



American Journal of Interdisciplinary Research and Innovation (AJIRI)

ISSN: 2833-2237 (ONLINE)

VOLUME 5 ISSUE 2 (2026)

**PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA**

Preparation and Evaluation of Alkali-Activated Coconut Coir as a Low-Cost Adsorbent for Turbidity Removal from Synthetic Wastewater

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Article Information

Received: January 28, 2026

Accepted: April 05, 2026

Published: June 10, 2026

Keywords

Alkali Activation, Coconut Coir, Natural Adsorbent, Turbidity Removal, Wastewater Treatment

ABSTRACT

Turbidity is a critical water quality parameter that reflects the presence of suspended particles in wastewater and can adversely affect aquatic environments and treatment efficiency. This study investigates the potential of alkali-activated coconut coir as a low-cost and sustainable adsorbent for turbidity removal from synthetic wastewater. Coconut coir was chemically activated with a sodium hydroxide solution, then dried and size-reduced prior to application. The turbidity removal performance was evaluated using synthetic wastewater with different initial turbidity levels, and removal efficiency was calculated based on the reduction in turbidity before and after adsorption. The results demonstrated significant turbidity reduction, with removal efficiencies ranging from 76.92% to 95.24%, depending on the initial turbidity concentration. Higher removal efficiency was observed at lower initial turbidity levels, whereas efficiency gradually decreased as turbidity increased, indicating that particle loading influences adsorption performance. The findings confirm that alkali activation effectively enhances the adsorption capability of coconut coir through improved surface characteristics, enabling efficient physical removal of suspended particles. Overall, the study highlights the feasibility of utilizing alkali-activated coconut coir as an environmentally friendly and economical alternative to conventional adsorbents for turbidity reduction in wastewater treatment applications, particularly in low-resource and small-scale treatment systems.

INTRODUCTION

Rapid industrialization and urban development have significantly increased the generation of wastewater containing suspended solids and other contaminants, leading to serious environmental and public health concerns. Among various indicators of water quality, turbidity is an important parameter as it reflects the presence of fine particulate matter that can interfere with light penetration, reduce water clarity, and affect aquatic ecosystems. Effective removal of turbidity is therefore a critical step in wastewater treatment prior to discharge or reuse.

Adsorption has been widely recognized as a simple and effective treatment method for removing pollutants from wastewater due to its operational flexibility, high efficiency, and minimal secondary pollution. Conventional adsorbents such as commercial activated carbon exhibit excellent adsorption performance; however, their high production cost and regeneration requirements limit large-scale application, particularly in developing regions (Ali Fawzi Al-Hussainy *et al.*, 2025). This has motivated increasing interest in low-cost and environmentally friendly adsorbents derived from natural and agricultural waste materials. Coconut coir, a fibrous by-product obtained from the husk of coconuts, is abundantly available in tropical countries and is often underutilized or discarded as agricultural waste. The material is rich in lignocellulosic components and possesses a naturally porous structure,

making it a promising candidate for adsorption-based applications. Previous studies have reported that coconut coir can be used as a natural adsorbent for wastewater treatment; however, its adsorption performance in raw form is often limited due to insufficient surface area and restricted availability of active sites (James & Yadav, 2021).

Chemical modification, particularly alkali activation, has been shown to improve the surface characteristics of lignocellulosic materials by enhancing porosity and exposing additional functional sites. Alkali treatment using sodium hydroxide is a simple and cost-effective approach that can alter the surface morphology of coconut coir, potentially improving its adsorption capability without the need for high-temperature carbonization or complex processing techniques (Tan. *et al.*, 2017). Despite its potential, studies focusing on the use of alkali-activated coconut coir specifically for turbidity removal remain limited.

Therefore, this study aims to prepare alkali-activated coconut coir using sodium hydroxide and evaluate its effectiveness as a low-cost adsorbent for turbidity removal from synthetic wastewater. The surface morphology of the material before and after alkali treatment is examined using scanning electron microscopy, and the adsorption performance is assessed through turbidity removal experiments. The findings of this work are expected to contribute to the development of sustainable wastewater

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treatment materials while promoting the valorization of agricultural waste.

