purchased from Fluka. Chemicals were used as received from suppliers. Experiments were performed at a laboratory temperature of 25°C, and distilled water was used for all solution preparation. pH was adjusted by H_2SO_4 (1M) and NaOH (1M).

2.2. Electrochemical measurements

The electrochemical oxidation of AMX was performed in a three-electrode cell (100 mL) with the Platinum (Pt) combined to ruthenium dioxide (RuO_2) as a working electrode (WE), a saturated calomel electrode (SCE) as a reference electrode (RE) and Platinum wire as a counter electrode (CE). Cyclic voltammetry measurements and chronoamperometry were performed using a Voltalab PGP 201 potentiostat, which was connected by the interface to a computer to collect the data. The measuring program is Voltmaster 1. Before each experiment, we electrochemically cleaned the electrode by cyclic voltammetry in 1 M sulfuric acid solution until a reproducible voltammogram was obtained. To minimize the ohmic drop, the reference electrode was mounted in a luggin capillary and placed close to the working electrode.

3. Results and Discussion

3.1. Pt-RuO_2 electrode and electrochemical response

A platinum electrode modified with ruthenium oxide (Pt-RuO_2) was developed and tested for the electrochemical oxidation of amoxicillin in different supporting electrolytes, specifically $KClO_4$, $HClO_4$, H_2SO_4, and NaOH (Figure 1).

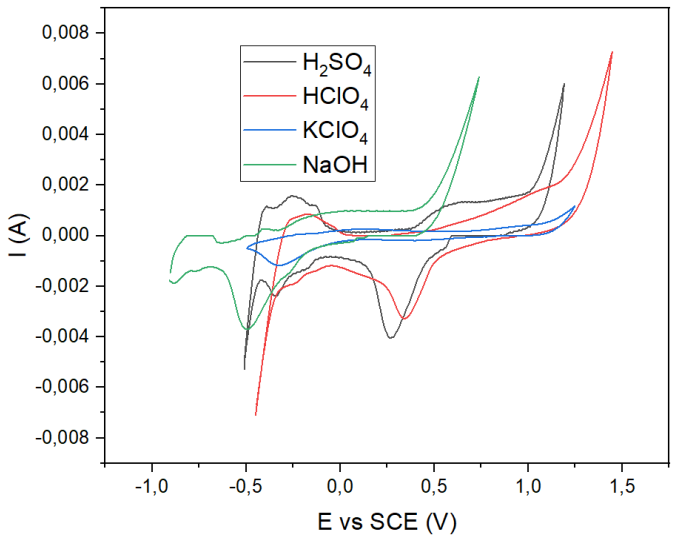

Figure 1. Electrochemical response of Pt-RuO_2 electrode in various electrolyte supporting (H_2SO_4, $HClO_4$, $KClO_4$, NaOH), in the absence of organic compounds. Scan rate v=480 mV/mn; CE: Platinum wire; ER: ECS; T=25°C.

The results reveal that the Pt-RuO_2 electrode exhibits a good electrochemical response in each supporting electrolyte, though with notable variations. In the neutral $KClO_4$ medium, the electrode demonstrates adequate stability and sensitivity, allowing for reproducible measurements. However, no clear hydrogen or oxide formation regions were observed. This behavior may be attributed to the influence of the RuO_2 component, which probably dominates the surface response under these conditions. In highly acidic media such as $HClO_4$ medium, distinct anodic and cathodic features are observed, with a broader potential window and the onset of oxygen evolution occurring at higher potentials. This suggests a higher electrochemical activity and stability of the electrode in this medium [23]. In H_2SO_4, the cyclic voltammogram shows well-defined hydrogen adsorption/desorption peaks and platinum oxide formation, although

interactions with sulfate ions may slightly influence the current response. The overall current response in the basic NaOH medium is less structured, and the oxygen evolution reaction occurs at lower potentials. These results indicate good catalytic activity of the Pt-RuO_2 electrode, with optimized performance in acidic media, particularly in $HClO_4$, opening prospects for tailored electrochemical oxidation applications based on specific degradation needs.

