

Evaluation of Ph Behaviour and Adsorption Performance of Coconut Husk Adsorbent in Industrial Wastewater Treatment

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ABSTRACT

Industrial wastewater containing heavy metals poses significant environmental challenges due to its impact on water quality parameters, particularly pH and contaminant concentration. The presence of copper ions can increase the acidity of wastewater, affecting both treatment efficiency and environmental safety. Therefore, there is a need for sustainable and cost-effective treatment methods that not only remove contaminants but also stabilize pH levels. This study aims to evaluate the pH behaviour and adsorption performance of a coconut husk adsorbent in industrial wastewater treatment. The adsorbent was prepared from coconut husk through washing, chemical activation using sodium hydroxide (NaOH), and low-temperature carbonization. Synthetic wastewater was formulated using kaolin and different concentrations of copper. Batch adsorption experiments were conducted to assess changes in pH and absorbance before and after treatment. The results showed that the initial pH decreased with increasing copper concentration, with values of 4.85, 4.66, and 4.01 recorded for Sample 1, Sample 2, and Sample 3, respectively. After treatment, the pH increased to 5.12, 4.99, and 4.60, indicating improved pH stabilization. In terms of adsorption performance, absorbance values decreased from 2.137 to 1.956 and from 2.494 to 2.357 for Sample 2 and Sample 3, respectively, demonstrating effective contaminant removal. However, a slight increase in absorbance from 1.292 to 1.404 was observed for Sample 1, suggesting reduced adsorption efficiency at lower contaminant concentration. In conclusion, the coconut husk adsorbent demonstrated promising potential as a low-cost and sustainable material for industrial wastewater treatment. Its ability to improve both pH stability and adsorption performance highlights its applicability as an alternative to conventional adsorbents, particularly under moderate to higher contaminant loading conditions.

Keywords: Adsorption; Chemical Activation; Coconut Husk; Wastewater

INTRODUCTION

Industrial wastewater generated from petrochemical, manufacturing, and metal-processing industries contains a wide range of pollutants, including suspended solids, organic compounds, and heavy metals such as copper. The discharge of untreated or inadequately treated wastewater can significantly alter water quality parameters, particularly pH, which plays a critical role in determining the chemical stability, toxicity, and overall treatability of contaminated water (Lemessa et al., 2023). Extreme pH conditions not only affect aquatic ecosystems but also influence the efficiency of subsequent treatment processes, making pH control a fundamental aspect of wastewater management (Shrestha et al., 2021).

Among various treatment technologies, adsorption has emerged as an effective and widely applied method due to its operational simplicity, high removal efficiency, and flexibility in handling different types of contaminants. Conventional adsorbents such as activated carbon is commonly used, however, their high production cost, energy-intensive processing, and disposal challenges have limited their large-scale application, particularly in developing regions. These limitations have driven increasing interest in the development of low-cost, sustainable, and environmentally friendly alternatives derived from natural materials (Реймбаев et al., 2025).

In recent years, agricultural waste materials have gained attention as potential adsorbents due to their abundance, biodegradability, and rich lignocellulosic composition. Coconut husk, the outer fibrous layer of coconut, is one such material that is widely available in tropical regions and often underutilized (de Araújo et al., 2024). It contains cellulose, hemicellulose, and lignin, which provide functional groups such as hydroxyl and carboxyl groups capable of interacting with pollutants through adsorption mechanisms. The conversion of coconut husk into a value-added adsorbent not only contributes to wastewater treatment but also supports waste valorisation and circular economy principles (Pandey et al., 2023).

Despite the growing interest in coconut-based adsorbents, most studies have primarily focused on adsorption efficiency, with limited attention given to the role of pH behaviour during the treatment process. pH is a critical parameter that influences both the surface charge of the adsorbent and the speciation of contaminants, thereby affecting adsorption performance. Understanding the relationship between pH variation and adsorption behaviour is essential for optimizing treatment efficiency and ensuring stable water quality (Oyededeji & Osinfade, 2010; Shukor et al., 2022).