LITERATURE REVIEW

The increasing demand for efficient and sustainable wastewater treatment technologies has intensified research on adsorption-based methods due to their simplicity, effectiveness, and adaptability to different types of pollutants. Adsorption is particularly attractive for turbidity removal, as it enables the capture of fine suspended particles and colloidal matter that are difficult to remove using conventional sedimentation or filtration processes. Compared to advanced treatment technologies, adsorption systems require lower operational costs and generate minimal secondary pollution, making them suitable for small-scale and decentralized applications (Biswas *et al.*, 2024).

Commercial activated carbon is widely used as an adsorbent because of its high surface area and strong adsorption capacity. However, its high production cost, energy-intensive manufacturing process, and regeneration challenges have prompted exploration of alternative low-cost materials (Hamad & Idrus, 2022). As a result, agricultural waste-derived adsorbents have gained increasing attention due to their abundance, renewability, and environmental compatibility. Materials such as sugarcane bagasse, banana peels, rice husk, and coconut coir have been investigated for their potential in wastewater treatment applications (Pandey *et al.*, 2023).

Coconut coir, a fibrous residue obtained from coconut husks, is particularly attractive as a natural adsorbent because of its high lignocellulosic content and porous structure. It contains cellulose, hemicellulose, and lignin, which contribute to the presence of functional groups capable of interacting with suspended particles and dissolved contaminants. Several studies have reported the successful application of raw coconut coir in wastewater treatment, demonstrating moderate removal efficiencies for turbidity and other pollutants under controlled conditions (James & Yadav, 2021).

Despite its advantages, untreated coconut coir often exhibits limited adsorption performance due to insufficient surface area and restricted availability of active sites. To overcome these limitations, various modification techniques have been proposed, including physical treatment, chemical activation, and thermal processing. Among these methods, alkali activation using sodium hydroxide has been widely reported as an effective and economical approach for enhancing the adsorption properties of lignocellulosic materials. Alkali treatment can remove surface impurities, disrupt the lignin structure, and increase surface roughness and porosity, thereby improving adsorption efficiency (Tan *et al.*, 2017).

Previous studies have shown that alkali-activated coconut coir exhibits improved surface morphology and enhanced adsorption performance compared to its untreated counterpart. The modification process

promotes the exposure of internal pores and increases the accessibility of adsorption sites, which contributes to better interaction with suspended solids in wastewater (Anwana Abel *et al.*, 2020). Although many studies have focused on the removal of heavy metals or dyes using modified coconut coir, limited attention has been given to its application specifically for turbidity reduction using low-temperature and low-cost preparation methods.

Therefore, there remains a research gap in evaluating the effectiveness of alkali-activated coconut coir for turbidity removal under simple and energy-efficient preparation conditions. Addressing this gap is important for developing sustainable wastewater treatment materials that are economically viable and environmentally friendly. This study builds upon previous findings by focusing on sodium hydroxide activation of coconut coir and assessing its performance for turbidity removal from synthetic wastewater, while emphasizing surface morphology changes and practical applicability.

MATERIALS AND METHODS

Materials

Coconut coir was used as the primary raw material to prepare the natural adsorbent. The coir was collected from a local coconut source in Panchor, Johor, Malaysia. Sodium hydroxide (NaOH) pellets were used as the chemical activating agent, while distilled water was used throughout the preparation process for solution preparation and rinsing to ensure the removal of residual chemicals

Preparation of Alkali-Activated Coconut Coir

The collected coconut coir was first washed thoroughly with tap water to remove surface impurities such as dirt and dust. The cleaned coir was then dried under sunlight to reduce its initial moisture content. After drying, the coir was cut into smaller pieces (approximately 1–3 cm) to facilitate grinding and chemical treatment. A sodium hydroxide solution with a concentration of 2 M was prepared by dissolving 80 g of NaOH pellets in 1 L of distilled water. The dried coconut coir was soaked in the NaOH solution for 1 hour to promote alkali activation. During this process, the alkali treatment helped to remove lignin and other impurities while enhancing surface roughness and porosity. Following the soaking process, the treated coir was filtered and repeatedly rinsed with distilled water until a neutral pH of approximately 7 was achieved, as confirmed using litmus paper. This step was essential to ensure complete removal of residual alkali. The rinsed coir was then pressed manually to remove excess water before being dried in a laboratory oven at 60 °C for 24 hours. After drying, the material was ground using a blender to obtain smaller particle sizes and subsequently stored in an airtight container prior to characterization and adsorption testing.