3.2. Electrode Reproducibility and Stability in the Presence of Amoxicillin

To evaluate the reproducibility and stability of the Pt-RuO_2 electrode's electrochemical response, cyclic voltammetry (CV) experiments were conducted by varying the scan rate in the presence of amoxicillin (AMX) (Figure 2.A). As expected, an increase in the scan rate led to a rise in the oxidation peak currents, consistent with theoretical predictions for electrochemical systems dominated by surface processes [24]. This behavior is commonly associated with the capacitive or adsorption-controlled nature of the electrode surface, wherein higher scan rates facilitate rapid charge transfer, thus enhancing the peak currents [25].

To isolate the effect of the scan rate on the electrode's we normalized the peak current values by removing the scan rate contribution (Figure 2.B). Upon normalization, the oxidation peaks aligned closely, indicating consistent electrode response and validating the stability and reproducibility of the Pt-RuO_2 surface across a range of experimental conditions. This reproducibility is crucial for electrochemical detection applications, as it suggests that the Pt-RuO_2 electrode maintains its active surface properties and provides reliable data across multiple scans and varying operational conditions [26].

Such findings support the robustness of Pt-RuO_2 in electrochemical applications, particularly for the detection and degradation of pharmaceutical contaminants, where stable and reproducible performance is essential. The electrode's reliable response at different scan rates suggests minimal surface fouling or degradation, which is often a concern in the electrochemical oxidation of organic compounds like AMX. This characteristic may be attributed to the synergy between Pt and RuO_2, where Pt provides excellent conductivity while RuO_2 contributes chemical stability, minimizing electrode surface passivation [19,21]

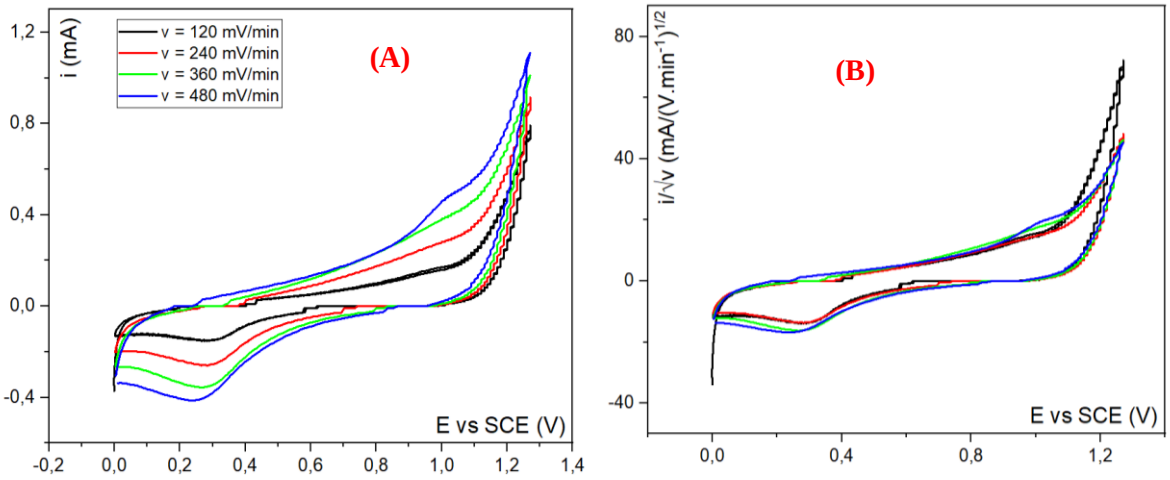

Figure 2. (A) Cyclic voltammetry curves recorded at Pt-RuO_2 electrode in 0.1 M $KClO_4$ electrolyte containing 1 g/L amoxicillin at several potential scan rates (120-480 mV/mn), CE: Platinum wire; ER: ECS; T=25°C; (B) Cyclic voltammograms obtained after peak normalization.

