https://doi.org/10.7250/CONECT.2026.108

WHEN BIOREMEDIATION MEETS CIRCULAR ECONOMY: VALORIZATION OF ORGANIC WASTES FOR ENHANCED REMEDIATION OF HYDROCARBON-CONTAMINATED SOILS

Andrea FRANZETTI[1*], Asia ROSATELLI[2], Davide ROSSI[3], Alessandra SUAGHER[4], Mentore VACCARI[5], Teklit GEBREGIORGIS[6], Alif CHEFFI[7], Silvia SBAFFONI[8], Tiziana BELTRANI[9]

[1–4] *University of Milano-Bicocca, Department of Earth and Environmental Sciences (DISAT), Milan, Italy*
[5–7] *University of Brescia, Piazza del Mercato, 15, 25121 Brescia BS, Italy*
[8,9] *ENEA C.R. Casaccia, Via Anguillarese, 301, 00123, Rome, Italy*
[*] ***Corresponding author.*** *Email address: andrea.franzetti@unimib.it*

Abstract – The integration of biological treatment strategies with circular resource management offers a sustainable solution for restoring hydrocarbon-contaminated land while simultaneously valorizing organic residues. This study evaluates the performance of waste-derived amendments – including biochar, rhamnolipid biosurfactants, compost, and digestate – in enhancing biological and bioelectrochemical degradation processes. Laboratory and pilot-scale experiments were conducted to assess contaminant removal, electrochemical activity, and shifts in microbial community structure. Biochar obtained from biomass pyrolysis was tested as a conductive soil amendment in microbial electrochemical systems. An optimized dose of 8 % (w/w) resulted in hydrocarbon removal efficiencies up to 87.8 % and a maximum current density of 3.5 A/m^2, demonstrating improved extracellular electron transfer. Higher biochar concentrations reduced performance, likely due to mass-transfer limitations and decreased abundance of electroactive genera such as Geobacter and Desulfuromonas. Rhamnolipid biosurfactants produced from organic waste substrates were applied to increase contaminant bioavailability. A concentration of 100 mg/L enhanced removal to 72.5 % and increased current output ninefold compared with untreated controls, alongside enrichment of electroactive and hydrocarbon-degrading microbial taxa. A sequential treatment combining electro-Fenton oxidation with a rhamnolipid-assisted bioslurry phase was also investigated. Electrochemical oxidation using boron-doped diamond electrodes achieved 70.6 % degradation and generated more biodegradable intermediates, which were subsequently mineralized during the biological phase, leading to an overall removal of 93.6 % within 72 hours. These findings demonstrate that materials derived from organic waste streams can significantly intensify remediation processes while contributing to resource recovery and waste reduction. Optimization of amendment dosages, reduction of energy demand, and validation at field scale are key steps toward practical implementation.

Keywords – Anodic Biofilms; electrochemical oxidation; environmental restoration; Microbial Electrochemical Technologies (MET); resource recovery; rhamnolipid; waste-derived amendments

ACKNOWLEDGEMENT

This work has been supported by Fondazione Cariplo within the project "CREIAMO".