Surface Morphology Analysis

The surface morphology of the coconut coir before

and after alkali activation was examined using scanning electron microscopy (SEM). SEM analysis was conducted to observe changes in surface structure, pore development, and overall texture resulting from the NaOH treatment. The comparison between untreated and alkali-activated coir provided qualitative insight into the effectiveness of the chemical modification process.

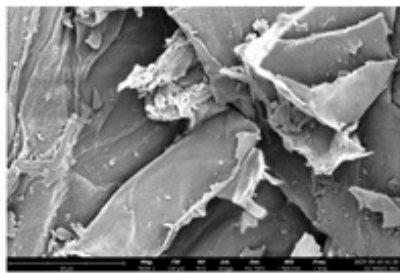
Turbidity Removal Experiment

The adsorption performance of the prepared coconut coir adsorbent was evaluated through turbidity removal experiments using synthetic wastewater. Initial turbidity values were measured prior to treatment, followed by adsorption using the prepared coir under laboratory conditions. After the adsorption process, the turbidity of the treated water was measured again to determine the effectiveness of the adsorbent.

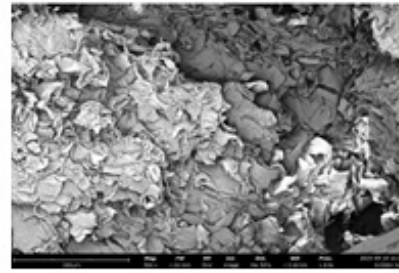
The turbidity removal efficiency was calculated using the following equation:

$$\text{Removal Efficiency} = \left(\frac{T_i - T_f}{T_i} \right) * 100\% \quad \text{Equation 1}$$

where T_i is initial turbidity (NTU) and T_f is final turbidity (NTU).



1 (a) Before



1 (b) After

Figure 1: SEM micrographs of coconut coir (a) before alkali activation and (b) after alkali activation using NaOH.

efficiency, particularly for turbidity removal that relies on physical entrapment and surface adhesion of fine particles (Amosa *et al.*, 2016).

In contrast, the SEM image of coconut coir after alkali activation as per Figure 1(b) showed a markedly different surface morphology. The NaOH-treated coir exhibited a rougher and more fragmented surface with clearer pore openings and increased fiber separation. The alkali treatment disrupted the lignocellulosic matrix by partially removing lignin and surface impurities, thereby exposing internal structures and increasing surface accessibility. The formation of more open pores and the loosening of fiber bundles enhanced the physical characteristics of the adsorbent, making it more suitable for adsorption applications. Although the SEM analysis conducted in this study was qualitative and did not involve pore size quantification, the visual increase in surface roughness and pore visibility strongly indicates an improvement in adsorption potential following chemical activation.

The comparison between untreated and alkali-activated coconut coir clearly demonstrates the effectiveness of sodium hydroxide treatment in modifying surface

RESULTS AND DISCUSSION

Surface Morphology Analysis

Scanning electron microscopy was employed to qualitatively evaluate the surface morphology of coconut coir before and after alkali activation in order to understand the structural changes induced by sodium hydroxide treatment. The SEM images presented in Figure 1 provide visual evidence of the modification effect and its potential influence on adsorption performance.

