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RESEARCH ARTICLE

Chemical activation of phosphogypsum exhibits enhanced adsorption of malachite green from aqueous solution due to porosity refinement

Anurag Panda[1], Anuradha Upadhyaya[1], Ramesh Kumar[2], Argha Acooli[1], Shirsendu Banerjee[1,3], Amrita Mishra[3], Moonis Ali Khan[4], Somnath Chowdhury[5], Byong-Hun Jeon (✉)[2], Sankha Chakrabortty (✉)[1,3], Suraj K. Tripathy (✉)[1,3]

1 School of Chemical Technology, Kalinga Institute of Industrial Technology, Bhubaneswar 751024, India
2 Department of Earth Resources & Environmental Engineering, Hanyang University, Seoul 04763, Republic of Korea
3 School of Biotechnology, Kalinga Institute of Industrial Technology, Bhubaneswar 751024, India
4 Department of Chemistry, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
5 Department of Chemical Engineering, National Institute of Technology, Durgapur 713209, West Bengal

Abstract Owing to its uncomplicated synthetic methodology and exorbitant market demand, malachite green is widely used in numerous industries, particularly as a fungicide in aquaculture. Considering its intrinsic toxicity and potential long-term health impacts, deployable and cost-effective strategies must be developed for eliminating water-soluble malachite green. In this study, chemically activated phosphogypsum, a byproduct of fertilizer production, was used to remove malachite green from an aqueous system. Due to its low cost and abundance, the use of phosphogypsum as a sorbent material may significantly reduce the cost of adsorption-based processes. Moreover, its structural durability allows efficient recycling without significant deformation during reactivation. However, untreated phosphogypsum exhibits minimal efficiency in adsorbing synthetic dyes due to its unfavorable surface chemistry. Our investigation revealed that Zn activation induced a noticeable increase in pore volume from 0.03 to 0.06 $cm^3 \cdot g^{-1}$. A 60 $mg \cdot L^{-1}$ sorbent dose, pH 7, 150 $r \cdot min^{-1}$, and operational temperature of 30 °C produced 99% quantitative sorption efficiency. Response surface methodology and artificial neural network were used to optimize process parameters by validating experimental values. No detectable toxicity was observed in *Escherichia coli* when exposed to the treated water.

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E-mails: bhjeon@hanyang.ac.kr (Jeon B-H),
sankha.chakrabortty@kiitbiotech.ac.in (Chakrabortty S),
suraj.tripathy@kiitbiotech.ac.in (Tripathy S K)

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1 Introduction

Throughout history, human societies have consistently established settlements near water sources and witnessed catastrophic crises resulting from water scarcity. Considering the influence of safe and sustainable water on food, transportation, and industry, it is undeniable that "water" is an invaluable resource on Earth [1,2]. Access to safe water is crucial for the survival and well-being of humanity and is consequently emphasized in the UN's Sustainable Development Goals [3]. However, despite the abundance of knowledge and experience, available water sources are compromised due to the overexploitation and discharge of pollutants from various anthropogenic activities [4]. Additionally, the proliferation of the human population and the demand for commodities have resulted in an exponential increase in industrialization and urbanization, causing the release of harmful substances into water bodies and unprecedented pollution [5]. Specifically, synthetic dyes are widely recognized as a prominent type of contaminant that regularly pollutes water sources, rendering them unsuitable for both aquatic life and humans [6]. A recent study revealed that approximately one million tons of synthetic dyes are produced and circulated annually in the global market [7]. Most of these compounds, at concentrations below 1 $g \cdot L^{-1}$, may impede the diffusion of sunlight through the