Exploring Waste Biomass-Derived Biochar for Carbendazim Removal in Fixed-Bed Systems: A Sustainable Approach to Wastewater Treatment

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Highlights

- Carbendazim (CBZ) adsorption from water using (waste biomass) sludge derived biochar.
- Identifying optimal conditions for CBZ removal, with experiments demonstrating increased adsorption capacities and detailed mass transfer zone analysis.
- Utilizing BDST model for understanding of adsorption mechanisms.
- Validating the system's effectiveness with real water samples.

Keywords
Carbendazim removal; Biochar; Fixed-bed adsorption; Waste-Reuse

INTRODUCTION

The widespread use of carbendazim as a benzimidazole fungicide in agriculture has raised significant concerns due to its classification as a hazardous class IV pesticide, posing threats to both human health and the environment (Ding et al., 2019). Exposure to carbendazim has been linked to congenital abnormalities and environmental contamination (McKinlay et al., 2008), particularly in water bodies where runoff can transport high concentrations of the compound (Merel et al., 2020). To address these challenges, several researchers have recently explored the combined use of biochar and clay to enhance their properties and expand their potential applications (Wang et al., 2019). For example in an investigation it was found that by using biochar/clay composites for methylene blue adsorption from aqueous solution, the adsorption capacity increased nearly five times (Yao et al., 2014). Li et al. (2015) reported that biochar-montmorillonite composites showed about a 7% increase in the adsorption of acetochlor herbicide compared to biochar alone within 24 hours. These studies suggest that combination of biochar and clay in fixed-bed columns can be promising approach in treatment of contaminated water. Thus the present study aimed to investigate the performance of clay and biochar as dual filter media for removal of carbendazim (commonly used fungicide) from the water. The study used the fixed-bed system incorporated with a layer of biochar between two layers of calcined clay. The performance of proposed system was also investigated under real field conditions using real water samples spiked with carbendazim.

METHODOLOGY

The clay utilized in this study was sourced from a river, washed thoroughly with deionized. The calcination of clay was carried out at 500 °C for 24 hours in a furnace to improve its stability for fixed-bed adsorption (Almeida Neto et al., 2012). The waste biomass underwent air drying, mechanical powdering, sieving, and washing with deionized water. Subsequently, it was oven-dried, carbonized at 600°C under N_2, cooled, washed, and oven-dried again. The resulting biochar, designated BC-W. Elemental composition was assessed using an elemental analyzer, surface characteristics analyzed using SEM and functional groups assessed using FTIR. Fixed-bed adsorption experiments for carbendazim fungicide utilized a vertically positioned column with upward flow, monitored at approximately 25°C. Residual carbendazim concentrations were analyzed via HPLC. Fluid dynamic studies explored various flow rates (3, 4 and 5 mL min^{-1}) and inlet carbendazim concentrations (0.1, 0.2 and 0.3 mmol L^{-1}). Bed depth of BC-W was also varied (1, 2 and 3 cm) and experiments were conducted under neutral pH condition.

RESULTS AND CONCLUSIONS

The results reveal that the optimal flow rate for maximum adsorption efficiency was 4 mL min^{-1}, with the carbendazim removal values reaching 0.42 mmol g^{-1} at this rate can be seen in Table 1. A carbendazim concentration of 0.2 mmol L^{-1} was identified as ideal as the height of the mass transfer zone was reduced to 0.64 cm while achieving a high saturation removal percentage of 31.25%. The optimal bed height was found to be 1 cm, at which the breakthrough time was sufficiently prolonged, and the saturation adsorption capacity was 0.38 mmol g^{-1}, offering a practical depth without excessive adsorbent use or diminished efficiency. Furthermore, the Bed Depth Service Time (BDST) model was effectively employed to predict system performance under varying conditions (Figure 1b). The model showed high accuracy, with a coefficient of determination (R^2) greater than 0.98, demonstrating its utility in scaling up the process and confirming the practical applicability of WB-BC in water treatment operations for the removal of pesticide such as carbendazim. Additionally the study investigated the removal of carbendazim from tap water using a fixed bed column composed of BC-W. Tap water sample was spiked with carbendazim to a concentration of 0.2 mmol L^{-1} and processed under optimized conditions: a flow rate of 4 mL/min, bed height of 1 cm, and pH of 7.6±0.2 (Figure 1a). The performance was compared against distilled water, revealing that breakthrough and saturation occurred earlier in tap water (average t_b=266 mins, t_s =1880 mins) than in distilled water (t_b =360 mins, t_s=2280 mins). This resulted in a reduced adsorption capacity in tap water from 0.38mmol g^{-1} to 0.33mmol g^{-1} (Table 1) due to the presence of competing substances such as chlorides, sulfates, nitrates, and minerals like Ca^{+} and Mg^{+} present in tap water.