Therefore, this study aims to evaluate the pH behaviour and adsorption performance of a coconut husk adsorbent in industrial wastewater treatment. The adsorbent is prepared through a combination of physical and chemical treatment processes, followed by application in synthetic wastewater containing varying concentrations of copper. The study focuses on analysing pH changes before and after treatment, as well as assessing the adsorption performance of the prepared material. The findings are expected to provide insights into the effectiveness of coconut husk adsorbent as a low-cost and sustainable solution for industrial wastewater treatment, while highlighting the importance of pH behaviour in adsorption-based processes.

LITERATURE REVIEW

Adsorption is widely recognized as an effective and versatile method for wastewater treatment due to its simplicity, high removal efficiency, and ability to treat a wide range of contaminants including heavy metals, dyes, and suspended solids. The process involves the accumulation of pollutants onto the surface of a solid material known as an adsorbent (Hussain et al., 2021). Compared to conventional methods such as chemical precipitation, membrane filtration, and ion exchange, adsorption offers several advantages including lower operational cost, minimal sludge production, and ease of operation (Sonkar, 2023). The efficiency of adsorption is influenced by various factors such as surface area, pore structure, functional groups, and operational parameters including pH, contact time, and initial pollutant concentration. Among these parameters, pH plays a particularly significant role as it governs both the surface properties of the adsorbent and the chemical behaviour of pollutants in solution (Hu & Hao, 2025).

The influence of pH on adsorption behaviour is especially critical in the removal of heavy metals from wastewater. Changes in pH affect the ionization of functional groups on the adsorbent surface, such as hydroxyl and carboxyl groups, which are responsible for binding metal ions (Adeleke et al., 2023). At low pH levels, the high concentration of hydrogen ions competes with metal ions for available adsorption sites, thereby reducing adsorption efficiency. In contrast, at higher pH levels, the surface of the adsorbent becomes more negatively charged, enhancing the electrostatic attraction between the adsorbent and positively charged metal ions such as copper (Cu^{2+}) (Molchanova et al., 2025). Additionally, pH influences the speciation and solubility of metal ions, which may form different complexes or precipitates depending on the solution conditions. These changes not only affect the adsorption mechanism but also determine the stability and quality of treated water. Despite its importance, many studies have focused primarily on adsorption capacity and removal efficiency, with limited emphasis on the variation of pH before and after treatment (Ayoub & Vishakha, 2026).

In response to the need for more sustainable wastewater treatment solutions, there has been increasing interest in the use of natural adsorbents derived from agricultural waste materials. Biomass such as rice husk, banana peel, sugarcane bagasse, and sawdust has been extensively studied due to its abundance, low cost, and biodegradability. These materials are rich in lignocellulosic components, which provide functional groups capable of interacting with pollutants through mechanisms such as ion exchange, surface complexation, and physical adsorption (Himu et al., 2024). The use of natural adsorbents not only reduces reliance on expensive

synthetic materials but also promotes waste valorization and environmental sustainability. However, the performance of these materials often depends on their surface characteristics, which can be enhanced through physical and chemical treatments such as grinding, thermal processing, and chemical activation (Himu et al., 2024).

Among various agricultural wastes, coconut husk has emerged as a promising material for adsorbent development due to its high lignocellulosic content and porous structure. Coconut husk, the outer fibrous layer of the coconut, contains cellulose, hemicellulose, and lignin, which contribute to the presence of functional groups such as hydroxyl and carboxyl groups that facilitate adsorption (Nath, 2026). The natural structure of coconut husk allows for effective interaction with pollutants, particularly heavy metals commonly found in industrial wastewater.

Previous studies have demonstrated that coconut-based materials can achieve significant removal efficiencies for contaminants such as copper, lead, and cadmium. The adsorption performance can be further improved through chemical activation, for example using sodium hydroxide (NaOH), which increases surface area and enhances the availability of active sites. Thermal treatment or carbonization processes also contribute to improving porosity and structural stability, resulting in better adsorption performance (Jock et al., 2022).

