EVALUATION OF GO AND rGO/CNT COATING MASS ON CARBON CLOTH ELECTRODES FOR DUAL-CHAMBER MICROBIAL FUEL CELLS

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ABSTRACT

Microbial fuel cells (MFCs) are promising bioelectrochemical systems for simultaneous wastewater treatment and electricity generation, but their performance is strongly influenced by electrode properties. Carbon cloth (CC) is attractive as an electrode support because of its conductivity, chemical stability, and accessible surface structure. In this preliminary study, graphene oxide (GO) was applied to the anode and reduced graphene oxide/carbon nanotube (rGO/CNT) composites were investigated as cathode coating materials. The coating mass was evaluated gravimetrically after the coating process. Based on the supplied experimental chart, the GO-coated anode showed a coating mass of 0.005 g, whereas rGO/CNT cathodes with ratios of 1:0, 1:1, 1:2, and 1:3 showed coating masses of 0.001, 0.003, 0.003, and 0.002 g, respectively. The highest cathode coating mass was obtained at rGO:CNT ratios of 1:1 and 1:2. Compared with rGO alone (1:0), these formulations produced a threefold coating mass. The results indicate that rGO:CNT composition affects the amount of material retained on the carbon cloth surface and provides a useful screening parameter before electrochemical evaluation. However, coating mass alone cannot establish the optimum electrode composition; electrical conductivity, electrochemical surface area, adhesion stability, polarization behavior, and MFC power output should be evaluated in subsequent experiments.

KEYWORDS

microbial fuel cell; carbon cloth; graphene oxide; reduced graphene oxide; carbon nanotube

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INTRODUCTION

Microbial Fuel Cels (MFC) is a bioelectrochemical system that employs microorganisms as biocatalysts and organic compounds as fuel sources to generate electricity. In this system, microorganisms metabolize biodegradable organic matter, converting the chemical energy stored in the substrate into electrical energy through a series of oxidation–reduction reactions. In MFC systems, electrons generated during microbial metabolism are captured by the anode and transported to the cathode through an external electrical circuit, resulting in the production of electric current. The unique capability of electroactive microorganisms to simultaneously oxidize organic contaminants and generate electricity has attracted considerable research interest, positioning MFCs as a promising technology for sustainable energy generation and wastewater remediation (Slate et al., 2019).

Microbial fuel cells convert chemical energy in biodegradable substrates into electricity through microbial oxidation at the anode and a reduction reaction at the cathode. Despite substantial research progress, practical MFC development is still constrained by relatively low power output, internal resistance, electrode limitations, and material cost. Electrode engineering is therefore one of the major routes for improving MFC performance.

Recent developments in MFC technology have focused on improving electrical performance while reducing system costs. Particular emphasis has been placed on optimizing electrode materials and configurations, as electrodes play a critical role in facilitating microbial attachment, electron transfer, and electrochemical reactions. In addition, sufficient substrate availability is essential to support microbial metabolism and enhance electron generation. Increased electron production contributes directly to improved electrochemical performance, resulting in higher voltage, power density, and overall energy output (Ibrahim et al., 2017).

The electrode is a critical component that significantly influences MFC performance, as it provides a surface for bacterial biofilm formation and serves as a conductor for the electrons generated during microbial metabolism. An ideal electrode material should possess several key characteristics, including biocompatibility, high electrical conductivity, corrosion resistance, chemical stability, large surface area, mechanical strength, low cost, hydrophilicity, and resistance to degradation within the substrate environment. Activated carbon has emerged as a promising electrode material for MFC applications because it exhibits many of these desirable properties. Its high surface area facilitates microbial attachment and biofilm development, while its excellent conductivity enhances electron transfer efficiency. Consequently, activated carbon electrodes have the potential to improve the bioelectrical performance and energy output of MFC systems elektroda (Agüero-quiñones et al., 2023)(Huda et al., 2022).

