Agro-waste to Water Purifier: Corncob Biochar for Efficient Anionic Dye Removal

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Abstract— **This study investigates the use of corncob biochar as a low-cost and sustainable adsorbent for the removal of methyl orange from aqueous solutions. Corncobs were washed, dried, ground, and chemically activated with NaOH to enhance adsorption efficiency. Batch adsorption experiments were conducted to evaluate the effects of solution pH, contact time, initial dye concentration, and adsorbent dosage. The results showed that adsorption was highly pH-dependent, with maximum removal efficiency of 96% at pH 4–5. Equilibrium was reached within 120 minutes, and adsorption capacity increased with higher dye concentrations. SEM analysis revealed a highly porous surface, while FTIR confirmed the involvement of hydroxyl and carbonyl functional groups in dye binding. The study demonstrates that corncob biochar is an effective, environmentally friendly, and economically viable adsorbent for dye removal from wastewater, offering potential applications in sustainable wastewater treatment**.

Index Terms— **Methyl Orange; Corncob Adsorbent; Adsorption; Wastewater Treatment; Anionic Dye**

I. INTRODUCTION

The release of dye-containing effluents from textile, paper, leather, and printing industries has become a major environmental concern due to their toxicity, aesthetic impact, and resistance to biodegradation. Among various synthetic dyes, methyl orange is a widely used anionic azo dye that poses serious risks to aquatic life and human health when discharged into water bodies. Conventional treatment methods such as coagulation, oxidation, and membrane filtration often suffer from high cost, secondary pollution, or limited efficiency. Adsorption has emerged as an effective and economical technique for dye removal, particularly when low-cost and sustainable adsorbents are employed. In this context, agricultural wastes have gained attention as eco-friendly alternatives to commercial adsorbents. In the present study, corncob, an abundant agricultural by-product, was investigated as a low-cost and sustainable adsorbent for the removal of methyl orange from aqueous solutions. The adsorption performance of corncob was evaluated through batch experiments by examining the effects of contact time, solution pH, adsorbent dosage, and initial dye concentration. This study aims to demonstrate the potential applicability of corncob as an efficient and environmentally benign adsorbent for the treatment of methyl orange-contaminated wastewater. The structure of methyl orange is depicted in figure 1.

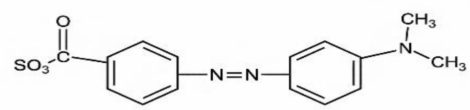

Fig. 1 Structure of Methyl Orange

II. MATERIALS AND METHODS

2.1 Materials

Methyl orange (analytical grade) was used as the model anionic dye without further purification. Raw corncobs were collected from local agricultural fields and used as the precursor for the adsorbent. Sodium hydroxide (NaOH), hydrochloric acid (HCl), and distilled water were used for adsorbent pretreatment and pH adjustment. All chemicals employed in this study were of analytical grade, and distilled water was used throughout the experiments.

2.2 Preparation of corn cob adsorbents

The collected corncobs were thoroughly washed with tap water followed by distilled water to remove adhering dust and impurities. The cleaned corncobs were dried in a hot air oven at 60 °C for 24 h and then ground into a fine powder using a mechanical grinder. The powdered corncob was sieved to obtain uniform particle size and stored in airtight containers for further use. To enhance adsorption efficiency, the corncob powder was chemically activated by treating it with 0.1 M sodium hydroxide solution under continuous stirring for 1 h. The treated material was repeatedly washed with distilled water until neutral pH was achieved and then dried at 60 °C. The resulting material was used as the corncob adsorbent.

2.3 Preparation of Methyl Orange Solution

A stock solution of methyl orange (1000 mg L^{-1}) was prepared by dissolving an accurately weighed amount of dye in distilled water. Experimental solutions of desired concentrations were prepared by appropriate dilution of the stock solution. The pH of the solutions was adjusted using dilute NaOH or HCl solutions.

2.4 Batch Adsorption Studies

Batch adsorption studies were conducted to evaluate the adsorption performance of the corncob adsorbent. Known amounts of adsorbent were added to conical flasks containing a fixed volume of methyl orange solution of known concentration. The flasks were agitated at a constant speed using a mechanical shaker at room temperature. The effects of contact time, initial dye concentration, solution pH, and adsorbent dosage on methyl orange removal were systematically investigated. At predetermined time intervals, samples were withdrawn, filtered, and analyzed for residual dye concentration. The following formula was used to determine the percentage of dye removed from the solution: $\% \text{ Removal} = \frac{C_0 - C_t}{C_0} \text{ X } 100 \rightarrow (1)$

Where C_0 and C_t are the initial and final concentration at time 't' respectively

