

RESEARCH ARTICLE

Bioremediation Mechanisms of Methyl Orange by *Ceriporia lacerata* RF-7: From Characterization of Nanoporous Surfaces to Spontaneous Thermodynamics

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ABSTRACT

This study focused on the critical environmental problem of harmful synthetic dyes being discharged into aquatic environments, which cannot be purified by conventional methods. We investigated the removal of methyl orange (MO) using *Ceriporia lacerata* RF-7, a recently discovered white-rot fungus, as a potent bioadsorbent. SEM and BET analyses of the biomass structure and texture revealed a complex, porous hyphae with sufficient surface area for dye adsorption, as well as a large specific surface area and mesoporous structure that promotes molecular diffusion. The efficiency of bioadsorption was significantly influenced by pH and temperature, achieving a maximum removal rate of 95.0% at pH 4. High removal efficiency was maintained up to 40°C, and at 30°C, the adsorption process was found to be thermodynamically spontaneous. This thermal stability shows that treating industrial wastewater does not require rigorous temperature control and is an energy-efficient method. Equilibrium results confirmed the Langmuir adsorption isotherm model ($R^2 > 0.999$) and demonstrated a significant maximum monolayer adsorption capacity q_{max} of 185.10 mg/g, surpassing many commercially available and biological adsorbents. Kinematic studies demonstrated that the bioadsorption process adheres to a pseudo-second-order reaction mechanism, indicating that the rate-limiting step is influenced by both definite chemisorption and surface interactions. Thermodynamic studies show that the process is spontaneous ($\Delta G^\circ < 0$), is endothermic ($\Delta H^\circ = +58.20$ kJ/mol), and leads to greater disorder at the solid-liquid interface ($\Delta S^\circ = +224.0$ J/mol·K). These findings underscore RF-7 as a strong, environmentally friendly, and highly effective biosorbent, providing a sustainable approach for the efficient treatment of industrial wastewater contaminated with dyes.

1 | Introduction

The worldwide growth of the textile and chemical sectors has led to the rampant release of synthetic azo dyes into water bodies, causing a significant environmental emergency (Upadhyay et al. 2025). Methyl orange (MO), an anionic dye with sulfonate groups, is commonly acknowledged as a persistent pollutant because of its intricate aromatic composition and significant solubility in water (Lopez-Moya et al. 2019; Yildirim and Acay 2025). The endurance of MO in water bodies obstructs light flow,

which interferes with the photosynthetic effectiveness of aquatic microflora and increases the chemical oxygen demand (COD) (Negi and Das 2023). Moreover, the breakdown of azo dyes can result in the generation of aromatic amines, known for their carcinogenic and mutagenic effects in advanced organisms (Aggour et al. 2025; Mohammed 2023). Thus, creating sustainable and high-performance technologies for the capture of MO from industrial wastewater is essential for environmental protection (Abdallah and Alprol 2024). MO is a very poisonous azo dye with persistent $-N=N-$ linkages that are resistant