ABSTRACT

Hospital wastewater (HWW), particularly containing pharmaceutically active compounds like sulfamethoxazole (SMX), represents a major environmental and public health concern due to its persistent, bioactive, and antimicrobial resistance-inducing constituents. Conventional wastewater treatment plants are largely ineffective in removing such micropollutants, necessitating the integration of decentralised and advanced technologies for effective treatment. To address these challenges, bioelectrochemical and electrochemical systems were developed, incorporating constructed wetlands integrated with microbial fuel cells (CW-MFC) and microbial carbon capture cells (CW-MCC). These systems, enhanced with reduced graphene oxide (rGO)-modified metallurgical coke and coagulant sludge as low-cost substrates, demonstrated simultaneous pollutant removal and energy recovery. The CW-MCC system achieved 2.8-fold higher SMX removal compared to control, along with a peak power density of 145.41 mW/m^3.

Resource-efficient pre-treatment strategies employing electrocoagulation (EC) and catalytic ozonation were implemented using waste-derived materials. Aluminium cans (AAcan) were transformed into 3D sacrificial anodes for EC, resulting in 76.28% SMX removal and a significant reduction in energy and material costs. Catalytic ozonation using activated coking coal further enhanced SMX degradation (84.26%) by promoting hydroxyl radical formation, demonstrating stable performance under varying water matrices and catalyst reuse cycles.

To advance oxidative post-treatment, a boron-doped MnO_2/carbon nanotube (CNT) composite was synthesised and anchored onto carbon felt for use as an anode in electrooxidation (EO) systems. The system achieved near-complete SMX degradation within 90 min due to enhanced hydroxyl radical production and improved electron transport. Similarly, a P–Co–Bi catalyst supported on metallurgical coke was developed as a cathode for electro-Fenton (EF) applications, exhibiting high H_2O_2 electrogeneration and SMX removal efficiency in both batch and flow-through modes. Overall, the use of waste-derived materials and hybrid electrochemical systems presents a promising approach for the decentralised treatment of hospital wastewater. These systems enhance treatment efficacy, reduce environmental burdens, and demonstrate practical potential for integration with existing wastewater infrastructure in low-resource settings, offering scalable, cost-effective, and sustainable solutions to pharmaceutical pollution.

Keywords: Bioelectrochemical systems, Electrochemical advanced oxidation, Hospital wastewater, Sulfamethoxazole removal, Waste-derived electrodes