3.3. Influence of Amoxicillin Concentration

The electrochemical behaviour of the Pt-RuO_2 electrode was further investigated by gradually increasing the concentration of amoxicillin in various supporting electrolytes (Figure 3). In all cases, the oxidation peak current of amoxicillin initially increased with concentration, suggesting enhanced interaction between the amoxicillin molecules and the active sites on the Pt-RuO_2 surface. However, a marked decrease in the oxidation peak current was observed after reaching a specific threshold concentration, despite continued increases in amoxicillin concentration. This behavior indicates a potential surface inhibition phenomenon, where high concentrations of amoxicillin likely lead to a saturation of active sites on the electrode surface, restricting further oxidation. Such inhibition can occur due to the adsorption of amoxicillin molecules or their intermediates on the electrode, blocking the accessibility of active sites, a phenomenon supported by studies on other pharmaceuticals in electrochemical systems [27].

Further supporting this hypothesis, a progressive decrease in the reduction peak current was observed, ultimately leading to the disappearance of the reduction peak. This effect could be attributed to forming an adsorbed layer or film of reaction intermediates on the Pt-RuO_2 surface, a behavior

commonly observed in the electro-oxidation of organic molecules, where surface fouling limits electron transfer [24,28]. The progressive disappearance of the reduction peak implies that the electrode surface may become increasingly passivated, corroborating the hypothesis of surface inhibition that limits the catalytic activity of Pt-RuO_2 in high-concentration environments.

This pattern aligns with findings from similar studies where electrochemical inhibition was observed at high substrate concentrations, impacting the efficacy of electrodes modified with metal oxides or other catalysts [29]. Such studies emphasize the importance of optimizing concentration ranges to balance high catalytic activity with preventing surface inhibition.