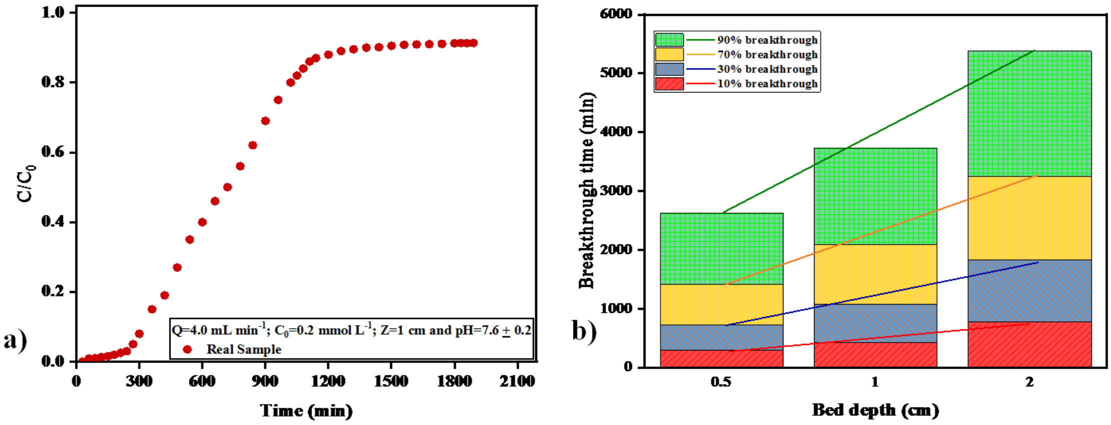

Figure 1 a) Adsorption behavior real water sample spiked with CBZ under optimized conditions b) BDST model for different breakthrough percentages under varying bed depths

The study confirms the potential of this waste derived biochar for practical, real-world applications, highlighting its efficiency and adaptability. As such, it offers a promising solution for addressing contamination issues, not only with pesticides like carbendazim but also with other harmful substances, thereby enhancing water quality through a comprehensive single-step treatment. Although there was a reduction in the adsorption capacity when treating tap water, the BC-W effectively removed carbendazim and significantly decreased the concentrations of co-existing substances in the water.

Table 1: Breakthrough curve parameters of CBZ adsorption on WB-BC under different experimental conditions

Experimental conditions				**Experimental parameters for breakthrough curves**						
Q (mL min^{-1})	**Z (cm)**	**C_o (mmol L^{-1})**	**pH**	**t_b (mins)**	**V_b (L)**	**t_s (mins)**	**V_s (L)**	**q_b (mmol g^{-1})**	**q_s (mmol g^{-1})**	**MTZ (cm)**
3.0	1	0.3	7.6±0.2	300	0.90	2400	7.20	0.12	0.41	0.71
4.0	1	0.3	7.6±0.2	240	0.96	1740	6.96	0.12	0.42	0.72
5.0	1	0.3	7.6±0.2	180	0.90	1440	7.20	0.09	0.40	0.76
4.0	1	0.2	7.6±0.2	360	1.44	2280	9.12	0.14	0.38	0.64
4.0	1	0.1	7.6±0.2	480	1.92	2820	11.28	0.09	0.21	0.57
4.0	2	0.2	7.6±0.2	540	2.16	3360	13.44	0.13	0.33	1.18
4.0	0.5	0.2	7.6±0.2	240	0.96	1500	6.00	0.12	0.34	0.33
Real Sample										
4.0	1	0.2	7.6±0.2	266	1.06	1880	7.52	0.11	0.33	0.65

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