

Fabrication of Zinc Oxide-Sawdust Composite Adsorbent for dyes removal

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Abstract

For the benefit of humanity, the waste products from the paper, forestry, and lumber industries must be converted into commercially viable commodities due to their constant growth. This paper describes the creation and use of zinc oxide-incorporated sawdust as a new adsorbent for the removal of congo red (CR) and methylene blue (MB) from water. The UV–vis spectrophotometer was used to measure the amount of MB and CR adsorbed. The findings showed that variations in solution pH, nanocomposite dose, beginning concentration, temperature, and reaction time were related to the removal effectiveness of MB and CR. Using a concentration of 30–150 mg L⁻¹ and a temperature range of 5–30 °C, the adsorption equilibrium isotherm was determined. The ZnO@SD nanocomposite has opportunities for more study and use in improving dye-containing effluent based on adsorption performance. Overall, the results suggest that the ZnO@SD composite is an effective, eco-friendly, and economical adsorbent for the treatment of dye-contaminated wastewater, offering significant potential for practical environmental remediation applications.

Keywords: Nanocomposite; Adsorption, Dyes.

Introduction

The rapid and aggressive growth of industrial activities and the world's population has destroyed aquatic, terrestrial, and atmospheric ecosystems, resulting in environmental effluences that are essential to both the survival of the ecosystem and the existence of humans and other living things. Water quality has been significantly deteriorated by the careless release of untreated industrial effluents, according to numerous studies. Among other industrial operations, industries including mining, paint production, metal plating, textiles, paper, leather processing, and petroleum refining frequently discharge these effluents into aquatic systems [1]. As a result, they greatly contribute to global warming and climate change, health issues, food scarcity (agricultural shortfall), etc. Up to 2.00×10⁵ tons of dyes are thought to be disposed of, released, or discharged into aquatic habitats as a result of poor wastewater management and treatment practices. This holds true for the vast majority of dye-using industries, such as the paint, leather, paper, textile, and cosmetics sectors [2]. These toxic and aromatic wastewaters are disposed of, released, or discharged into aquatic environments without first undergoing the proper treatment. The cosmetics, textile, paper, leather, and paint industries are among those that use synthetic and toxic dyes extensively, mainly for the purpose of coloring their products [3].

Various methods, such as chemical, biological, and physical processes, could be employed to extract dyes from wastewater. The restricted performance, non-biodegradability, and secondary waste production of several of these methods are disadvantages that lead to disposal problems. The adsorption process is widely used since it is easy to apply, inexpensive, and effective at eliminating color and other contaminants [4]. Adsorption techniques involving nanoparticles are gaining popularity as a possible way to extract color

from wastewater from textiles. Because of their higher surface-to-volume ratio than traditional adsorbents, nanoparticles have been shown to have a significant potential for adsorbing organic chemicals, particularly colors, from wastewater and sewage tanks [5].

Metal oxide nanoparticles have demonstrated significant potential in the adsorption of dangerous dyes. A wide range of inorganic metal oxides may be effective adsorbents because to their large surface area and chemical and thermal durability [6]. Zinc oxide nanoparticles (ZnO NPS) have garnered significant interest in water treatment due to their potent antibacterial qualities against microorganisms frequently present in water, long-term stability, low cost, biocompatibility, and nontoxicity. For instance, large quantities of metal nanoparticles can be produced more quickly using chemical, physical, and biological methods; however, these methods necessitate the use of dangerous substances as capping agents to guarantee stability, which can be damaging to the environment. Physicochemical methods for producing ZnO nanoparticles (NPS) include sol-gel, co-precipitation, laser vaporization, microemulsion, and ball milling. The objective of this work is to produce a zinc oxide-sawdust (ZnO@SD) composite adsorbent and assess how well it removes Congo red and methylene blue dyes from aqueous solutions. The effects of operational parameters on adsorption performance were methodically examined. This study demonstrates ZnO@SD's potential as an affordable and environmentally friendly adsorbent for the treatment of wastewater contaminated with dyes.