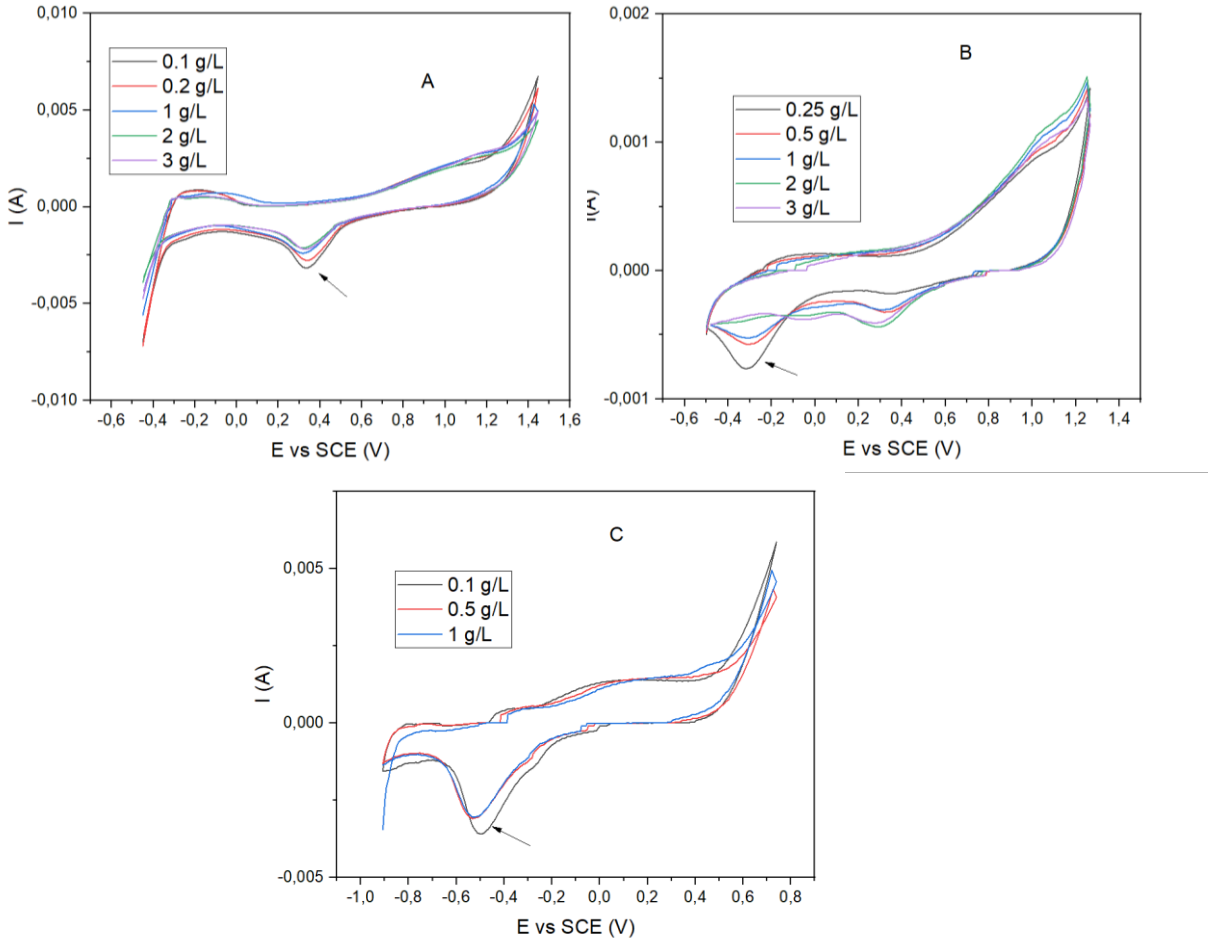

Figure 3. Cyclic voltammetry curves of various concentration of AMX at Pt-RuO_2 electrode for various concentrations recorded in 0.1 M of electrolyte supporting ($HClO_4$ (A), $KClO_4$ (B) and NaOH (C)) under the potential scan rate: 480 mV/mn, CE: Platinum wire, RE: SCE, T= 25°C.

3.4. Influence of pH on the Electrochemical Oxidation of Amoxicillin

The effect of the support medium's pH was investigated by varying this parameter in the electrochemical oxidation
tests of amoxicillin on the Pt-RuO_2 electrode. Regardless of the pH values applied (2.4, 5.2, 6.9, 9.3, and 11.7) (Figure 4), a similar trend was observed in the reduction currents, with a gradual decrease in the intensity of reduction peaks until they disappeared completely. This observation suggests an inhibition of the Pt-RuO_2 electrode surface, likely caused by the adsorption of reaction intermediates or amoxicillin molecules that block active sites required for electron transfer. This inhibition phenomenon, well-documented in the literature on electrochemical systems containing organic compounds [27], can be intensified by pH variations that alter the electrode surface state, the adsorption properties of amoxicillin, and its degradation byproducts [24]. Notably, the reduction peaks completely disappeared at pH 11.7, indicating possible fouling or increased passivation of the electrode surface. This supports the hypothesis that extreme or high pH conditions favor the formation of persistent adsorption layers, thereby limiting the electrocatalytic activity of Pt-RuO_2. These results confirm that the electrode's performance in amoxicillin degradation depends not only on concentration but also on the pH of the medium, underscoring the need to select optimal conditions to avoid surface inhibition.

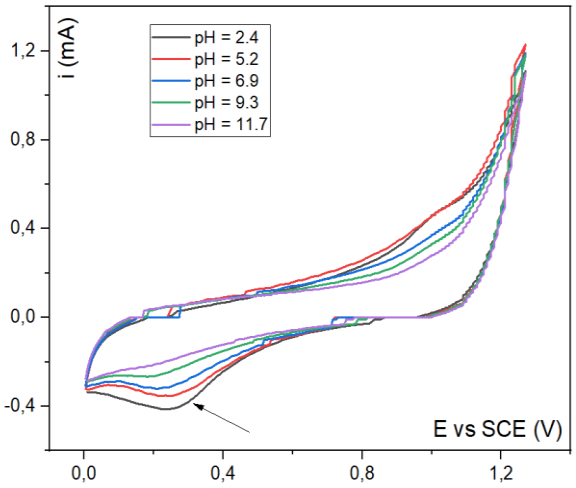

Figure 4. Cyclic voltammetry curves of AMX (1 g/L) at Pt-RuO_2 electrode for various pH (2.4-11.7) recorded in 0.1 M of electrolyte supporting ($KClO_4$) under the potential scan rate: 480 mV/mn, CE: Pt wire, RE: SCE, T= 25°C.

