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Sequential anaerobic–aerobic dye degradation and amine detoxification in textile effluent using integrated microbial–algal fuel cell

Archana Yadav [a,b], Aakriti Tiwari [a,c], Vandana Mishra [a,d,e,*], Ankit Rao [f], Pankaj Poria [a,g], Pankaj Kumar [a,h], Pooja Baweja [i], Anubha Kaushik [f], Radhey Shyam Sharma [a,j,**]

[a] *Bioresources and Environmental Biotechnology Laboratory, Department of Environmental Studies, University of Delhi, Delhi, 110007, India*
[b] *Department of Environmental Studies, Maitreyi College, University of Delhi South Campus, Chanakyapuri, New Delhi, 110021, India*
[c] *Department of Environmental Studies, Ramjas College, University of Delhi, Delhi, 110007, India*
[d] *Centre of Interdisciplinary Studies of Mountain & Hill Environment, University of Delhi, Delhi, 110007, India*
[e] *DDA Biodiversity Parks Program, CEMDE, University of Delhi, Delhi, 110007, India*
[f] *University School of Environment Management, GGS Indraprastha University, New Delhi, 110078, India*
[g] *Department of Environmental Studies, Dyal Singh (E) College, University of Delhi, New Delhi, 110003, India*
[h] *One Health and Sustainability Laboratory, Department of Environmental Sciences, Sri Venkateswara College, University of Delhi South Campus, Benito Juarez Road, New Delhi, 110021, India*
[i] *Department of Botany, Maitreyi College, University of Delhi South Campus, Chanakyapuri, New Delhi, 110021, India*
[j] *Delhi School of Climate Change & Sustainability, Institute of Eminence, University of Delhi, India*

A R T I C L E I N F O

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A B S T R A C T

Microbial fuel cells (MFCs) offer a sustainable route for wastewater treatment and bioelectricity generation; however, their large-scale deployment is constrained by costly cathode catalysts and aeration requirements. In this study, a dual-chamber MFC was constructed using physically separated anodic and cathodic chambers coupled through a Nafion 117 cation exchange membrane, and integrated with a *Chlorella sorokiniana* biocathode to couple photosynthetic oxygen generation with pollutant degradation and detoxification. The system treated a real textile effluent model containing Acid Black 1 (AB1) and 4-Nitroaniline (4-NA) through a sequential two-stage process: reductive decolorization in the anaerobic anodic chamber followed by oxidative mineralization in the algal cathodic chamber. The algal biocathode enhanced redox efficiency, achieving near-complete decolorization (99.3% for AB1 and 100% for 4-NA) and a 39.8% reduction in total dissolved solids, alongside COD and chloride removal. Peak power density (768 mW m^{-2}) and voltage (527 mV) were obtained when pollutants were introduced into the cathodic chamber. Ultra-performance liquid chromatography confirmed complete degradation of aromatic amine intermediates (aniline, nitrophenol, benzidine), while *Allium cepa* assays revealed substantial reductions in cytotoxicity and genotoxicity, confirming true detoxification. The results demonstrate the synergistic role of bacterial and algal biofilms in achieving complete mineralization and toxicity removal while simultaneously generating electricity. This integrative, catalyst-free, two-stage MFC design provides a scalable, energy-positive framework for sustainable treatment of dye- and amine-laden industrial effluents.

1. Introduction

The textile industry is globally recognized as one of the largest generators of high-strength industrial wastewater, discharging effluents rich in refractory azo dyes and their aromatic-amine intermediates into aquatic environments. These effluents are characterized by a complex chemical mixture, high salinity, and variable organic loading, making them difficult to treat using conventional physicochemical methods [1–3]. Azo dyes account for nearly 70% of synthetic dyes used worldwide, and their reductive cleavage during wastewater processing

* Correspondence to: V. Mishra, Bioresources and Environmental Biotechnology Laboratory, Department of Environmental Studies; Centre for Interdisciplinary Studies of Mountain & Hill Environment (CISMHE), Biodiversity Parks, DU-DDA Programme, University of Delhi, Delhi, 110007, India.
** Correspondence to: R. S. Sharma, Bioresources and Environmental Biotechnology Laboratory, Department of Environmental Studies; Delhi School of Climate Change & Sustainability, Institute of Eminence, University of Delhi, Delhi, 110007, India.
E-mail addresses: mistletoe_h@hotmail.com (V. Mishra), rads26@hotmail.com (R.S. Sharma).

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