Methodology

Sawdust is collected from a local sawmill and washed. After drying for 24 hours at 100°C in an oven, it is crushed and sieved. Biochar is produced from SD using direct pyrolysis, which is carried out in a muffle furnace. In a crucible with a lid, 20g of SD is heated to 600°C for two hours in a muffle furnace. Activated carbon is created by chemically activating biochar using ZnCl₂. ZnCl₂ to biochar impregnation ratios range from 1:1. 10 grams of biochar were added to the mixture after 10 grams of ZnCl₂ were dissolved in 150 milliliters of dissolved water. The mixture was left for six hours at room temperature. The liquid portion was filtered, and the leftover solids were dried for around 24 hours at 110°C in a hot oven. A crucible with a lid is filled with roughly 10 grams of impregnated biochar. The activated carbon produced under enhanced operating conditions is known as zinc biochar, or ZnBC. After the biochar has been cleaned with dil, it is finally cleaned with distilled water. HCl until the filtrates' pH reaches a steady level.

Methylene blue and congo red, two model organic pollutants from the Merck Group, were used to analyze the adsorption models. One liter of distilled water was used to dissolve the stock solution (1000 mg L⁻¹) that was made using 1000 mg of MB and CR. Concentrations of 30, 50, 70, 90, 110, 130 and 150 mg L⁻¹ of MB and CR were created. The MB and CR solutions' pH parameters were adjusted to the anticipated values of 2, 4, 6, 8, 10 and 12 using 0.010M of NaOH and/or HCl solutions.

$$\text{Adsorption efficiency (\%)} = \frac{C_i - C_e}{C_i} * 100$$

$$\text{Adsorption capacity (q}_e\text{)} = \frac{C_i - C_e}{m} * v$$

Result and Discussion

Effect of pH

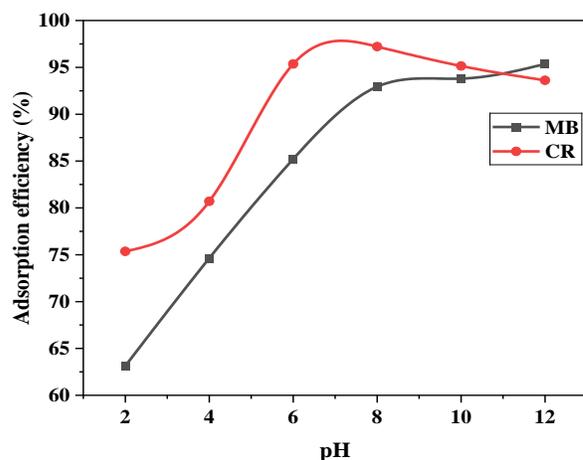


Fig. 1: Effect of pH on MB and CR dye adsorption efficiency onto ZnO@SD NC.

The pH of the solution and surface-charge distribution of nanocomposite have a significant impact on adsorption of MB and CR dye using ZnO@SD. Electrostatic interactions between active site on surface of composite and dye molecules can be either repulsive or attracting, depending on the pH of the solution. Figure 1 shows how altering pH of solution affects adsorption of dye molecules. The adsorption effectiveness of the cationic MB dye rose significantly as pH rose, peaking at 93% between pH 8.0 and pH 10. This enhancement is attributed to surface deprotonation of the nanocomposite under alkaline conditions, which generates negatively charged sites that favor electrostatic attraction with MB cations. On the other hand, at acidic conditions (pH 4.0–6.0), where protonation of the ZnO@SD surface creates positive sites that improve interaction with negatively charged CR molecules, the anionic CR dye demonstrated a high adsorption efficiency (96%). Increased electrostatic repulsion caused a modest drop in efficiency at higher pH values. According to these findings, the ZnO@SD nanocomposite has pH-responsive surface behavior, which, at the right pH, allows for the efficient removal of both cationic and anionic dyes through electrostatic interactions.

Effect of adsorbent dose

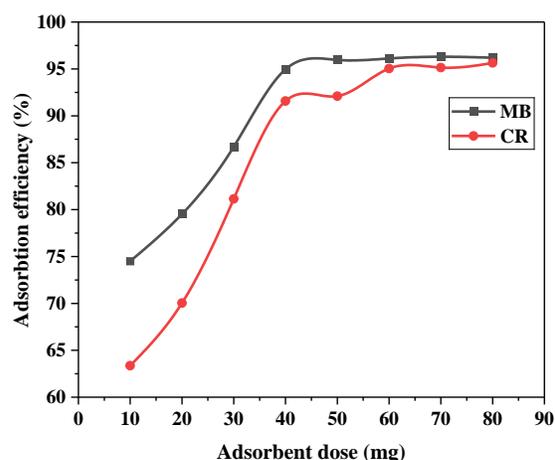


Fig. 2: Effect of adsorption dose on MB and CR dye adsorption efficiency onto ZnO@SD NC.

