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NOVEL WASTE-DERIVED CIRCULAR MATERIAL FOR WASTEWATER DECONTAMINATION

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Introduction

The continuous growth of anthropogenic waste generated by industrial and domestic activities remains a major, largely unresolved environmental issue, contributing to soil, water and air pollution. Water pollution with synthetic dyes and heavy metals is a persistent concern, particularly in regions with a long history of industrial and mining activity. In Romania, the mining sector active during the socialist period left behind a considerable environmental footprint, notably polluted mining wastewater and tailings; tailings ponds and abandoned mines still pose major environmental and human health risks. In this context, there is a constant need for sustainable, "*green*" solutions addressing both waste accumulation and water decontamination. Valorising waste as a raw resource for new functional materials is one such strategy, supporting the principles of both circular economy and sustainable development. The present study aimed to develop a new eco-friendly composite material by combining an industrial mineral waste (stone dust) with a food-derived organic residue (banana peels), and to evaluate its ability to adsorb dyes (such as tartrazine) and heavy metals (Cu, Zn, Ni, As, Cd, Mn, Fe, Pb) from contaminated effluents, including real wastewater from the Borsa mining perimeter (Maramures County, Romania).

Materials and methods

The composite material was obtained by combining, in an optimised ratio (4:1), an organic residue from food and daily consumption activities (banana peels), rich in cellulose and hemicellulose, with an inorganic mineral residue from the extractive materials industry (stone dust). The two waste fractions were dried, ground, homogenised and combined to obtain a porous, brown-coloured, friable composite material. The material was characterised by FTIR, to identify the functional groups, and by SEM-EDX, to evaluate morphology and elemental composition. Batch adsorption experiments evaluated heavy metal (Cu, Zn, Ni, As, Cd, Mn, Fe, Pb) and tartrazine removal performance from solutions with initial concentrations between 1 and 100 mg/L, and the influence of contact time (up to 240 minutes); data were fitted with pseudo-first- and pseudo-second-order kinetic models. Preliminary tests were also performed on real water from the Borsa mining perimeter. Heavy metals were determined by ICP-OES, while dyes were analysed via UV-Vis.

Results and conclusions

FTIR analysis showed that the composite incorporates absorption bands characteristic of both starting residues. The intensity of the band at 2844-2924 cm^{-1} (aliphatic C-H stretching) increased noticeably in the composite spectrum, and a broad -OH band was observed at 3428 cm^{-1}, confirming the contribution of the organic residue's hydroxyl, phenolic and amino groups. SEM images revealed that the novel material has a more homogeneous, perforated morphology than the mineral residue. EDX analysis of the composite showed a higher carbon content, confirming successful incorporation of the organic residue. Preliminary batch tests showed that removal efficiency and adsorption capacity for dyes increased with initial contaminant concentration. The composite performed better than its mineral precursor, adsorbing up to two to three times more dye (76.7% removal for the hybrid material and 25.6% for the stone dust at 10 mg/L tartrazine; 99.5% efficiency for the composite compared to 49.1% for the stone dust at 100 mg/L tartrazine). Contact time had little influence beyond the first 10-20 minutes, after which maximum removal (99.5%) was already attained, indicating a fast retention rate. The pseudo-second-order model fitted the data far better than the pseudo-first-order model (R^2 = 0.999 versus R^2 = 0.470), suggesting chemisorption governs the process. Preliminary heavy metal tests on real mining-impacted water from the Borsa perimeter showed that the composite achieved up to 98% copper removal using 10 g of material within 4 hours of contact with 50 mL volume of contaminated wastewater.

Overall, these preliminary results indicate that the new waste-derived composite is a promising, low-cost, eco-friendly adsorbent for treating dye- and heavy-metal-contaminated effluents, combining fast adsorption with high removal efficiency and supporting residue valorization and environmental remediation goals.

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