Influence of Electrode Surface Properties in the Valorization of Waste Biomass for Sustainable Hydrogen Peroxide Production

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Hydrogen peroxide (H_2O_2) is an environmentally friendly oxidant widely used in water treatment, disinfection, and various industrial processes, due to its ability to decompose into water and oxygen without forming harmful by-products. Despite its advantages, the traditional anthraquinone process for H_2O_2 production presents significant drawbacks, including high energy demands, risks associated with transport and storage, and a reliance on fossil-based feedstocks. As a sustainable alternative, it is possible to investigate on the use of waste biomass to produce functional carbon materials for the electrogeneration of H_2O_2 via the two-electron oxygen reduction reaction (2e⁻-ORR) (Cazier *et al.*, 2024).

In this work, *Phragmites australis* (PA), a lignocellulosic waste biomass sourced from natural wetlands, was transformed into carbon-based catalysts through hydrothermal carbonization (HTC) and chemical activation with NaOH. This waste biomass was selected based on promising previous results in H_2O_2 accumulation (Ramirez *et al.*, 2024). Comprehensive physicochemical analyses, including FTIR, BET surface area measurements, and SEM-EDS imaging, were conducted to correlate material properties with performance metrics.

Electrochemical assays demonstrated that the ratio of carbon catalyst to polytetrafluoroethylene (PTFE) significantly influenced electrode performance. Electrodes prepared with a 1:50 catalyst-to-PTFE ratio achieved optimal results, producing 450 mg L^{-1} of H_2O_2 with a Faradaic efficiency of 70% after 120 minutes. Contact angle measurements (ranging from 120° to 143°) confirmed the formation of effective three-phase boundaries, which facilitated oxygen diffusion and reaction at the catalyst surface (Petsi *et al.*, 2023). Conversely, excessive catalyst loading increased hydrophilicity and reduced efficiency, while lower PTFE content hindered oxygen transport. Figure 1 illustrates the trends in Faradaic efficiency for H_2O_2 accumulation for different catalyst/PTFE ratios, underscoring the importance of balancing electrode surface properties for an efficient production.

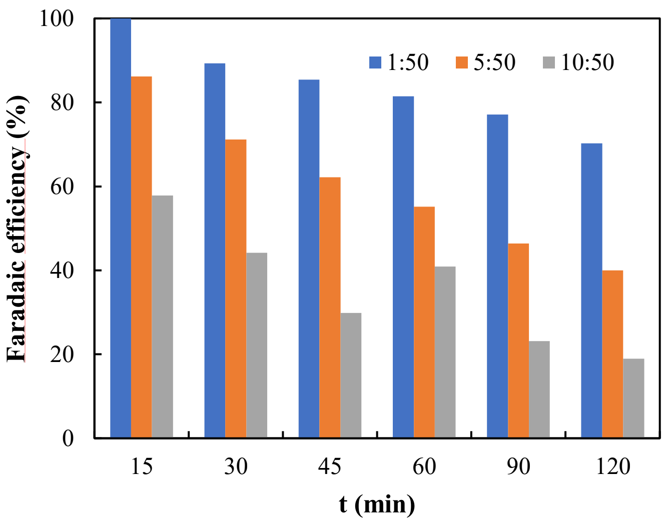

Fig. 1. Faradaic efficiency for mixtures 1:50, 5:50 and 10:50 (mg activated PA ml^{-1}: mg PTFE ml^{-1}). Electrolyte: 0.05 M Na_2SO_4 with constant aeration and stirring. Potential: -0.9 V vs Ag/AgCl (3M)

Regarding material characterization, the proposed conversion process yielded mesoporous carbon materials with a specific surface area of 389 $m^2\ g^{-1}$ and moderate structural disorder ($A_{D1}/A_G = 1.23$), as revealed by Raman spectroscopy. The materials also exhibited oxygenated and nitrogenated functional groups, which are known to enhance the selectivity and efficiency of the $2e^-$-ORR.

This study highlights the potential of valorizing waste biomass to develop scalable and sustainable cathodes for electrochemical H_2O_2 production. By leveraging waste-derived materials, the proposed approach aligns with cleaner production practices and circular economy principles, paving the way for more sustainable industrial processes.

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