Various carbon-based materials are widely used as anodes in MFC due to their excellent chemical stability, resistance to harsh environmental conditions, large surface area, and high electrical conductivity, which facilitate microbial biofilm formation. Commonly used materials include carbon cloth, carbon paper, carbon brush, carbon mesh, carbon veil, granular activated carbon (GAC), graphene, and carbon felt. Each material possesses distinct advantages and limitations in terms of flexibility, surface area, porosity, mechanical stability, cost, and electron transfer capability. Among these materials, graphene and carbon felt have demonstrated superior performance owing to their high electrical conductivity, large porosity, and ability to effectively support biofilm growth. Therefore, the selection of an appropriate anode material plays a crucial role in enhancing

electron transfer efficiency and improving the overall performance of MFC systems (Merga et al., 2025).

Graphene-based materials have attracted considerable attention as advanced carbonaceous materials for electrochemical and energy-related applications, including microbial fuel cells (MFCs) (Chadha et al., 2022). Graphene is a two-dimensional carbon material composed of sp^2-hybridized carbon atoms arranged in a hexagonal lattice. Its high theoretical surface area, excellent electrical conductivity, mechanical stability, and chemical tunability make it an attractive material for electrode modification. In MFC systems, the characteristics of the electrode surface are closely related to microbial adhesion, biofilm development, electron transfer, and electrochemical reactions. Therefore, incorporating graphene-based materials onto conventional carbon electrodes can provide additional active sites and conductive pathways, potentially improving electron transport between electroactive microorganisms and the external circuit (Zhao et al., 2014). Previous studies have reported that graphene and its derivatives can enhance electrode performance through modifications of surface morphology, electrical conductivity, wettability, and interfacial electron-transfer characteristics. However, the tendency of graphene sheets to aggregate or undergo restacking can reduce their effective surface area and limit the accessibility of electrochemically active sites. Consequently, graphene derivatives and graphene-based hybrid materials have been increasingly investigated to overcome these limitations (Starowicz et al., 2023).

Graphene oxide (GO) is an oxidized derivative of graphene that is commonly produced through the chemical oxidation and exfoliation of graphite. The GO structure contains various oxygen-containing functional groups, including hydroxyl, epoxy, carbonyl, and carboxyl groups. The presence of these functional groups disrupts the extended sp^2 carbon network of graphene, resulting in lower electrical conductivity compared with pristine graphene (Abdel et al., 2025). Nevertheless, GO possesses high hydrophilicity and can be readily dispersed in aqueous media, making it particularly attractive for solution-bsed coating and surface modification processes. In electrode applications, the oxygen-containing functional groups can facilitate interactions between GO and the electrode surface as well as with the surrounding aqueous environment. For MFC anodes, the hydrophilic nature and functionalized surface of GO may promote electrolyte wetting and microbial attachment, which are important factors in biofilm formation and extracellular electron transfer. GO can therefore function not only as a carbon-based coating but also as a surface-functionalization material. However, its relatively low electrical conductivity remains a limitation, particularly when GO is used as the primary conductive component of an electrode. Consequently, GO is frequently employed as a precursor for the preparation of reduced graphene oxide or combined with other conductive materials to obtain a better balance between surface functionality and electrical conductivity (Rajesh et al., 2018).

Reduced graphene oxide (rGO) is obtained through the partial removal of oxygen-containing functional groups from GO using chemical, thermal, electrochemical, photochemical, or biological reduction processes. Reduction partially restores the sp^2-conjugated carbon structure, resulting in substantially improved electrical conductivity compared with GO. This combination of relatively high surface area and enhanced electrical conductivity makes rGO particularly promising for electrochemical electrode applications. In MFCs, rGO can provide conductive pathways that facilitate electron transfer from electroactive microorganisms to the anode and can also contribute to the development of electrochemically active interfaces. Several studies have demonstrated that rGO-modified carbon electrodes can exhibit improved charge-transfer characteristics and enhanced microbial colonization compared with unmodified carbon electrodes.

Nevertheless, the reduction of GO also removes some oxygen-containing functional groups, which can decrease hydrophilicity and alter the interaction between the electrode surface and microorganisms. Therefore, the effectiveness of rGO as an electrode coating does not depend solely on its electrical conductivity but also on its surface chemistry, morphology, degree of reduction, and interaction with the underlying carbon substrate. An appropriate balance between conductivity and surface functionality is consequently important when designing rGO-based electrodes for MFC applications (Nosek & Cydzik-kwiatkowska, 2022).

