

IMPROVED CONSTRUCTED WETLAND-MICROBIAL FUEL CELL: DEVICE FOR ENHANCED REMOVAL OF PHARMACEUTICALLY ACTIVE COMPOUNDS FROM HOSPITAL WASTEWATER AND POWER GENERATION

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Abstract

The pharmaceutically active compounds (PhACs) released from hospitals are becoming a significant concern for the wastewater treatment systems. Conventional systems struggle to manage these toxic contaminants without increasing cost or causing secondary pollution. The Constructed Wetlands (CW) provide a suitable low-cost approach for the treatment of such contaminants without causing secondary pollution and other bioelectrochemical systems, i.e., Microbial Fuel Cells (MFC) are capable of handling wastewater with high COD along with bioelectricity generation. An integrated CWMFC complements the properties of both systems, enhancing the total treatment efficiency and generating bioelectricity. Although, CWMFCs have been explored in some studies, their design parameters, plant selection, treatment mechanism, low voltage generation, low redox gradient, and high HRT requires further investigation.

In this thesis, an integrated CWMFC was developed and its best-suited plants and other design parameters, such as electrode spacing, substrate-to-water depth ratio, and initial COD concentration, were identified for the treatment of HWW containing two PhACs, i.e., paracetamol (PCL) and diclofenac (DCF), by using multivariate optimization. Duckweed planted CWMFC (DW-CWMFC) performed better than the Water Hyacinth (WH-CWMFC) system, achieving an average power density of 42.93 mW/m². Mechanistic studies confirmed that plant uptake, substrate adsorption, and microbial degradation were the principal removal pathways, with non-toxic intermediates ensuring environmental safety.

Furthermore, to enhance system performance, the cathode was modified using a 3.9% Al-ZnO/Zeolite@Graphite composite, imparting improved conductivity, adsorption capacity, and photocatalytic activity. The modified system effectively treated PCL and DCF and was subsequently evaluated for the simultaneous removal of carbamazepine (CBZ) in a continuous-flow photocatalytic CWMFC (PCWMFC), demonstrating stable operation and an average power density of 59.5 mW/m². Another major issue with CWMFC systems is the development of a redox environment between anodic and cathodic zones. Hence, an Enhanced Photocatalytic CWMFC (EPCWMFC) was designed to augment treatment efficacy and establish a redox gradient by dividing CWMFC into anoxic pre-treatment, photocatalytic CWMFC, and sand filter. The modified design reduced HRT from 48 h,

achieving maximum power generation performance at a 24 h HRT and 1400 mg/l COD. The anoxic unit lowered the dissolved oxygen (DO) concentration to 0.6 mg/l, thereby improving redox gradient and facilitating better electron transfer in the bioelectrochemical system. The EPCWMFC system achieved efficiencies of around 87.0%, 80.4%, 85.5%, and 250 mV for BOD, COD, TSS, and voltage, respectively, compared to 76.6%, 69.1%, 55.9%, and 156 mV in the control system for real HWW at HRT of 24 h and initial COD of around 1400 mg/l. Metagenomic analysis provided insights into biofilm interactions driving both biodegradation and electricity generation. The modified cathode also exhibited little antimicrobial and antifouling behaviour, thereby improving long-term stability. Overall, this study presents a sustainable, economical, and scalable hybrid treatment approach that integrates phytoremediation, bioremediation, photocatalysis, and bioelectrochemical processes. The developed systems demonstrate significant potential for decentralised hospital wastewater treatment and enhance eco-friendly wastewater management solutions, especially in resource-constrained environments.

Keywords: Hospital wastewater, Pharmaceutically active compounds (PhACs), Paracetamol (PCL), Diclofenac (DCF), Carbamazepine (CBZ), Constructed Wetland Microbial Fuel Cell (CWMFC), Multivariate optimization, Plant uptake, Degradation pathway, Toxicity assessment, Photocatalytic CWMFC (PCWMFC), Al-ZnO/Zeolite@Graphite photocathode, Enhanced Photocatalytic CWMFC (EPCWMFC), Bioelectricity generation, Photocatalysis, Metagenomic analysis, Antifouling and antimicrobial cathode