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Utilization of Carbonized Lignin for the Removal of Azithromycin in Deionized Water

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1. ABSTRACT

The presence of pharmaceutical contaminants, particularly antibiotics, in aquatic environments has become a significant environmental concern due to their persistence and potential ecological impacts. In this study, carbonized lignin (CL) was investigated as a sustainable and low-cost adsorbent for the removal of azithromycin from aqueous solutions and compared with commercial activated carbon (AC). The adsorbents were characterized using Brunauer–Emmett–Teller (BET) surface area analysis and Fourier-transform infrared (FTIR) spectroscopy. The BET surface areas of CL and AC were determined to be 632 and 707 m^2/g, respectively. Adsorption experiments were designed using the Taguchi method with a L9 orthogonal array to investigate the effects of pH, adsorbent dosage, and temperature on azithromycin removal efficiency. The signal-to-noise ratio was analyzed based on the larger-the-better criterion to determine the optimum adsorption conditions. The optimum conditions for both adsorbents were obtained at pH 3, adsorbent dosage of 1.5 g/L, and temperature of 60 °C. Under these conditions, the removal efficiencies of azithromycin were 89.50% for CL and 93.02% for AC. Although commercial activated carbon exhibited slightly higher removal efficiency due to its higher surface area and developed porous structure, carbonized lignin showed comparable adsorption performance. These results demonstrate the potential of carbonized lignin as an economical, environmentally sustainable, and effective adsorbent for antibiotic-contaminated water treatment.

Keywords: Azithromycin adsorption; carbonized lignin; activated carbon; Taguchi method; emerging pharmaceuticals

2. INTRODUCTION

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The occurrence of pharmaceutical compounds in aquatic environments has attracted increasing attention due to their persistence, biological activity, and potential risks to aquatic ecosystems. Antibiotics are among the important emerging contaminants detected in wastewater and water resources. Azithromycin, a macrolide antibiotic, is an emerging pharmaceutical pollutant because of its extensive consumption, low biodegradability, and continuous release into aquatic systems [1].

Various treatment methods, including advanced oxidation processes, membrane technologies, biological treatments, and adsorption, have been applied for pharmaceutical removal. Among these methods, adsorption is widely recognized as an effective approach because of its simplicity, high efficiency, and low formation of harmful by-products [2]. Recently, carbon-based adsorbents derived from renewable resources have received considerable attention for sustainable water treatment applications.

Lignin, as an abundant and renewable lignocellulosic material, is a promising precursor for the production of carbonaceous adsorbents. Previous studies have reported the effectiveness of lignin-derived carbon materials for removing pharmaceutical pollutants. However, many reported materials require chemical activation processes, which may increase production costs and environmental impacts [3]. Therefore, evaluation of carbonized lignin without chemical activation and comparison with commercial activated carbon as an industrial reference are important.

The study investigated carbonized lignin as a bio-based adsorbent for azithromycin removal and compare its adsorption performance with commercial activated carbon. The effects of pH, adsorbent dosage, and temperature were optimized using the Taguchi experimental design method.

3. MATERIALS AND METHODS

Carbonized lignin was prepared through physical carbonization of lignin without chemical activation and used as an adsorbent for azithromycin removal. Commercial activated carbon was selected as a reference adsorbent. The surface properties and functional groups of both adsorbents were evaluated using BET surface area analysis (ASAP 2020, Micromeritics, USA) and Fourier-transform infrared spectroscopy (FTIR).

The adsorption experiments were designed using the Taguchi method with a L9 orthogonal array. Three operational parameters, including pH (3, 6, and 9), adsorbent dosage (0.5, 1, and 1.5 g/L), and temperature (30, 45, and 60 °C), were investigated. The initial azithromycin concentration was fixed at 200 mg/L and the contact time was 2 h. All experiments were performed in three independent replicates, and the average removal efficiency was considered as the response value.

The azithromycin removal efficiency was calculated using Equation (1):

$$R(\%) = \frac{C_0 - C_t}{C_0} \times 100 \qquad (1)$$

where C_0 and C_t represent the initial and final azithromycin concentrations, respectively.

4. RESULTS AND DISCUSSION

4.1. Characterization of Adsorbents

The BET analysis showed that both adsorbents possessed suitable porous structures for adsorption applications. The BET surface areas of CL and AC were 632 and 707 m^2/g, respectively. Nitrogen adsorption–desorption analysis showed type IV isotherms with H4 hysteresis loops for both adsorbents, indicating mesoporous structures. The combination of micro- and mesoporous structures provides suitable sites for adsorption of relatively large molecules such as azithromycin [4].
FTIR analysis confirmed the presence of oxygen-containing functional groups, including hydroxyl, carbonyl, and C–O groups, on both adsorbents. These functional groups can participate in hydrogen bonding and surface interactions with azithromycin molecules, contributing to the adsorption process.

4.2. Application of the Taguchi Method to Azithromycin Adsorption

The effects of pH, adsorbent dosage, and temperature on azithromycin adsorption were evaluated using the Taguchi method. The signal-to-noise ratio based on the larger-the-better criterion indicated that pH was the most influential parameter affecting adsorption efficiency. Lower pH values improved azithromycin removal, while increasing adsorbent dosage and temperature enhanced adsorption performance.

Based on Taguchi analysis, the optimum conditions for both CL and AC were pH 3, adsorbent dosage of 1.5 g/L, and temperature of 60 °C. Under these conditions, AC achieved a removal efficiency of 93.02%, while CL reached 89.50%. Although AC showed slightly higher adsorption efficiency due to its higher surface area and developed pore structure, the comparable performance of CL indicates that adsorption is also affected by pore distribution and surface functional groups.

Table 1. Comparison of surface properties and adsorption performance of CL and AC

Parameter	Carbonized Lignin (CL)	Commercial Activated Carbon (AC)
BET Surface Area (m^2/g)	632	707
Total Pore Volume (cm^3/g)	0.329	0.447
Optimum condition	pH=3, dosage=1.5 g/L, T=60 °C	pH=3, dosage=1.5 g/L, T=60 °C
Azithromycin removal efficiency (%)	89.50	93.02

5. CONCLUSION

Carbonized lignin was successfully evaluated as a sustainable adsorbent for azithromycin removal from aqueous solutions. The Taguchi optimization results showed that pH 3, adsorbent dosage of 1.5 g/L, and temperature of 60 °C were the optimum conditions for both adsorbents. Carbonized lignin achieved 89.50% removal efficiency, which was comparable with commercial activated carbon (93.02%). Considering its renewable origin, low production cost, and acceptable adsorption performance, carbonized lignin can be considered a promising alternative adsorbent for sustainable water treatment applications. Further studies on regeneration, real wastewater treatment, and scale-up processes are recommended.

6. REFERENCES

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