Reduced graphene oxide (rGO) is particularly attractive because reduction removes part of the oxygen-containing functional groups present in GO and generally increases electrical conductivity. Combining rGO with carbon nanotubes (CNTs) can provide a hybrid conductive network and potentially improve structural connectivity across the electrode surface. CNT-based cathode materials have also been investigated as alternatives to conventional expensive catalysts for oxygen reduction in MFCs (Rani & Kumar, 2019).

Carbon nanotubes (CNTs) are one-dimensional nanocarbon materials consisting of cylindrical carbon structures formed from rolled graphene sheets. Depending on their structure, CNTs can be categorized as single-walled or multi-walled carbon nanotubes. CNTs possess high electrical conductivity, excellent mechanical strength, large aspect ratios, and high surface-to-volume ratios, making them attractive for electrode modification and conductive network formation. In MFC applications, CNTs can improve the electrical connectivity of carbon electrodes and provide nanoscale structures that increase the effective electrode surface area. Their one-dimensional architecture can also facilitate electron transport across the electrode interface. However, pristine CNTs are relatively hydrophobic and tend to form aggregates because of strong van der Waals interactions, which can limit their dispersion and reduce the accessibility of their active surface. Functionalization of CNTs, for example through acid treatment, can introduce oxygen-containing groups such as carboxyl groups onto the CNT surface, improving their dispersibility and interfacial interaction with other materials. Such functionalization is particularly relevant when CNTs are incorporated into aqueous coating formulations (Shah et al., 2024).

The combination of rGO and CNTs provides an attractive strategy for developing hybrid conductive coatings because the two materials possess complementary structural characteristics. rGO has a two-dimensional sheet-like structure with a relatively large surface area, whereas CNTs provide one-dimensional conductive pathways. When combined, CNTs can act as conductive bridges or spacers between rGO sheets, potentially reducing the restacking of rGO and generating a more interconnected conductive network. This synergistic structure can improve electron transport while maintaining a high accessible surface area. In addition, the incorporation of CNTs can influence the morphology, porosity, mechanical stability, and dispersion characteristics of the rGO coating. Therefore, the performance of an rGO/CNT composite is expected to depend strongly on the ratio between the two components. An insufficient CNT content may provide limited structural bridging, whereas excessive CNT content may promote aggregation and produce a less homogeneous coating. Optimization of the rGO/CNT ratio is therefore important for obtaining a stable and conductive electrode surface (Pareek et al., 2019).

For carbon cloth electrodes, the use of rGO/CNT hybrid coatings offers an opportunity to combine the three-dimensional porous structure of carbon cloth with the nanoscale characteristics of rGO and CNTs. Carbon cloth provides a mechanically stable and electrically conductive substrate, while rGO can increase the accessible surface area and provide additional electroactive sites. CNTs can further contribute to the formation of

interconnected conductive pathways and potentially improve the structural stability of the coating. This hierarchical architecture may be beneficial for MFC electrodes because efficient electrode performance requires simultaneous optimization of electrical conductivity, surface area, wettability, mass transfer, and electrode–microorganism interactions. Accordingly, the use of rGO/CNT coatings represents a promising approach for tailoring the surface properties of carbon cloth electrodes for bioelectrochemical applications (Rani & Kumar, 2019).

In the present work, carbon cloth was modified using GO on the anode and rGO/CNT composites on the cathode. The first experimental question addressed was straightforward but important: how much coating material is retained by the electrode for different rGO:CNT compositions. This study therefore focuses on gravimetric coating-mass evaluation as a preliminary step toward electrochemical optimization of the electrode pair.

RESEARCH METHOD

Synthesis of Graphene Oxide (GO)

Graphene oxide (GO) was synthesized using a modified Hummers' method [22]. Briefly, 0.5 g of graphite and 0.5 g of $NaNO_3$ were added to 23 mL of concentrated H_2SO_4 under continuous stirring. Subsequently, 3 g of $KMnO_4$ was added gradually until a grayish-purple mixture was obtained. Deionized water (140 mL) was then added slowly, followed by heating in a water bath at 95 °C until the suspension turned dark brown. Subsequently, 30% H_2O_2 was added dropwise until a yellowish color was observed. The resulting suspension was repeatedly washed with ethanol, 10% HCl, and deionized water to remove residual manganese species and acidic impurities. The washing procedure consisted of two cycles using 30 mL ethanol per cycle, followed by three cycles using 30 mL of 10% HCl per cycle and six to eight cycles using 40 mL deionized water per cycle, or until the supernatant reached a pH of 6.5–7.0. The obtained GO was subsequently dried at 60 °C for 6–12 h. Based on the initial graphite mass and the synthesis conditions, the expected GO yield was approximately 0.75 g.

