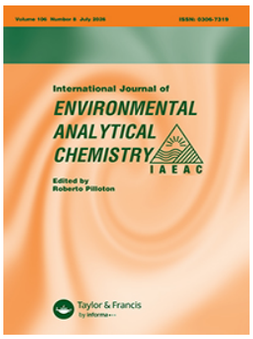

International Journal of Environmental Analytical Chemistry

ISSN: 0306-7319 (Print) 1029-0397 (Online) Journal homepage: www.tandfonline.com/journals/geac20

Facile synthesis, characterisation and applications of bio-polymer immobilized Zn-modified bauxite residue beads for malachite green dye removal: batch and column studies with CFD analysis

Abhrajit Chatterjee , Anurag Panda , Darpan Borah , Jitendra Kumar Patel , Shirsendu Banerjee , Bijoy K. Satpathy , Byong-Hun Jeon , Ramesh Kumar , Moonis Ali Khan , Sankha Chakrabortty & Suraj K. Tripathy

To cite this article: Abhrajit Chatterjee , Anurag Panda , Darpan Borah , Jitendra Kumar Patel , Shirsendu Banerjee , Bijoy K. Satpathy , Byong-Hun Jeon , Ramesh Kumar , Moonis Ali Khan , Sankha Chakrabortty & Suraj K. Tripathy (26 Jan 2026): Facile synthesis, characterisation and applications of bio-polymer immobilized Zn-modified bauxite residue beads for malachite green dye removal: batch and column studies with CFD analysis, International Journal of Environmental Analytical Chemistry, DOI: 10.1080/03067319.2025.2596300

To link to this article: https://doi.org/10.1080/03067319.2025.2596300

INTERNATIONAL JOURNAL OF ENVIRONMENTAL ANALYTICAL CHEMISTRY
https://doi.org/10.1080/03067319.2025.2596300

Facile synthesis, characterisation and applications of bio-polymer immobilized Zn-modified bauxite residue beads for malachite green dye removal: batch and column studies with CFD analysis

Abhrajit Chatterjee[a], Anurag Panda[a], Darpan Borah[a], Jitendra Kumar Patel[a,b], Shirsendu Banerjee[a], Bijoy K. Satpathy[c], Byong-Hun Jeon[d], Ramesh Kumar[d], Moonis Ali Khan[e], Sankha Chakrabortty[a] and Suraj K. Tripathy[a]

[a]School of Chemical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, India; [b]School of Mechanical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, India; [c]Research & Development and Buisness & Development, National Aluminium Company Limited, Bhubaneswar, India; [d]Department of Earth Resources & Environmental Engineering, Hanyang University, Seoul, Republic of Korea; [e]Department of Chemistry, College of Science, King Saud University, Riyadh, Saudi Arabia

ABSTRACT

A sustainable approach for dye pollution mitigation through industrial residue and natural polymer-based wastewater treatment was developed in this work. In the present study, environmentally friendly biopolymer-immobilised Zn-modified bauxite residue beads (BR-Zn-SA) were prepared to effectively remove toxic cationic dye malachite green, which has widespread applications in textile and paper industries. Zinc chloride was applied to activate the bauxite residue by enhancing its surface porosity, acidity, and Lewis active sites, which increased the amount of electrostatic and coordination binding centres for MG adsorption. Biodegradable polysaccharide sodium alginate acted as an encapsulating matrix providing mechanical stability with a hydrophilic nature and extra -COOH/-OH functional groups, preventing particle leaching and improving reusability in continuous systems. XRD, FTIR, BET, and PZC analyses identified a mesoporous structure with positive surface potential, hence favourable for cationic dye uptake. Batch adsorption study under optimised conditions resulted in the removal of 96–97% at pH 7, 60 g L^{-1} dosage, 300 rpm, and 10 mg L^{-1} MG. Fixed-bed column experiments demonstrated better breakthrough performance for the highest bed height of 14 cm and lowest flow rate of 10 mL min^{-1}. Models fitted the column data, and CFD simulation confirmed the optimality of flow uniformity and mass transfer. In this work, a unique combination of waste valorisation through zinc activation, alginate-based biopolymer immobilisation, and CFD-assisted modelling was employed to develop a cost-effective, easily scalable, and ecofriendly adsorbent system for industrial dye remediation.

ARTICLE HISTORY
Received 10 September 2025
Accepted 22 November 2025

KEYWORDS
Bauxite residue; CFD; material characterisations; adsorption; kinetics and hydrodynamics; economic analysis

CONTACT Byong-Hun Jeon bhjeon@hanyang.ac.kr; Ramesh Kumar rameshibt@hanyang.ac.kr; Sankha Chakrabortty sankha.chakrabortty@kiitbiotech.ac.in; Suraj K. Tripathy suraj.tripathy@kiitbiotech.ac.in