3.5. Effect of Chloride Ions (Cl^-) on the Oxidation of Amoxicillin

Electrochemical tests conducted at a fixed concentration of amoxicillin revealed a significant increase in the oxidation peak when the chloride ion (Cl^-) concentration was gradually increased from 100 to 5800 mg/L in $KClO_4$. This behavior could be attributed to the catalytic Effect of Cl^- ions on the Pt-RuO_4 electrode surface, a phenomenon observed in several studies on the electrochemical oxidation of organic compounds in the presence of halides. Chloride ions can promote the generation of reactive species at the electrode surface, such as active chlorine or chlorinated radicals, capable of oxidizing amoxicillin or accelerating its decomposition. This increase in the oxidation peak may also result from a synergistic effect between Cl^- ions and the electrode's active sites, facilitating electron transfer. Additionally, increased Cl^- concentration could alter the electrochemical double layer, affecting interactions between amoxicillin molecules and the electrode [23]. These findings suggest that adding Cl^- at optimal concentrations could enhance the efficiency of amoxicillin's electrochemical oxidation; however, excessively high concentrations risk promoting electrode corrosion or producing undesirable byproducts [31]

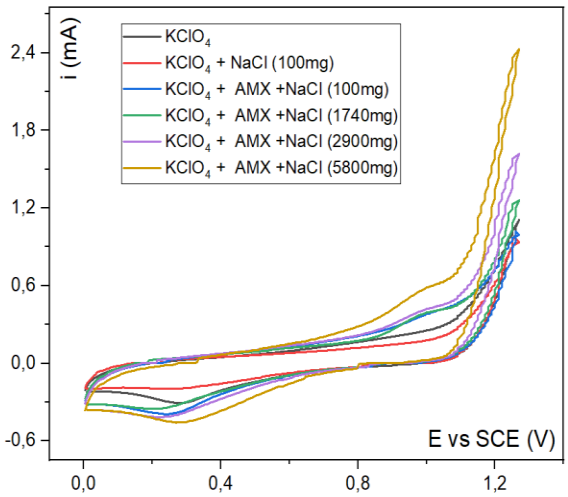

Figure 5. Cyclic voltammetry curves of AMX (1 g/L) at Pt-RuO_2 electrode for various concentrations of NaCl recorded in 0.1 M of electrolyte supporting ($KClO_4$) under the potential scan rate: 480 mV/mn, CE: Pt wire, RE: SCE, T= 25°C.

3.6. Inhibitory Layer Formation in Chronoamperometry

The results of the chronoamperometry experiment conducted at a potential of 1000 V vs SCE show an initial rise in current during the first 30 seconds, followed by a gradual decrease. This behavior suggests the formation of an inhibitory layer on the electrode surface, which reduces charge transfer and

limits the flow of electroactive species to the surface. Such phenomena are often observed in systems where a passivating layer, typically oxidized or adsorbed products, develops on the electrode surface [32].

In these systems, the current decrease over time can be attributed to the adsorption of species generated by the oxidation of analytes or electrolyte components, forming a barrier on the electrode surface that restricts access of electroactive species to the reaction site. This behaviour is well-documented in anodic oxidation studies of various organic compounds and contaminants, where the formation of secondary products or oxidized byproducts reduces the electrode's electrochemical activity. This progressive passivation could also result from the precipitation of oxides or other surface deposits, as observed in similar electrochemical degradation experiments where high potentials induce the formation of thin layers of metal oxides [31].

