Microporous and Mesoporous Materials 378 (2024) 113253

Contents lists available at ScienceDirect

Microporous and Mesoporous Materials

journal homepage: www.elsevier.com/locate/micromeso

Hybrid mesoporous microbeads based on sheets-like sulfur-doped copper oxide embedded in calcium alginate-derived carbon for batch and columnar adsorption of cationic dye

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ARTICLE INFO

Keywords:
Crystal violet
Mesoporous adsorbent
Adsorptive removal
S-doped CuO
Alginate-derived carbon beads
Agriculture and fabric wastewater

ABSTRACT

Recent increases in the release of untreated water containing cationic dyes have led to significant environmental issues in ecosystems. Many industries contribute to this pollution by discharging water containing various organic pollutants, including crystal violet (CV). Therefore, a novel hybrid mesoporous sulfur-doped copper oxide embedded in Cu-alginate-derived carbon micro-beads (SCO@CACBs) adsorbent was developed for CV-decolorization through batch and fixed-bed columnar techniques. Comparative studies on the effectiveness of CV removal using CACBs and SCO@CACBs under different conditions such as pH, stirring time, amount of sorbent, initial CV concentration, and temperature were conducted. The results demonstrated that the optimal CV removal reached up to 99 % at neutral pH conditions (pH of 7), with an adsorption capacity of 87 mg/g through a batch approach. The CV adsorption process was analyzed using various methods, including adsorption isotherms, kinetics, thermodynamics, zeta potential measurements, and density-functional theory (DFT) calculations. Langmuir (R^2 = 0.995) and pseudo 2nd order (R^2 = 0.998) models most agree with experimental CV-adsorption data. Thermodynamic parameters indicated that CV adsorption is spontaneous, favorable, and endothermic. The columnar adsorption tests showed that the adsorption capacity of SCO@CACBs varied from 83.6 to 71.3 mg/g as the flow rate varied from 2 to 6 mL/min and 81.5–115.6 mg/g as the adsorbent mass varied from 1 to 4 g. The Thomas and Yoon-Nelson models fitted the breakthrough curves. The adsorbent maintained high removal efficiency (about 93 %) after five reuse cycles through batch and fixed-bed columnar approaches. Notably, the SCO@CACBs showed over 96 % efficiency in removing CV dye from actual agricultural and textile wastewater samples using batch and column setups. Thus, SCO@CACBs is an effective sorbent for removing CV dye from water contaminated by natural sources.

1. Introduction

The lack of clean water is a global dilemma that has bothered researchers worldwide. In particular, the rapid escalation of human activities irrefutably damages several water resources [1–3]. For instance, generated dyes-comprising effluents from industries like leather, food, textile, pharmaceutical, and dyeing cause a pollution expansion in water bodies [4,5]. Notably, the flexible interaction feature

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https://doi.org/10.1016/j.micromeso.2024.113253
Received 15 May 2024; Received in revised form 1 July 2024; Accepted 9 July 2024
Available online 10 July 2024