Biochar-based electrochemical sensors

Many fields, including industry, medicine, and environmental protection, are very interested in the design of sensitive and selective electrochemical sensors with a good affinity for the target analyte and a fast and reliable analytical response. For many researchers, it is important to understand the interactions that take place between the electrode and the analyte, which provide insight into the mechanism of the electrochemical reaction [1].

By improving the functionality of conventional electrodes, modified electrodes have completely revolutionized electrochemical sensing. Thanks to the numerous design possibilities of electrochemical sensors, i.e. working electrodes, the aim is to select modifiers with the most favorable interactions with the analyte in order to achieve the lowest possible limits of detection and determination by an optimized analytical method. Particular importance is attached to modifiers with a catalytic effect on the electron transfer process in the electrochemical system. It is expected that the modification of the electrochemical sensors will lead to an increase in the selectivity and reproducibility of the electrode surface during the determination of analytes. First of all, it is important to determine which parameters and interactions affect the results of the experiment, and then to choose the appropriate combinations of factors that will ensure optimal sensor response. These modifications increase sensitivity, selectivity, and overall analytical capabilities by changing the characteristics of the electrode surface. For efficient monitoring, these advancements allow for improved detection of pollutants in the environment [2, 3].

The electrochemical sensor should be modified in a way that is economically feasible while maintaining the proper stability of the resulting sensor [4]. Adding mediators or modifiers to the electrochemical sensor/working electrode composition, such as a carbon paste electrode, alters the electrode surface's physical or physicochemical characteristics. The primary goals of electrode modification are to produce or improve the electrochemical signal and/or lower the overvoltage, move and separate signals that would otherwise overlap, or enhance the analytical performance of the electrochemical sensor with predefined properties [5].

The sustainability of materials for developing the modified electrochemical sensor is crucial in the framework of a circular economy due to the need for environmentally friendly and greener analytical chemistry. Carbon-based sensing platforms have revolutionized contemporary electrochemical systems and are easily compatible with other carbon-rich materials, like biochar. The entire potential of biochar to enhance the analytical capabilities of electrochemical sensors can be realized through its use as a role of modifier. A green chemical approach to simulating new perspectives in expanding the variability of electrode material during the design of electrochemical sensors is closely linked to biochar usage, an environmentally friendly material that becomes a significant research axis that contributes to sustainable development [6].

This research was supported by the Science Fund of the Republic of Serbia, # 10810
Sustainable solutions in environmental chemistry: exploring biochar potential–EnviroChar

Ovaj dokument je sačinjen uz finansijsku podršku Fonda za nauku Republike Srbije. Za sadržinu ove publikacije isključivo je odgovoran Univerzitet u Novom Sadu Prirodno-matematički fakultet i ta sadržina ne izražava stavove Fonda za nauku Republike Srbije

Because of its favorable characteristics, including its high surface area, tunable porosity, strong chemical stability, and good electrical conductivity that reflects its catalytic effect for sensing applications, biochar has been considered a suitable choice as an electrode modifier [7, 8]. Biochar, as a sustainable material, could replace more complex electrode materials and act as an electrocatalyst due to the synergistic effect and ensuring reliable analytical performance in a variety of environmental samples, which illuminates their unique characteristics [9, 10].

A green material that is both economically and environmentally feasible, biochar may be produced from waste, mostly industrial and agricultural wastes, revealing the many forms of biomass as inexpensive resources with high availability [6]. Sensor response may be impacted by the differences in characteristics of biochars produced from a variety of biomass sources, electrode manufacturing techniques [3]. Functional groups including carboxyl, hydroxyl, and carbonyl are abundant on the surface of the biochar, allowing for strong interactions with target analytes and enhancing the sensitivity and selectivity of the sensor [3, 11, 12].

Recent advancements in the development of next-generation sustainable sensing devices have made it necessary to carry out comprehensive studies on the interactions between the analyte of interest depended on the composition, morphology, and electrochemical properties of carbon materials, such as biochar. Given that the process of producing biochar is inexpensive and environmentally friendly, the design and manufacturing of biochar-based electrochemical sensors represents a strategy that may eventually lead to the mass production and commercialization of this type of sensors [13].

Utilizing waste materials to produce biochar-based electrochemical sensors that analyze environmental samples without preparation is part of the effort to achieve a more environmentally friendly analysis. Before biochar-based electrochemical sensors could be commercialized, very precise estimates of the interactions between the biochar and the target analyte are still required to increase the practical use of the generated biochar-based electrodes for detecting analytes in a variety of real samples [6, 14].