The SEM micrograph of untreated coconut coir as per Figure 1(a) revealed a relatively compact and heterogeneous surface structure. The surface appeared irregular, with tightly packed fiber bundles and limited visible pore openings. This morphology suggests that a significant portion of the internal surface area was not readily accessible for adsorption. The presence of surface impurities and lignin-rich layers likely contributed to the blockage of pores and restricted interaction between the adsorbent surface and suspended particles in wastewater. Such structural characteristics are typical of raw lignocellulosic materials, where cellulose fibers are embedded within a matrix of lignin and hemicellulose. In this untreated state, adsorption is mainly governed by external surface contact, which limits adsorption

structure. Before activation, the compact and less porous morphology limited adsorption sites, whereas after activation, the increased surface irregularity and pore exposure provided more opportunities for particle attachment and entrapment. These morphological changes are particularly relevant for turbidity removal, where adsorption mechanisms are dominated by physical processes such as surface adhesion, interception, and pore entrapment of suspended solids. The enhanced surface roughness observed after alkali treatment increases contact between the adsorbent and turbidity-causing particles, leading to improved removal efficiency (Amosa *et al.*, 2016; Chen *et al.*, 2017).

Turbidity Removal Performance and Discussion

The turbidity removal performance of alkali-activated coconut coir was evaluated using synthetic wastewater with different initial turbidity levels, and the corresponding removal efficiencies are presented graphically in Figure 2. The figure clearly illustrates the variation in turbidity removal efficiency as a function of initial turbidity concentration, providing a visual comparison of

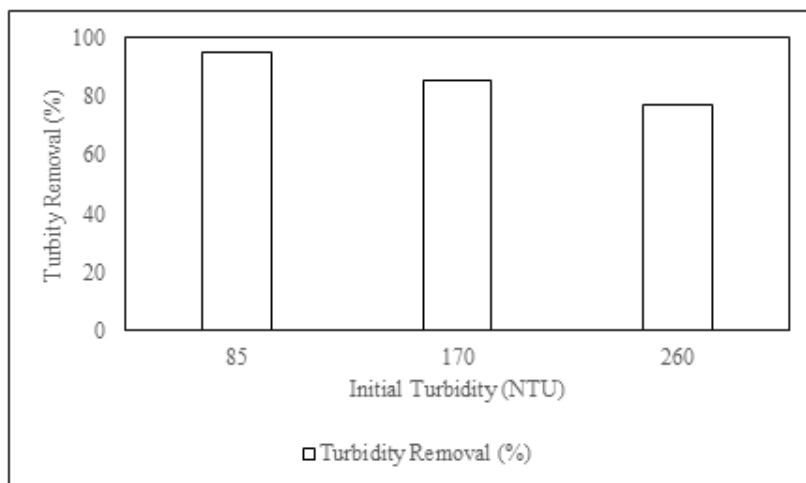


Figure 2: Turbidity removal efficiency (%) of alkali-activated coconut coir at different initial turbidity concentrations

adsorption performance across the three samples. As shown in Figure 2, the highest turbidity removal efficiency was observed for Sample 1, which had the lowest initial turbidity of 85.0 NTU, achieving a removal efficiency of 95.24%. The bar corresponding to Sample 1 is noticeably higher than those of the other samples, indicating near-complete removal of suspended particles under this condition. This result suggests that at lower turbidity levels, sufficient adsorption sites were available on the alkali-activated coconut coir surface to effectively capture suspended particles. When the initial turbidity increased to 170.0 NTU (Sample 2), the removal efficiency decreased to 85.29%, as reflected by the reduced bar height in Figure 2. A further increase in initial turbidity to 260.0 NTU (Sample 3) resulted in the lowest removal efficiency of 76.92%, which is clearly illustrated by the shortest bar in the figure. The decreasing trend in removal efficiency across Samples 1 to 3 demonstrates an inverse relationship between initial turbidity concentration and percentage removal.