GO-Coated Anode Preparation

Carbon cloth (CC) was modified with GO using a dip-coating method. Prior to coating, the carbon cloth was sequentially cleaned with deionized water, acetone, and 10% HCl solution to remove surface contaminants and facilitate surface activation, followed by drying in an oven at 60 °C for 12 h. A GO suspension was prepared by dispersing GO in deionized water at a concentration of 1 mg/mL, with a total volume of 20 mL, corresponding to 20 mg of GO. The suspension was ultrasonicated for 3 h to obtain a homogeneous dispersion. The cleaned carbon cloth was then immersed in the GO suspension for 10 coating cycles, with an immersion time of 5 min per cycle, until the prepared suspension was completely utilized. After the coating process, the GO-coated carbon cloth was dried at 80 °C to remove residual moisture and obtain a stable GO-coated electrode, denoted as GO/CC, for use as the anode material.

Synthesis of Reduced Graphene Oxide (rGO)

Reduced graphene oxide (rGO) was synthesized through the chemical reduction of GO using ascorbic acid as a reducing agent. Briefly, 0.25 g of GO was dispersed in 250 mL of deionized water to obtain a GO suspension with a concentration of 1 mg/mL,

followed by ultrasonication for 60 min to achieve homogeneous dispersion. Subsequently, 2.5 g of ascorbic acid was dissolved in 25 mL of deionized water and gradually added to the GO suspension under continuous magnetic stirring, corresponding to an ascorbic acid-to-GO mass ratio of 10:1. The resulting mixture was heated at 95 °C for 2 h under continuous stirring. During the reduction process, the suspension gradually changed from brown to black, indicating the formation of rGO. After completion of the reaction, the suspension was cooled to room temperature and the rGO was separated by vacuum filtration. The resulting solid was repeatedly washed with deionized water until the filtrate reached a pH of 6.5–7.5 to remove residual ascorbic acid and soluble impurities, followed, when necessary, by a final washing step with absolute ethanol. The obtained rGO was then dried in an oven at 60 °C for 12 h until a dry black powder was obtained.

CNT Functionalization

Carbon nanotubes (CNTs) were functionalized through acid oxidation to introduce oxygen-containing functional groups, particularly carboxyl groups (–COOH), onto their surfaces. A mixed acid solution was prepared using H_2SO_4 and HNO_3 at a volume ratio of 1:3 (v/v), corresponding to 10 mL of H_2SO_4 and 30 mL of HNO_3. Subsequently, 1 g of pristine CNTs was dispersed in the acid mixture and continuously stirred at 60 °C for 4 h to facilitate surface oxidation. After the oxidation treatment, the suspension was cooled to room temperature and filtered using a filtration membrane. The collected CNT residue was repeatedly washed with deionized water until the filtrate reached a neutral pH of 6.5–7.5 to remove residual acids. The functionalized CNTs (CNT–COOH) were subsequently dried in an oven at 80 °C for 6 h to obtain a dry powder for the preparation of the rGO/CNT composite coating.

rGO/CNT-Coated Cathode Preparation

The rGO/CNT coating suspensions were prepared at rGO:CNT mass ratios of 1:0, 1:1, 1:2, and 1:3, with a total material concentration of 1 mg/mL. For each formulation, a total of 50 mg of rGO/CNT was dispersed in 50 mL of deionized water, consisting of 50.00 mg rGO and 0 mg CNT for the 1:0 ratio, 25.00 mg rGO and 25.00 mg CNT for the 1:1 ratio, 16.67 mg rGO and 33.33 mg CNT for the 1:2 ratio, and 12.50 mg rGO and 37.50 mg CNT for the 1:3 ratio. Each suspension was ultrasonicated for 3 h to improve dispersion and minimize agglomeration before coating. The cleaned carbon cloth was subsequently immersed in the respective rGO/CNT suspension using a dip-coating method for 10 cycles, with an immersion time of 5 min per cycle, until the prepared suspension was completely utilized. Following the coating process, the modified carbon cloth was dried at 80 °C to obtain the rGO/CNT-coated cathode electrodes, which were designated as rGO/CC, rGO/CNT-1:1/CC, rGO/CNT-1:2/CC, and rGO/CNT-1:3/CC, respectively.