These observations support the hypothesis of an inhibitory layer or passivating effect on the electrode during high-potential application. Future studies could investigate the properties of this inhibitory layer through complementary techniques, such as electrochemical impedance spectroscopy or atomic force microscopy, to better understand the mechanisms of passivation and their impact on analyte degradation.

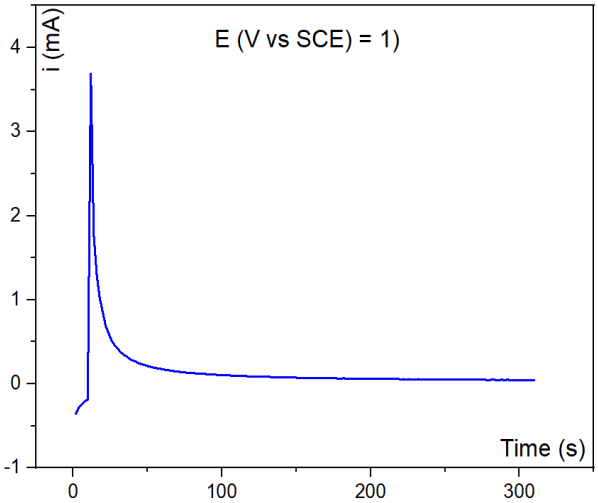

Figure 6. Chronoamperometric was recorded for the oxidation of amoxicillin (1 g/L) on the Pt-RuO_2 electrode in $KClO_4$ (0.1M) for 300 s at 1000 mV. CE: platinum wire; ER: SCE; T = 25°C.

4. Conclusion

In conclusion, the electrochemical oxidation of amoxicillin using the Pt-RuO_2 electrode demonstrated significant potential for effective degradation in various media. Acidic conditions improved catalytic performance, while amoxicillin concentration influenced oxidation efficiency, with surface inhibition observed at higher levels. The enhancing effect of chloride ions highlights the role of supporting electrolytes in optimizing the degradation process. Chronoamperometry experiments exhibited the formation of an inhibitory layer on the electrode surface. Future research should focus on exploring the mechanistic pathways of amoxicillin oxidation and investigating the long-term stability of the Pt-RuO_2 electrode in real-world applications, such as wastewater treatment. Overall, these findings contribute to a better understanding of the electrochemical behavior of pharmaceutical compounds and the potential for using modified electrodes in environmental remediation efforts.

Declaration

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. K. Kulik, A. Lenart-Boron, K. Wyrzkowska, Impact of antibiotic pollution on the bacterial population within surface water with special focus on mountain rivers. Water, 2023, 15(5), 975. https://doi.org/10.3390/w15050975
2. F. Madhi, A. Rybak, R. Basmaci, A.-S. Romain, A. Werner, S. Biscardi, F. Dubos, A. Faye, E. Grimprel, J. Raymond, B. Ros, R. Cohen, Antimicrobial treatment of urinary tract infections in children. Infections D children. Infectious Diseases Now, 2023,53, 04786. https://doi.org/10.1016/j.idnow.2023.104786