III. RESULTS AND DISCUSSION

3.1. SEM Analysis

The SEM micrograph of corncob-derived biochar reveals a highly irregular, rough, and porous surface morphology as shown in figure 2. The biochar particles exhibit a well-developed network of cavities, channels, and fractured edges formed during the thermal decomposition of lignocellulosic components. These pores are distributed unevenly across the surface, indicating the formation of both micro- and mesoporous structures. The presence of numerous pores and voids significantly increases the surface area of the biochar, providing abundant active sites for dye adsorption. The rough texture and heterogeneous structure further facilitate the diffusion and attachment of methyl orange molecules onto the biochar surface. Such morphological characteristics are favorable for adsorption processes, as they enhance physical adsorption and promote stronger interactions between the adsorbent and dye molecules.

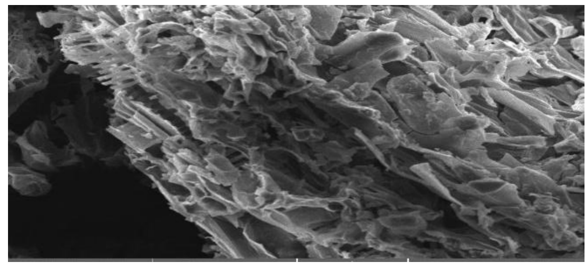

Fig. 2 SEM of corncob biochar

3.2. FTIR Analysis

The FTIR spectra of corncob biochar before (figure 3) and after methyl orange adsorption (figure 4) reveal the presence and involvement of surface functional groups in the adsorption process. The pristine biochar exhibits characteristic bands corresponding to –OH, C–H, C=O/C=C, and C–O functional groups, indicating a chemically active surface. After adsorption, a noticeable reduction in the intensity of the broad –OH band (3400–3200 cm^{-1}) and slight shifts in the C=O and aromatic C=C region (1700–1600 cm^{-1}) are observed, suggesting the participation of hydroxyl and carbonyl groups in dye binding. Additionally, changes in the C–O stretching region (1250–1050 cm^{-1}) further confirm interactions between the biochar surface and methyl orange molecules. These spectral variations collectively confirm the successful adsorption of methyl orange onto the corncob biochar through hydrogen bonding and electrostatic interactions.

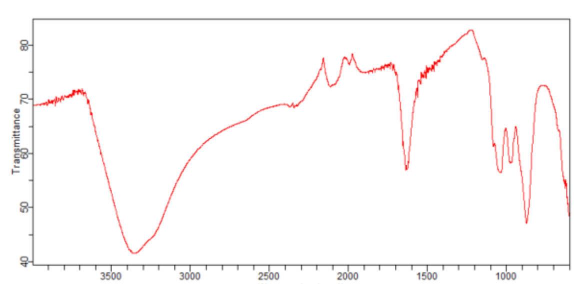

Fig. 3 FTIR spectra of corncob biochar

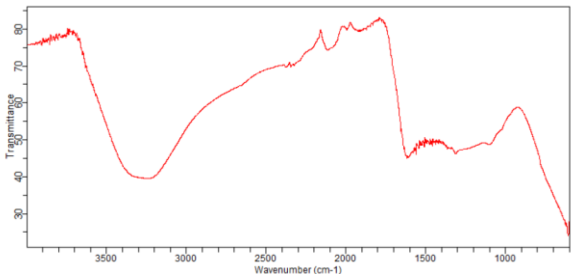

Fig. 4 FTIR spectra of corncob biochar after adsorption

3.3 pH Studies

The effect of solution pH on methyl orange removal was investigated by varying the initial pH from 2 to 10 using 0.1 M HCl and 0.1 M NaOH. A fixed adsorbent dose of 0.5 g per 100 mL of 50 mg/L methyl orange solution was used, and the mixtures were agitated at 150 rpm for 120 minutes at room temperature (~25°C). The results indicated a significant influence of pH on adsorption efficiency. At acidic pH 2, the removal efficiency was 85%, which increased to a maximum of 96% at pH 4–5. Beyond pH 6, the efficiency gradually decreased, reaching 70% at pH 10 as shown in figure 5. This trend suggests that the adsorption of anionic methyl orange is favored in slightly acidic conditions due to protonation of surface functional groups on the corncob, enhancing electrostatic attraction between the dye and adsorbent surface.