Determination of Coating Mass

The carbon cloth electrodes were cleaned and dried before coating. The corresponding GO or rGO/CNT suspension was applied to the electrode surface using the established coating method. After coating, the electrodes were dried under controlled conditions until a stable mass was obtained. The coating mass was determined gravimetrically from the difference between the mass of the coated and uncoated electrode, according to Eq. (1):

$$m_coating = m_coated\ electrode - m_uncoated\ electrode$$

This gravimetric measurement was used to compare the deposition characteristics of GO and the different rGO/CNT formulations on the carbon cloth surface. The coating mass was considered an initial indicator of the amount of graphene-based material retained on the electrode surface before further morphological and electrochemical characterization.

RESULT AND DISCUSSION

The gravimetric analysis showed that the GO-coated anode had the highest coating mass of 0.005 g, while the rGO/CNT cathodes showed coating masses between 0.001 and 0.003 g. Among the cathode formulations, rGO ratios of 1:1 and 1:2 produced the highest coating mass (0.003 g), followed by 1:3 (0.002 g) and rGO alone (1:0) (0.001 g). Thus, incorporation of CNT increased the retained coating mass compared with rGO alone, with the 1:1 and 1:2 formulations showing approximately a 200% increase in coating mass relative to the 1:0 formulation.

The increase in coating mass with moderate CNT incorporation may be associated with improved interaction between rGO, CNT, and the carbon cloth substrate. CNTs can form an interconnected network with rGO sheets, potentially improving suspension retention and physical attachment to the carbon cloth. However, the decrease in coating mass at the 1:3 ratio suggests that increasing CNT content does not necessarily result in greater material deposition. Excessive CNT incorporation may promote aggregation or alter the dispersion characteristics of the coating suspension, thereby reducing coating uniformity and retention.

The identical coating mass obtained for the 1:1 and 1:2 formulations (0.003 g) indicates that increasing the CNT fraction from 1:1 to 1:2 did not further increase material retention. This may suggest that the available surface area of the carbon cloth and the properties of the coating suspension limit the maximum retained mass under the present coating conditions. Nevertheless, replicate measurements are required to determine whether these differences are statistically significant.

Importantly, coating mass should not be considered a direct indicator of electrochemical performance. A higher loading may provide more active material, but an excessively thick or poorly adhered coating can block pores and increase mass-transfer resistance. Therefore, electrochemical parameters such as open-circuit voltage, polarization curve, power density, internal resistance, and EIS are required to determine the optimum cathode formulation.

Based on the gravimetric results, the 1:1 and 1:2 rGO formulations are suitable candidates for further electrochemical evaluation, with 1:0 and 1:3 retained as comparison formulations. The 0.005 g GO loading on the anode can also be used as a reference for evaluating the influence of GO modification on anodic electron transfer and biofilm development. Overall, the results indicate that moderate CNT incorporation improves coating retention, but the optimum electrode composition should ultimately be determined from electrochemical performance rather than coating mass alone.

The higher coating mass at intermediate CNT incorporation may indicate improved retention of the composite suspension on the carbon cloth structure. However, the relationship should not be interpreted as a direct measure of electrochemical performance. A heavier coating can increase the amount of active material but can also block pores, increase diffusion resistance, or reduce mechanical stability if the coating is poorly adhered.

Therefore, the gravimetric result is best treated as an initial screening parameter rather than a performance indicator.

Table 1. *Gravimetric coating mass of GO- and rGO/CNT-modified carbon cloth electrodes.*

Electrode	Coating Formulation	Coating Mass (g)
Anode	GO	0.005
Cathode	rGO:CNT = 1:0	0.001
Cathode	rGO:CNT = 1:1	0.003
Cathode	rGO:CNT = 1:2	0.003
Cathode	rGO:CNT = 1:3	0.002

The equal coating mass obtained for rGO:CNT ratios of 1:1 and 1:2 is particularly interesting because it suggests that increasing the CNT fraction from 1:1 to 1:2 did not further increase the retained mass under the present coating conditions. This may indicate a coating-loading region in which the available carbon cloth surface and suspension properties limit further material deposition. Reproducibility testing with at least triplicate electrodes is required to determine whether the difference among ratios is statistically meaningful.