The adsorbent dosage is a crucial parameter, because it directly affects adsorption performance and, thus, controls the effectiveness of pollutant removal. ZnO@SD composite doses ranging from 10 mg to 80 mg were used to optimize the adsorbent's dosage and determine its impact. The percentage removal with ZnO@SD rose from 74.5 to 96.3% and 63.36% to 95.14% at equilibrium for MB and CR when the adsorbent dosage was increased (Fig. 2). The sorbate's consistent improvement in percentage absorption with adsorbent dose is due to increased surface area and more binding sites for adsorption. The lowest adsorbent dose of 10 mg was found to have the highest adsorption capacity of 372.5 mg g⁻¹ and 316.8 mg g⁻¹ for MB and CR, respectively. It is crucial to remember that particle amalgamation and aggregation may happen at greater adsorbent dosages, which would lower the effective surface area per unit weight of the adsorbent and, in turn, lower adsorption efficiency.

Effect of initial dye concentration

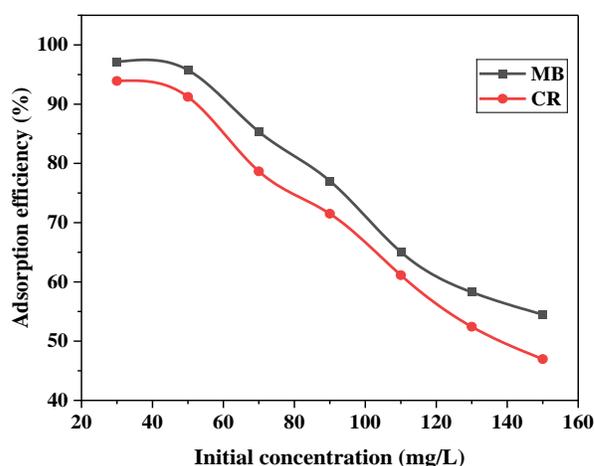


Fig. 3: Effect of initial dyes concentration on MB and CR dye adsorption efficiency onto ZnO@SD NC. Figure 3 shows how the initial dye concentration affects the dye's adsorption from a solution onto ZnO@SD nanoparticles. While maintaining constant other parameters, the starting dye concentration was changed from 30 mg/L to 150 mg/L (30, 50, 70, 90, 110, 130, and 150 mg L⁻¹). MB concentrations ranged from 10 to 150 mg L⁻¹, with the highest adsorption efficiency of 97.13% recorded at 30 mg L⁻¹. The experiment involved 40 milliliters of dosage, 100 milliliters of dye solutions with concentrations ranging from 30 to 150 mg L⁻¹, and 80 minutes of agitation at 150 rpm at 25 °C. Figure 3 illustrates how the percentage of clearance falls as the dye concentration rises. Specifically, MB dye adsorption was found to decrease with increasing concentration (from 97.13% at 30 mg L⁻¹ dye concentration to 54.49% at 150 mg L⁻¹). Additionally, adsorption efficiency for CR dye drops from 93.9% to 46.97% as concentration increases from 30 mg L⁻¹ to 150 mg L⁻¹. The many dye molecules that vary for the fixed active site on the composite at higher dye concentrations can be used to explain this pattern. Consequently, a higher ratio of adsorbent to adsorbate results in a lower proportion of color removal. The adsorption capacity (q_e) of MB and CR dyes increased from 72.85 mg/g to 204.33 mg/g and 70.42 mg/g to 176.15 mg/g, respectively, when the initial dye concentration rose from 30 mg L⁻¹ to 150 mg L⁻¹.