The trend observed in Figure 2 can be attributed to the progressive saturation of available adsorption sites on the coconut coir surface at higher turbidity levels. At lower particle concentrations, suspended solids can readily interact with and adhere to the adsorbent surface, resulting in high removal efficiency. However, as the initial turbidity increases, the number of suspended particles exceeds the available adsorption sites, leading to increased competition for surface attachment and a reduction in overall removal efficiency (Husain *et al.*, 2023). Despite the decrease in percentage removal at higher turbidity concentrations, Figure 2 shows that substantial turbidity reduction was still achieved for all samples. This indicates that alkali-activated coconut coir maintains effective adsorption capability even under relatively high suspended solid loading. The consistent turbidity reduction across all samples confirms the robustness of the adsorbent and highlights its potential applicability for wastewater treatment under varying turbidity conditions (Husain *et al.*, 2023).

Previous studies have shown that untreated natural fibers typically exhibit moderate turbidity removal performance, often below 60–70%, due to limited surface accessibility and weak interaction with suspended particles (Lapointe *et al.*, 2021). Chemical modification methods, particularly alkali treatment, have been widely reported to enhance turbidity removal by increasing surface roughness and exposing additional adsorption sites (Ren *et al.*, 2023). For example, alkali-treated agricultural wastes such as rice husk, sugarcane bagasse, and banana peel have demonstrated turbidity or suspended solids removal efficiencies generally to 90%, depending on wastewater characteristics and treatment conditions (Badawi *et al.*, 2024).

In comparison, the maximum turbidity removal efficiency of 95.24% observed in this study exceeds or matches the performance reported for many alkali-modified natural adsorbents, despite the simplicity of the preparation method employed. Unlike some reported studies that require high-temperature treatment or multiple chemical modification steps, the coconut coir adsorbent in this work was prepared using a single alkali activation step under relatively mild conditions. This highlights the effectiveness of sodium hydroxide activation in enhancing turbidity removal performance while maintaining low processing complexity (Mohd Faizal *et al.*, 2024; Purwaningsih & Muliawati, 2022).

When compared with commercial activated carbon, which frequently achieves high turbidity removal efficiencies, alkali-activated coconut coir demonstrates competitive performance, particularly at lower initial turbidity levels. Although activated carbon generally offers higher adsorption capacity, its high production cost and energy-intensive manufacturing process limit its application in low-resource settings. In contrast, coconut coir is an abundant agricultural by-product that requires minimal processing, making it a more sustainable and economically attractive alternative for turbidity reduction (Chaudhuri *et al.*, 2012).

Overall, the comparison with previous literature

confirms that alkali-activated coconut coir performs at least as effectively as many reported natural adsorbents for turbidity removal. The results presented in Figure 2 therefore reinforce the potential of coconut coir as a practical, low-cost adsorbent for wastewater treatment applications, particularly in small-scale and decentralized systems where cost and sustainability are critical considerations.

CONCLUSIONS

This study demonstrated the effectiveness of alkali-activated coconut coir as a low-cost and sustainable adsorbent for turbidity removal from synthetic wastewater. The adsorption results showed significant turbidity reduction across all tested samples, with removal efficiencies ranging from 76.92% to 95.24%. The highest removal efficiency was achieved at lower initial turbidity levels, while a gradual decrease in efficiency was observed as the initial turbidity increased, indicating the influence of particle loading on adsorption performance. The strong turbidity reduction achieved confirms that sodium hydroxide activation effectively enhances the adsorption capability of coconut coir by improving its surface characteristics and facilitating physical adsorption mechanisms such as particle adhesion and entrapment. Despite the decrease in percentage efficiency at higher turbidity concentrations, the adsorbent maintained substantial removal performance, highlighting its robustness under varying conditions.

The findings of this study suggest that alkali-activated coconut coir can serve as an environmentally friendly alternative to conventional adsorbents for turbidity reduction, particularly in applications where cost-effectiveness and sustainability are prioritized. The simple preparation method and the use of agricultural waste further support its potential for small-scale and decentralized wastewater treatment systems. However, since the experiments were conducted under controlled laboratory conditions using synthetic wastewater, future studies involving real wastewater samples and optimization of operational parameters are recommended to further evaluate practical applicability and long-term performance.

Acknowledgements (if any)

This research was not funded by any grant. During the preparation of this work the author(s) used ChatGPT to refine the languages. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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