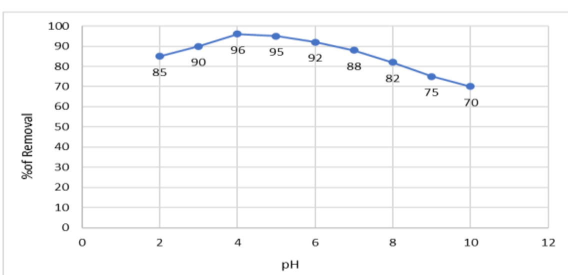

Fig. 5 Effect of Ph

3.4 Effect of Contact Time on Adsorption

The influence of contact time on methyl orange removal was examined by agitating 0.5 g of corncob adsorbent with 100 mL of 50 mg/L dye solution at pH 5 and room temperature (~25°C). Samples were withdrawn at regular intervals (10, 20, 30, 45, 60, 90, 120, and 150 minutes), filtered, and analyzed for residual dye concentration. The adsorption was rapid during the initial 30 minutes due to the availability of abundant active sites on the adsorbent surface as shown in figure 6. Equilibrium was attained at approximately 120 minutes, beyond which no significant increase in removal was observed.

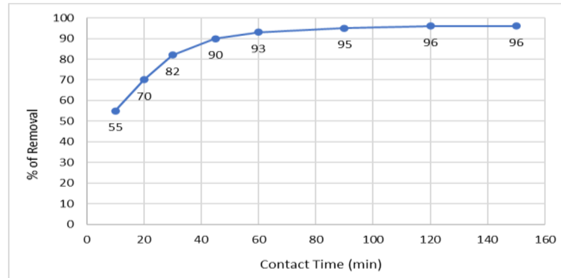

Fig. 6 Effect of contact time

3.5 Effect of Initial Dye Concentration on Adsorption

The effect of initial methyl orange concentration on adsorption was studied by varying the dye concentration from 25 to 150 mg/L while keeping the corncob adsorbent dose constant at 0.5 g per 100 mL solution, pH 5, and contact time of 120 minutes at room temperature (~25°C). As shown in figure 7, the removal efficiency decreased slightly with increasing dye concentration, while the amount of dye adsorbed per gram of adsorbent (adsorption capacity) increased, indicating that higher concentrations provide a greater driving force for mass transfer but also saturate available active sites.

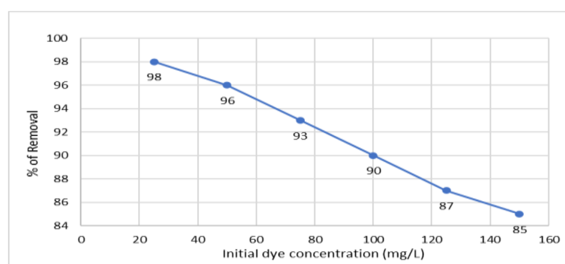

Fig. 7 Effect of initial dye concentration

3.6 Effect of adsorbent dosage

The influence of corncob adsorbent dosage on methyl orange removal was investigated by varying the adsorbent amount from 0.1 g to 1.0 g per 100 mL of 50 mg/L dye solution at pH 5 and room temperature (~25°C) with a contact time of 120 minutes. As shown in figure 8, the results showed that increasing the adsorbent dose significantly enhanced the removal efficiency due to the availability of more active sites. However, the adsorption capacity per gram of adsorbent decreased at higher dosages because of site overlapping and aggregation effects.

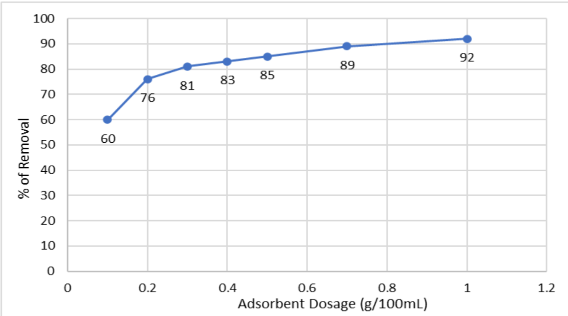

Fig. 8 Effect of adsorbent dosage

IV. CONCLUSION

Corncob biochar, prepared from agricultural waste and chemically activated with NaOH, was demonstrated to be an effective and low-cost adsorbent for the removal of methyl orange from aqueous solutions. Batch adsorption studies revealed that the process is highly influenced by solution pH, contact time, initial dye concentration, and adsorbent dosage. Maximum removal efficiency of 96% was achieved at pH 4–5, 0.5 g/100 mL adsorbent dose, and 120 minutes of contact time. SEM and FTIR analyses confirmed a porous surface structure with active functional groups that facilitate adsorption through hydrogen bonding and electrostatic interactions.

The study highlights the potential of corncob biochar as a sustainable adsorbent for treating dye-contaminated wastewater. The adsorption process is rapid, efficient, and environmentally friendly, making it suitable for practical applications. Future work could explore adsorbent regeneration, treatment of mixed dye effluents, and scale-up for industrial wastewater treatment.

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