Although coconut husk has shown considerable potential as a low-cost and sustainable adsorbent, existing studies have largely focused on adsorption efficiency without thoroughly examining the role of pH behaviour during the treatment process. The interaction between pH variation and adsorption performance remains insufficiently explored, particularly under varying pollutant concentrations (Rangamani et al., 2025). Understanding this relationship is important not only for improving adsorption efficiency but also for ensuring the stability and suitability of treated water for discharge or reuse.

Therefore, there is a need for an integrated study that evaluates both pH behaviour and adsorption performance using coconut husk adsorbent in industrial wastewater treatment. Such an approach provides a more comprehensive understanding of the adsorption process and supports the development of more effective and sustainable treatment systems.

MATERIAL AND METHODS

Preparation of Coconut Husk Adsorbent

Coconut husk (the outer fibrous layer of coconut) was collected from local sources and used as the raw material for adsorbent preparation. The collected husk was thoroughly washed with distilled water to remove adhering dirt and impurities, followed by drying at ambient conditions for 24 hours to reduce moisture content. The dried material was then cut into smaller pieces and ground using a mechanical grinder to obtain a uniform particle size.

Chemical activation was performed using sodium hydroxide (NaOH) solution to enhance the surface properties of the adsorbent. The ground coconut husk was soaked in NaOH solution at a predetermined concentration for 24 hours to promote the development of active functional groups and increase porosity. After activation, the material was filtered and repeatedly washed with distilled water until the pH of the wash water reached neutral conditions, ensuring the removal of excess alkali.

The activated material was then dried and subjected to low-temperature carbonization at 120–150°C for 2 hours in a laboratory oven to improve structural stability and surface characteristics. The final product obtained was cooled to room temperature and stored in an airtight container for further use. This processed material was referred to as coconut husk adsorbent.

Preparation of Synthetic Wastewater

Synthetic industrial wastewater was prepared to simulate contaminated water conditions commonly found in industrial effluents. Tap water was used as the base solution, and kaolin was added to represent suspended solids.

Copper ions were introduced into the solution at three different concentrations to simulate heavy metal contamination. The wastewater samples were prepared by dissolving measured quantities of copper salts into the kaolin suspension, followed by continuous stirring to ensure homogeneity. The prepared solutions were allowed to stabilize before use in adsorption experiments.

Adsorption Experiment Procedure

Batch adsorption experiments were conducted to evaluate the performance of the coconut husk adsorbent. A fixed dosage of the adsorbent was added to a known volume of synthetic wastewater in a beaker. The mixture was stirred at a constant speed using a magnetic stirrer to ensure uniform contact between the adsorbent and the contaminants.

The contact time was maintained for a specified duration to allow sufficient interaction for adsorption equilibrium to be approached. After the completion of the adsorption process, the mixture was filtered using filter paper to separate the solid adsorbent from the treated water.

pH Measurement and Analysis

The pH of the wastewater samples was measured before and after the adsorption process using a calibrated digital pH meter. Calibration was performed using standard buffer solutions (pH 4, 7, and 10) prior to measurement to ensure accuracy. The pH values were recorded to evaluate the effect of adsorption on the acidity or alkalinity of the solution.

Analysis Evaluation of Adsorption Performance

The adsorption performance of the coconut husk adsorbent was evaluated by analysing the reduction in contaminant levels before and after treatment. Absorbance was measured and used as a relative indicator of contaminant concentration to assess the effectiveness of the adsorption process. While this approach provides a comparative evaluation of adsorption performance, it does not represent the exact concentration (mg/L) of contaminants. Parameters such as turbidity and absorbance were measured using appropriate instruments. The removal efficiency (%) was determined using the following equation (Equation 1):

$$\text{Removal efficiency (\%)} = \left(\frac{C_i - C_f}{C_i} \right) \times 100\% \quad \dots\dots\dots \text{Equation 1}$$

where C_i and C_f represent the initial and final concentrations of the contaminant, respectively. All experiments were conducted in triplicate to ensure the reliability and reproducibility of the results.