From an MFC design perspective, the rGO/CNT cathode requires additional electrochemical evaluation because cathodic oxygen reduction is often a rate-limiting process. Carbon-based catalysts, including graphene-derived materials and CNT-containing composites, have been reported as promising alternatives for improving cathode activity while reducing reliance on noble-metal catalysts.

For the next stage of the experiment, the 1:1 and 1:2 cathode formulations are recommended as priority candidates for electrochemical comparison, together with the 1:0 and 1:3 controls. The comparison should include open-circuit voltage, polarization curve, power density, internal resistance, electrochemical impedance spectroscopy (EIS), and coating adhesion/stability. For the anode, the 0.005 g GO loading provides a practical reference for evaluating the effect of GO modification on biofilm formation and anodic electron transfer.

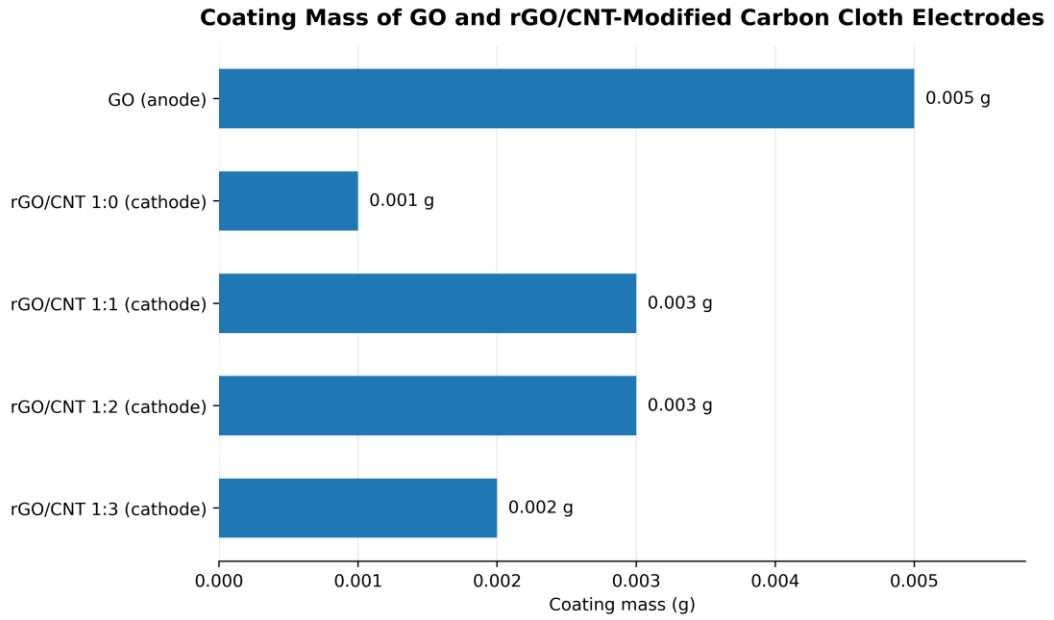


Figure 1. *Comparison of coating mass for the GO anode and rGO/CNT cathode formulations.*

CONCLUSION

GO and rGO/CNT coatings were successfully screened using a gravimetric approach. The GO-coated anode showed a coating mass of 0.005 g, while the cathode coating masses for rGO:CNT ratios of 1:0, 1:1, 1:2, and 1:3 were 0.001, 0.003, 0.003, and 0.002 g, respectively. The 1:1 and 1:2 formulations gave the highest cathode coating mass and were three times higher than the rGO-only formulation. These results establish a useful baseline for subsequent electrochemical optimization. Future work should combine gravimetric loading with morphological, electrical, electrochemical, and MFC performance measurements to identify the most effective electrode composition.