Effect of Contact time

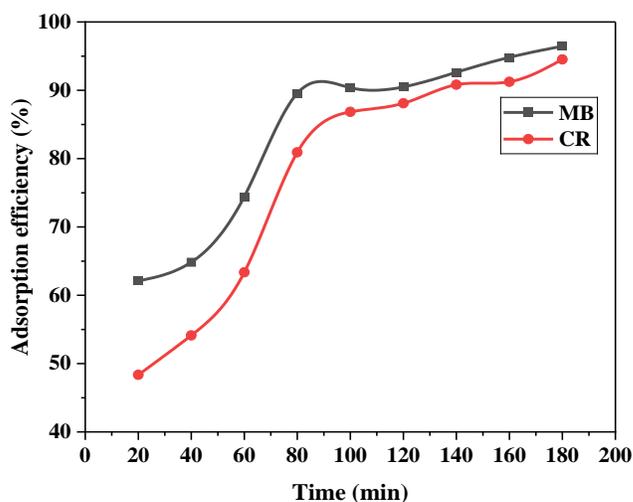


Fig. 4: Effect of time on adsorption of MB and CR dye onto ZnO@SD NC.

Contact time is a crucial instrument in adsorption research. The effect of contact duration on MB and CR dye adsorption onto ZnO@SD NPs is depicted in Fig. 4. Contact time was adjusted from 20 to 180 minutes while maintaining the same initial dye concentration of 50 mg/L at 25°C, 40 mg composite dosage, and 8.0 pH in order to determine the influence of the time. The elimination percentage increases significantly as the contact period reaches 80 minutes, and equilibrium is reached for both MB and CR dye. The initial rapid removal of dyes is caused by the huge number of active sorption sites on the adsorbent surface. However, the rate of dye removal slows down and equilibrium is attained as time passes and these spots get saturated.

Effect of Temperature

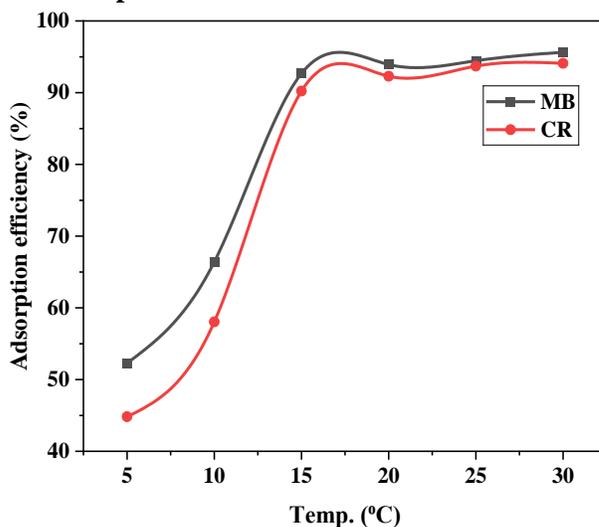


Fig. 5: Effect of temperature on adsorption of MB and CR dye onto ZnO@SD NC.

At 5, 10, 15, 20, and 25 degrees Celsius, the effects of solution temperature on ZnO@SD NPs' capacity to eliminate MB and CR were examined. Increasing the temperature of the solution significantly affected the % removal of MB and CR, as shown in Fig. 5. In particular, the removal of MB and CR increased from 52.3% to 95.64% and 44.82% to 94.1%, respectively, when the temperature was raised from 5 to 30°C, suggesting that the removal process is endothermic. By absorbing more heat energy, the dye adsorption

equilibrium changes as the temperature rises. The interaction between dye molecules and adsorbent particles is improved by this temperature increase, which results in increased contact until equilibrium is reached.

Conclusion

The goal of the current study is to develop adsorbents that are environmentally friendly, economical, and highly effective using lingo-cellulosic components found in sawdust waste. In this study, a cost-effective and environmentally benign zinc oxide–sawdust (ZnO–SD) composite adsorbent was successfully fabricated and evaluated for the removal of methylene blue (MB) and Congo red (CR) dyes from aqueous solutions. Cellulosic adsorbents produced in this work have promising uses in water purification and disinfection, as well as the effective removal of various hazardous contaminants from their aqueous media. Batch adsorption experiments demonstrated that the ZnO–SD composite exhibited high removal efficiency toward both cationic (MB) and anionic (CR) dyes, indicating its dual adsorption capability. The adsorption performance was strongly influenced by solution pH, initial dye concentration, contact time, and adsorbent dosage. Future studies should focus on scaling up the ZnO–sawdust composite for continuous-flow systems, evaluating its reusability and stability over multiple adsorption cycles, and testing its performance with real industrial wastewater. Assessing metal leaching and environmental safety will further support its practical application.

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