RESULT AND DISCUSSION

pH Behaviour Before and After Treatment

The pH variation of the synthetic wastewater before and after treatment using the coconut husk adsorbent is illustrated in Figure 1. The results show that the initial pH of the wastewater decreased with increasing copper concentration, with values of approximately 4.85, 4.66, and 4.01 observed for Sample 1, Sample 2, and Sample 3, respectively. This trend indicates that higher copper concentrations contributed to increased acidity in the solution.

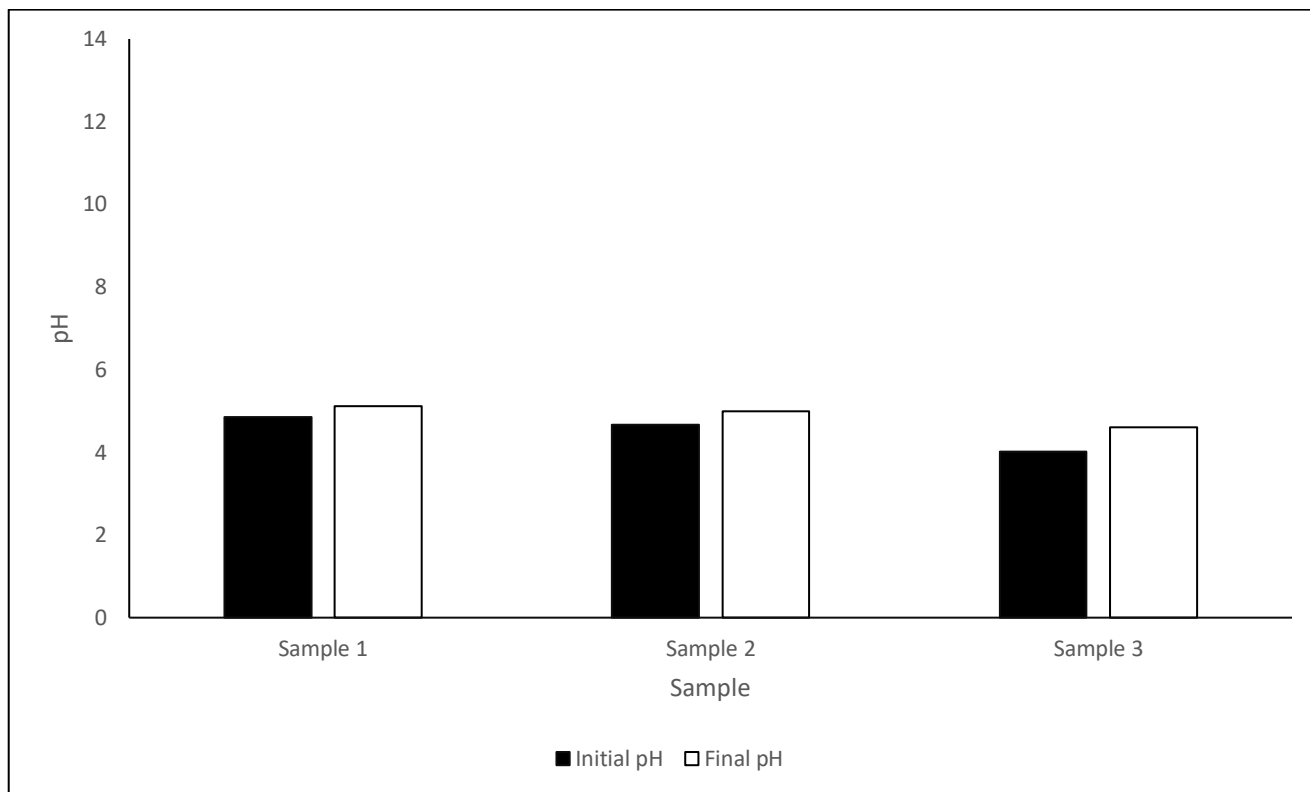


Figure 1: pH behaviour before and after treatment

After the adsorption process, the pH values increased for all samples, reaching approximately 5.12, 4.99, and 4.60 for Sample 1, Sample 2, and Sample 3, respectively. The increase in pH suggests that the coconut husk adsorbent played a role in reducing the acidity of the wastewater. This behaviour may be attributed to the interaction between functional groups present in the adsorbent, such as hydroxyl (-OH) and carboxyl (-COOH) groups, with hydrogen ions and copper ions in the solution, leading to partial neutralization.