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REFERENCES

Abdel, A., Mohamed, R., El, A., Ali, D., Salah, M., Din, E., Amel, H., El, A., Kashyout, H. B., He, Z., & Moustafa, H. (2025). Performance evaluation of microbial fuel cell fabricated using green nano - graphene oxide as coating anode material. *Biomass Conversion and Biorefinery*, 297–310. https://doi.org/10.1007/s13399-023-04964-6

Agüero-quiñones, R., Zairi, Á.-S., Rojas-Flores, S., Cabanillas-chirinos, L., Cruz-Noriega, M. D. La, Nazario-Naveda, R., & Rojas-Villacorta, W. (2023). Activated Carbon Electrodes for Bioenergy Production in Microbial Fuel Cells Using Synthetic Wastewater as Substrate. *Sustainability*, *15*, 13767. https://doi.org/https://doi.org/10.3390/ su151813767

Chadha, U., Selvaraj, S. K., Vishak Thanu, S., Cholapadath, V., Abraham, A. M., Zaiyan M, M., Manoharan, M., & Paramsivam, V. (2022). A review of the function of using carbon nanomaterials in membrane filtration for contaminant removal from wastewater. *Materials Research Express*, *9*(1). https://doi.org/10.1088/2053-1591/ac48b8

Huda, A. N., Lestari, I., & Hidayat, S. (2022). Pemanfaatan Karbon Aktif dari Sekam Padi Sebagai Elektroda Superkapasitor. *JIIF (Jurnal Ilmu Dan Inovasi Fisika)*, *06*(02), 102–113.

Ibrahim, B., Suptijah, P., & Syahreza, F. (2017). Kinerja Microbial Fuel Cells Pada Pengolahan Limbah Cair Pemindangan dengan Membran Separator Campuran Polimer Kitosan/PVA. *Jurnal Teknologi Industri Pertanian*, *27*(3), 235–241. https://doi.org/10.24961/j.tek.ind.pert.2017.27.3.235

Merga, T., Gebreslassie, G., Hailu, T., & Nwanya, A. C. (2025). Results in Chemistry Progress of carbon-based electrodes in microbial fuel cells : A comprehensive review.

Results in Chemistry, *17*(June), 102627. https://doi.org/10.1016/j.rechem.2025.102627

Nosek, D., & Cydzik-kwiatkowska, A. (2022). *Anode Modification with Reduced Graphene Oxide – Iron Oxide Improves Electricity Generation in Microbial Fuel Cell*. *23*(10), 147–153.

Pareek, A., Sravan, J. S., & Mohan, S. V. (2019). Materials Science for Energy Technologies Exploring chemically reduced graphene oxide electrode for power generation in microbial fuel cell. *Materials Science for Energy Technologies*, *2*(3), 600–606. https://doi.org/10.1016/j.mset.2019.06.006

Rajesh, P. P., Noori, T., & Ghangrekar, M. M. (2018). *Graphene Oxide / Polytetrafluoroethylene Composite Anode and Chaetoceros pre-Treated Anodic Inoculum Enhancing Performance of Microbial Fuel Cell*. *6*(3). https://doi.org/10.18178/jocet.2018.6.3.467

Rani, R., & Kumar, S. (2019). *Enhanced Performance of a Single Chamber Microbial Fuel Cell Using NiWO 4 / Reduced Graphene Oxide Coated Carbon Cloth Anode*. *0*, 1–10. https://doi.org/10.1002/fuce.201800120

Shah, S. A., Ali, H., Inayat, M. I., E. Mahmoud, E., AL Garalleh, H., & Ahmad, B. (2024). Effect of carbon nanotubes and zinc oxide on electrical and mechanical properties of polyvinyl alcohol matrix composite by electrospinning method. *Scientific Reports*, *14*(1), 1–13. https://doi.org/10.1038/s41598-024-79477-x

Slate, A. J., Whitehead, K. A., Brownson, D. A. C., & Banks, C. E. (2019). Microbial fuel cells: An overview of current technology. *Renewable and Sustainable Energy Reviews 101*, 60–81.

Starowicz, A., Zieli, M., & Rusanowska, P. (2023). *Microbial Fuel Cell Performance Boost through the Use of Graphene and Its Modifications — Review*.

Zhao, C., Wang, W., Sun, D., Wang, X., & Zhang, J. (2014). *Nanostructured Graphene / TiO 2 Hybrids as High-Performance Anodes for Microbial Fuel Cells*. 1–8. https://doi.org/10.1002/chem.201400272