References:

1. Casanova, A.; Iniesta, J.; Gomis-Berenguer, A., Recent progress in the development of porous carbon-based electrodes for sensing applications. *Analyst* **2022,** *147*, 767–783. https://doi.org/10.1039/D1AN01978C
2. Karimi-Maleh, H.; Karimi, F.; Alizadeh, M.; Sanati, A.L., Electrochemical sensors, a bright future in the fabrication of portable kits in analytical systems. *Chemical Record* **2020**, 20, 1–12. https://doi.org/10.1002/tcr.201900092
3. Zheng, A.L.T.; Lih, E.T.Y.; Hung, Y.P., Boonyuen, S.; Al Edrus, S.S.O.; Chung, E.L.T.; Andou, Y., Biochar-based electrochemical sensors: a tailored approach to environmental monitoring. *Analytical Sciences* **2025**, https://doi.org/10.1007/s44211-025-00726-8.
4. Baig, N.; Rana, A.; Kawde, A.-N., Modified electrodes for selective voltammetric detection of biomolecules. *Electroanalysis* **2018**, *30*, 2551–2574. https://doi.org/10.1002/elan.201800468

This research was supported by the Science Fund of the Republic of Serbia, # 10810
Sustainable solutions in environmental chemistry: exploring biochar potential–EnviroChar

Ovaj dokument je sačinjen uz finansijsku podršku Fonda za nauku Republike Srbije. Za sadržinu ove publikacije isključivo je odgovoran Univerzitet u Novom Sadu Prirodno-matematički fakultet i ta sadržina ne izražava stavove Fonda za nauku Republike Srbije

5. Kalcher, K.; Svancara, I.; Buzuk, M.; Vytras, K.; Walcarius, A., Electrochemical sensors and biosensors based on heterogeneous carbon materials. *Monatshefte für Chemie* **2009**, *140*, 861–889. https://doi.org/10.1007/s00706-009-0131-9
6. Kalinke, C.; de Oliveira, P.R.; Bonacin, J.A.; Janegitz, B.C.; Mangrich, A.S.; Marcolino-Junior, L.H.; Bergamini, M.F., State-of-the-art and perspectives in the use of biochar for electrochemical and electroanalytical applications. *Green Chemistry* **2021**, *23*, 5272–5301. https://doi.org/10.1039/D1GC00843A
7. Akhil, D.; Lakshmi, D.; Kartik, A.; Vo, D.-V.N.; Arun, J.; Gopinath, K.P., Production, characterization, activation and environmental applications of engineered biochar: a review. *Environmental Chemistry Letters* **2021**, *19*, 2261–2297. https://doi.org/10.1007/s10311-020-01167-7
8. Li, Y.; Xu, R.; Wang, H.; Xu, W.; Tian, L.; Huang, J.; Liang, C.; Zhang, Y., Recent advances of biochar-based electrochemical sensors and biosensors. *Biosensors* **2022**, *12,* 377. https://doi.org/10.3390/bios12060377
9. Gibi, C.; Liu, C.-H.; Barton, S.C.; Anandan, S.; Wu, J.J., Carbon materials for electrochemical sensing application – A mini review. *Journal of the Taiwan Institute of Chemical Engineers* **2024**, *154*, 105071. https://doi.org/10.1016/j.jtice.2023.105071
10. Kangmennaa, A.; Forkuo, R.B.; Agorku, E.S., Carbon-based electrode materials for sensor application: a review. *Sensing Technology* **2024**, *2*, 2350174. https://doi.org/10.1080/28361466.2024.2350174
11. Saravanan, A.; Kumar, P.S., Biochar derived carbonaceous material for various environmental applications: Systematic review. *Environmental Research* **2022**, *214*, 113857.
12. Bhattacharya, T.; Khan, A.; Ghosh, T.; Kim, J.T.; Rhim, J.-W., Advances and prospects for biochar utilization in food processing and packaging applications. *Sustainable Materials and Technologies* **2024**, *39*, e00831. https://doi.org/10.1016/j.susmat.2024.e00831
13. Berkel, C.; Özbek, O., Green Electrochemical Sensors, Their Applications and Greenness Metrics Used: A Review. *Electroanalysis* **2024**, *36*, e202400286. https://doi.org/10.1002/elan.202400286
14. Onfray, C.; Thiam, A., Biomass-derived carbon-based electrodes for electrochemical sensing: a review, *Micromachines* **2023**, *14*, 1688. https://doi.org/10.3390/mi14091688

This research was supported by the Science Fund of the Republic of Serbia, # 10810
Sustainable solutions in environmental chemistry: exploring biochar potential–EnviroChar

Ovaj dokument je sačinjen uz finansijsku podršku Fonda za nauku Republike Srbije. Za sadržinu ove publikacije isključivo je odgovoran Univerzitet u Novom Sadu Prirodno-matematički fakultet i ta sadržina ne izražava stavove Fonda za nauku Republike Srbije