3. L. Bergamonti, C. Bergonzi, C. Graiff, P.P. Lottici, R. Bettini, L. Elviri, 3D printed chitosan scaffolds: A new TiO_2 support for the photocatalytic degradation of amoxicillin in water. Water Res., 2019, 163, 114841. https://doi.org/10.1016/j.watres.2019.07.008
4. H. Shi, Q. Wang, J. Ni, Y. Xu, Y., N. Song, M. Gao, Highly efficient removal of amoxicillin from water by three-dimensional electrode system within granular activated carbon as particle carbon as particle electrode. J. Water Process Eng., 2020, 38,101656. https://doi.org/10.1016/j.jwpe.2020.101656
5. P. Domínguez-García, O. Aljabasini, C. Barata, C. Gómez-Canela, Environmental risk assessment of pharma- ceuticals in wastewaters and reclaimed water from catalan main river basins. Sci. Total Environ., 2024, 949, 175020. https://doi.org/10.1016/j.scitotenv.2024.175020
6. W. Li, G. Zhang, Detection and various environmental factors of antibiotic resistance gene horizontal transfer. Environ. Res., 2022, 212, 113267. https://doi.org/10.1016/j.envres.2022.113267
7. E.D. González-González, L.M. Gómez-Oliván, H. Islas-Flores, M. Galar-Martínez, Developmental effects of amoxicillin at environmentally relevant concentration using Zebrafish Embryotoxicity Test (ZET). Water, Air, Soil Pollut., 2021,232,196. https://oi.org/10.1007/s11270-021-05148-6
8. T. Unutkan, S. Bakırdere, S. Keyf, Development of an analytical method for the determination of amoxicillin in commercial drugs and wastewater samples, and assessing its stability in simulated gastric digestion. J. Chromatogr. Sci., 2018, 56(1), 36-40. https://doi.org/10.1093/chromsci/bmx078
9. A. Hrioua, A. Loudiki,A. Farahi, M. Bakasse, S. Lahrich, S. Saqrane, M.A. El Mham-Medi, Recent advances in electrochemical sensors for amoxicillin detection in biological and environmental samples. Bioelectrochemi -stry, 2021, 137,107687. https://doi.org/10.1016/j.bioelechem.2020.107687
10. M.H. Hassan, R. Khan, S. Andreescu, Advances in electrochemical detection methods for measuring contaminants of emerging concerns. Electrochem. Sci. Adv., 2021, 2(6), e2100184. https://doi.org/10.1002/elsa.202100184.
11. Y. Zhu, C. Ye, X. Xiao, Z. Sun, X. Li, L. Fu, H. Karimi-Maleh, J. Chen, C.-T. Lin, Graphene-based electro- chemical sensors for antibiotics: sensing theories, synthetic methods, and on-site monitoring applications. Mater. Horiz., 2024,12, 343-363. https://doi.org/10.1039/D4MH00776J
12. B. Kanwar, M. Koli, S. P. Singh, Antibiotic amoxicillin degradation by electrochemical oxidation process: effects of process parameters and degradation pathway at environmentally relevant concentrations. Environ. Sci. Pollut. Res. 2025, 32, 575–586. https://doi.org/10.1007/s11356-024-35780-8
13. R.C.F.G. Lopes, B.G.M. Rocha, E.M.S. Maçôas, E. F. Marques, J.M.G. Martinho, Combining metal nano-clusters and carbon nanomaterials: Opportunities and challenges in advanced nanohybrid. Adv. Colloid Interface Sci., 2022, 304,102667. https://doi.org/10.1016/j.cis.2022.102667
14. C. Zhou, H. Zou, C. Sun, Y. Li., Recent advances in biosensors for antibiotic detection: Selectivity and signal amplification with nanomaterials. Food Chemistry, 2021, 361, 130109. https://doi.org/10.1016/j.foodchem.2021.130109.
15 R. Anjali, S. Shanthakumar, Insights on the current status of occurrence and removal of antibiotics in waste- water by advanced oxidation processes. J. Environ. Manage., 2019, 246, 51-62. https://doi.org/10.1016/j.jenvman.2019.05.090
16. Q.Yuan, S. Qu, R. Li, Z.-Y. Huo, Y., Gao, Y., Luo, Degradation of antibiotics by electrochemical advanced oxidation processes (EAOPs): Performance, mechanisms, and perspectives. Sci. Total Environ. 2023, 856, 159092. https://doi.org/10.1016/j.scitotenv.2022.159092.
17. H.M. Abd El-Lateef, M. Elrouby, I.M. A. Mohamed, A. Elsayed, H.A.S. Shilkamy, Electrochemical reduction of carbon dioxide based on surface modification of GCE by in situ electropolymerized xylenol orange and its composite with PtCo. Ionics 2024, 30, 4325–4342. https://doi.org/10.1007/s11581-024-05567-5.
18. Y. Zhang, C. Kirk, N. Robertson, Ti_2O_3 film electrode for water treatment via electrochemical chlorine evolution. Mater. Adv., 2024, 5, 1631-1638. htpps://doi.org/10.1039/D3MA00908D.
19. C.A. Martínez-Huitle, M.A. Rodrigo, I. Sirés, O. Scialdone, Single and coupled electrochemical processes and reactors for the abatement of organic water pollutants: A Critical Review. Chem. Rev.., 2015, 115 (24), 3362–13407. https://doi.org/10.1021/acs.chemrev.5b00361.