The influence of copper concentration on pH behaviour further demonstrates a clear relationship between metal ion presence and solution acidity. Higher copper concentrations resulted in lower initial pH values, indicating stronger acidic conditions. However, after treatment, the pH values consistently increased across all samples, indicating that the adsorption process contributed to pH stabilization. In addition, the magnitude of pH change was observed to be slightly higher at greater copper concentrations, suggesting that the coconut husk adsorbent exhibited a stronger buffering effect under more acidic conditions (Dada et al., 2024).

These findings are consistent with previous studies on lignocellulosic adsorbents, which reported that natural materials containing hydroxyl and carboxyl functional groups are capable of influencing pH during adsorption processes. Studies on coconut-based and other agricultural adsorbents have shown that adsorption of metal ions is often accompanied by changes in solution pH due to ion exchange mechanisms and surface interactions. Similar observations were reported where the adsorption of copper ions resulted in an increase in pH, indicating the removal of hydrogen ions and stabilization of the aqueous system (Israel et al., 2012; Oyedeji & Osinfade, 2010).

However, most existing studies primarily focus on adsorption efficiency and contaminant removal, with limited emphasis on pH behaviour as a key parameter. In contrast, the present study highlights the dual role of coconut husk adsorbent in both contaminant interaction and pH stabilization. This provides additional insight into the adsorption process, particularly in understanding how pH variation contributes to overall treatment performance.

Overall, these results indicate that the coconut husk adsorbent not only facilitates contaminant interaction but also improves water quality by moderating pH levels, which is essential for effective and stable wastewater treatment systems.

Adsorption Performance of Coconut Husk Adsorbent

The adsorption performance of the coconut husk adsorbent was evaluated based on the change in absorbance values before and after treatment, as illustrated in Figure 2. The results show varying trends across the samples, indicating that adsorption behaviour is influenced by the initial concentration and system conditions.

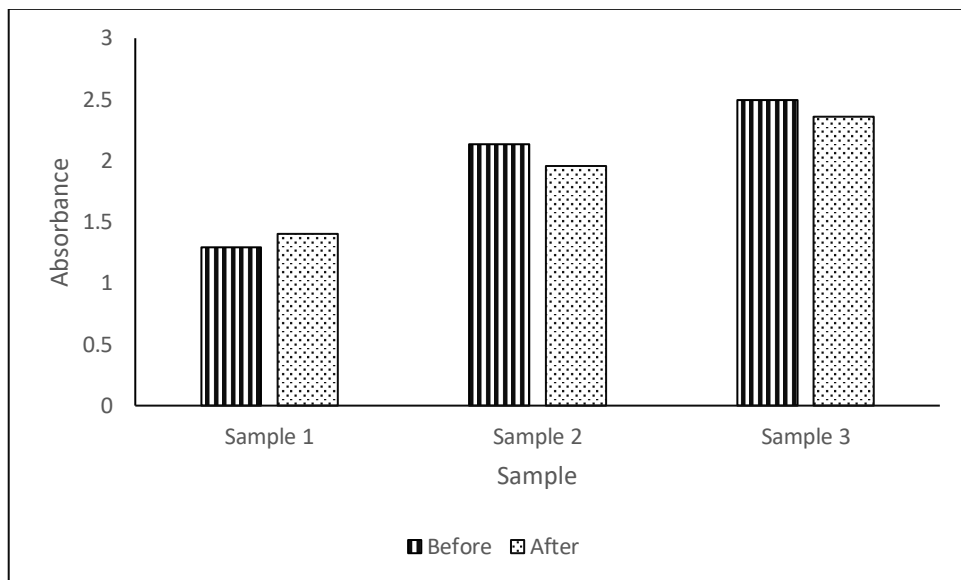


Figure 2: Adsorption performance before and after treatment

For Sample 2 and Sample 3, a reduction in absorbance was observed, where values decreased from 2.137 to 1.956 and from 2.494 to 2.357, respectively. This decrease in absorbance indicates successful removal of contaminants from the synthetic wastewater, demonstrating the effectiveness of the coconut husk adsorbent under these conditions. The reduction can be attributed to the adsorption of dissolved and suspended particles onto the adsorbent surface, facilitated by the presence of functional groups such as hydroxyl (-OH) and carboxyl (-COOH), which promote interactions through electrostatic attraction and surface complexation.