20. M. Panizza, G. Cerisola, Direct and mediated anodic oxidation of organic pollutants. Chem. Rev.., 2009, 109 (12), 6541–6569. https://doi.org/10.1021/cr9001319.
21. F.T.A. Appia, L. Ouattara, (2021). Electrochemical Degradation of Amoxicillin on a $Ti/Ta_2O_5/Pt$- RuO_2-IrO_2 Electrode. OALiB J., 2021, 18 (8), e6558. https://doi.org/10.4236/oalib.1106558.
22. L. Duan, Q. Yun, G. Jiang, D. Teng, G. Zhou, Y. Cao, A review of chloride ions removal from high chloride industrial wastewater: Sources, hazards, and mechanisms. J. Environ. Manage., 2024, 351, 120184. https://doi.org/10.1016/j.jenvman.2024.120184.
23. C.Q.-M. Gnamba, F.T.A. Appia, E.M.H. Loba, S. Ibrahima, L. Ouattara, Electrochemical oxidation of amoxicillin in its pharmaceutical formulation at boron doped diamond (BDD) electrode. J. Electrochem. Sci. Eng.,2015, 5(2), 129– 43. https://doi.org/10.5599/jese.186.
24. A.J. Bard, L.R. Faulkner, Electrochemical Methods: Fundamentals and applications, wiley, 2001.
25. E. Laviron, General expression of the linear potential sweep voltammogram in the case of diffusionless electrochemical systems. J. Electroanal. Chem. Interf. Electrochem., 1979, 101,19-28. https://doi.org/10.1016/S0022-0728(79)80075-3.
26. J. Wang, Analytical electrochemistry. Wiley, 3rd Edition, 2006, 272. https://doi.org/10.1002/0471790303.
27. M.A. Edwards, A.L. Whitworth, P.R. Unwin, Quantitative analysis and application of tip position modulation scanning electrochemical microscopy. Anal. Chem., 2011, 83 (6), 1977-1984. https://doi.org/10.1021/ac102680v.
28. S. Tak, S. Grewal, S. Shreya, P. Phogat, M. Jangra, R. Jha, S. Singh, Mechanistic insights and emerging trends in photocatalytic dye degradation for wastewater treatment.Chem. Eng. Technol., 2024, 47 (11), e202400142. https://doi.org/10.1002/ceat.202400142.
29. F. Durand, B. Limoges, N. Mano, F. Mavré, J-M. Savéant, effect of substrate inhibition and cooperativity on the electrochemical responses of glucose dehydrogenase. Kinetic characterization of wild and mutant types. J. Am.Chem. Soc., 2011, 133 (32), 12801-12809. https://doi.org/10.1021/ja204637d.
30. R.L. McCreery, Advanced carbon electrode materials for molecular electrochemistry. Chem. Rev.., 2008, 108, (7), 2646-2687. https://doi.org/10.1021/cr068076m.
31. H. He, P. Zhou, K.K. Shimabuku, X. Fang, Degradation nd deactivation of bacterial antibiotic resitance genes during exposure to free chlorine, monochloramine, chlorine dioxide, ozone, ultraviolet light, and hydroxyl radical. Environ.Sci. Technol., 2019, 53(4), 2013-2026. https://orcid.org/0000-0001-8497-5945.
32. Z.D. Wang, T. Xia, Z.-H. Li, M.-F. Shao, A review of carbon-based catalysts and catalyst supports for simultaneous organic electro-oxidation and hydrogen evolution reactions. New Carbon Mater., 2024, 39 (1),67-77. https://doi.org/10.1016/S1872-5805(24)60829-2.