In contrast, Sample 1 showed a slight increase in absorbance after treatment. This behaviour may be attributed to the leaching of fine particles or soluble organic matter from the coconut husk adsorbent into the solution, particularly at lower contaminant concentrations where the adsorption driving force is weaker. This leaching effect may have contributed to increased turbidity and absorbance, as also suggested in previous studies involving lignocellulosic materials (Amosa et al., 2016).

The results also indicate that adsorption performance improved with increasing contaminant concentration, as observed in Sample 2 and Sample 3. Higher concentrations provide a stronger concentration gradient, enhancing the interaction between pollutants and available active sites on the adsorbent. This suggests that the coconut husk adsorbent performs more effectively under moderate to higher contaminant loading conditions (N Guruprashanth & G Udaykumar, 2024).

Furthermore, the adsorption performance observed in this study is consistent with the pH behaviour discussed in Section pH Behaviour Before and After Treatment. The increase in pH after treatment creates a more favourable environment for adsorption, as reduced acidity enhances the interaction between the adsorbent surface and positively charged metal ions. This highlights the interconnected role of pH and adsorption processes in determining overall treatment efficiency.

These findings agree with previous studies on lignocellulosic adsorbents, which reported improved adsorption performance at higher contaminant concentrations due to increased availability of adsorption sites and enhanced mass transfer. Coconut-based and other agricultural adsorbents have similarly demonstrated the ability to reduce absorbance and turbidity through surface interactions and pore diffusion mechanisms.

Overall, the results indicate that the coconut husk adsorbent exhibits promising adsorption performance, particularly at higher contaminant concentrations. Despite some variability at lower concentrations, the adsorbent demonstrates its potential as a low-cost and sustainable material for industrial wastewater treatment, especially when combined with its ability to influence pH behaviour. It should be noted that absorbance was used as a relative indicator in this study. Future work should include calibration methods to convert absorbance values into concentration (mg/L) for more accurate quantitative analysis and comparison with existing literature.

CONCLUSION

This study evaluated the pH behaviour and adsorption performance of a coconut husk adsorbent for industrial wastewater treatment. The findings demonstrated that the initial pH of the synthetic wastewater decreased with increasing copper concentration, indicating higher acidity at elevated contaminant levels. After treatment, the pH values increased across all samples, showing that the coconut husk adsorbent contributed to reducing acidity and stabilizing the pH of the solution.

In terms of adsorption performance, a reduction in absorbance was observed for Sample 2 and Sample 3, indicating effective removal of contaminants at moderate to higher concentrations. However, Sample 1 showed a slight increase in absorbance after treatment, suggesting that adsorption efficiency may be limited at lower contaminant concentrations or influenced by experimental factors such as particle release or insufficient interaction. The results also revealed a relationship between pH behaviour and adsorption performance, where the increase in pH after treatment created more favourable conditions for adsorption. This highlights the importance of considering pH as a key parameter in adsorption-based wastewater treatment processes.

Overall, the coconut husk adsorbent demonstrated promising potential as a low-cost and sustainable material for industrial wastewater treatment. Its ability to influence both pH stabilization and contaminant interaction supports its applicability as an alternative to conventional adsorbents. Future studies are recommended to optimize operational parameters, improve adsorption efficiency at lower concentrations, and investigate additional performance indicators such as removal efficiency and adsorption capacity.

In addition, future studies should include detailed characterization techniques such as Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) to better understand the surface properties and adsorption mechanisms of the adsorbent.

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