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Coconut Husk as a Natural Coagulant for Removing Colloidal Particles from Raw Water in River of Mendana Strait

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ABSTRACT

The escalating global water quality crisis necessitates sustainable and efficient treatment solutions, particularly for challenging raw water sources. This study investigates the potential of coconut husk, an abundant agricultural byproduct, as a natural coagulant for treating raw water from the Mendana Strait River in Johor, Malaysia. A systematic jar test approach was employed to comprehensively optimize key coagulation parameters, revealing an optimal coagulant dosage of 1.2 g, a contact time of 40 minutes, an agitation speed of 80 rpm, and a remarkably high optimal pH of 11.13. This unique alkaline preference, distinct from conventional coagulants like alum (optimal pH 6–8), suggests novel underlying mechanisms, potentially involving surface modification and the release of active components from the lignocellulosic husk. The optimized process achieved an exceptional turbidity removal efficiency of up to 95.16%, demonstrating coconut husk's strong potential in clarifying highly turbid water. Furthermore, detailed characterization using Fourier Transform Infrared (FTIR) spectroscopy, Scanning Electron Microscopy (SEM), and Elemental Microanalysis (CHNS) provided crucial insights into the material's physicochemical changes and its active role in contaminant removal, including nitrogenous compounds. Beyond its technical performance, coconut husk offers significant environmental and economic advantages by minimizing chemical usage, valorizing agro-waste, and reducing treatment costs, making it a highly promising and sustainable solution for water purification, particularly in resource-constrained and rural settings.

Keywords: coagulation; coconut husk; turbidity; dosage; pH

INTRODUCTION

The world is facing a water quality crisis due to factors such as land use changes, industrial activities, agricultural practices, sewage issues, and inadequate raw water management. Raw water typically consists of a mixture of domestic wastewater, industrial effluents, agricultural runoff, and water from commercial facilities. Discharging untreated raw water into the environment can lead to significant health, environmental, and economic problems. To mitigate these impacts, raw water treatment processes are implemented worldwide to remove contaminants before reuse or environmental discharge. The main objective of raw water is to safely dispose of human and industrial effluents while preventing risks to human health and minimizing environmental damage. This is particularly relevant in regions like Johor, Malaysia, as exemplified by the Mendana Strait River, which faces unique water quality challenges.

Elevated turbidity levels in water pose a serious concern, as they affect both human health and aquatic ecosystems. In water bodies such as lakes, rivers, and reservoirs, high turbidity reduces light penetration, which inhibits the growth of submerged aquatic plants. Additionally, it compromises the gill function of fish and shellfish, limiting their ability to absorb dissolved oxygen (DO). Turbidity is a critical parameter in water treatment processes, particularly when water is sourced from natural bodies like rivers and lakes (Abdol Jani et al. 2021). Coagulation, as a vital and widely used primary treatment step in water purification processes, should be briefly introduced.2 Coagulants are used to reduce water turbidity, with the required dosage influenced by factors such as contact time, agitation speed, and pH. This optimal amount is typically determined through a jar test experiment. The challenges encountered in the jar test resemble those found in a standard arithmetic reasoning test. Due to the time-consuming nature and inherent errors in these experiments, they may not consistently yield an accurate estimate of the optimal coagulant dosage. In some cases, they might lead to excessive use of coagulant, reducing the treatment plants' ability to effectively manage and meet requirements. Employing the correct procedure can prevent the need for lengthy and repetitive solutions. Coagulation is becoming increasingly crucial in the raw water treatment process.

Nowadays, aluminum sulfate (alum) is widely used as a coagulant due to its effectiveness in removing foreign matter from water, such as microorganisms and fine suspended particles (Jack Lin et al. 2017; Ismaeel O. Adebayo et al. 2021). However, alum has several disadvantages. It requires hydroxide and alkalinity to function properly and is only effective within a specific pH range. Optimal coagulation with alums typically occurs when the pH is between 6.0 and 8.0. Additionally, alum is not effective in highly turbid water, even when its dosage is increased (Ahmad Hussaini Jagaba et al. 2018). Coconut husk has been suggested to replace alum as a natural coagulant over renewable sources due to cost-effective, biodegradable, non-toxic, and non-corrosive alternatives to chemical coagulants. The application of natural coagulants for treating raw water was investigated, and it was discovered that coagulants from plants can be used in the raw treatment coagulation and flocculation processes. The presence of active components such as proteins, tannins, saponins, and mucilage in plant extracts, known to contribute to their coagulation efficacy, should also be mentioned (S. Nimesha et al. 2022). In this case, coconut husk will be chosen as a coagulant. Coconut is one of the most important agricultural products in Malaysia. Many people are unaware the processing of coconut products generates a substantial amount of waste, primarily in the form of coconut husks. Of the approximately 50 billion coconuts harvested annually, about 85% are discarded as waste, adding gasoline to the global pollution fire. This demonstrates that the problem is a concern, as it continues to grow and has an impact on the ecosystem. By converting coconut husk into a coagulant, the amount of waste coconut husk can be reduced.

The objective of this study is to assess the efficacy of natural coagulants in treating actual untreated water discharges sourced from the Mendana Strait in Johor, Malaysia. A jar test using coconut husk is employed with the hypothesis that it will reduce water turbidity, thereby helping to identify the optimal parameters under consistent input conditions. Furthermore, it is important to distinguish this study from previous research. While other studies have focused on the use of coconut husk as activated carbon for adsorption, this study clarifies its role specifically as a coagulant for turbidity removal. Therefore, this work contributes empirical data on the performance of coconut husk as a natural coagulant, marking a distinct departure from prior studies that emphasized statistical analysis, predictive modeling of water quality parameters, or alternative applications of coconut husk.

METHODOLOGY

MATERIALS

In this research, polluted river water from the Mendana Strait in Johor, Malaysia, was utilized as the sample for the experiment. The collected raw water samples were evaluated based on water quality parameters, focusing on turbidity removal and coagulation performance. Coconut husks were obtained from a local market in Pasir Gudang, Johor, Malaysia. The preparation process began by washing the coconut husks using distilled water for the impurity's removal. Subsequently, the husks were oven-dried at 60°C for 300 minutes. After drying, the coconut husks were ground into a fine texture and then sieved using a 250 μm sieve (to ensure a consistent and optimal particle size for coagulation).

JAR TEST PROCEDURES

This study aimed to evaluate the effectiveness of coagulant dosage, agitation speed, contact time, and pH in removing colloids through jar test experiments. This method is the most cost-effective way of obtaining good, reliable data and optimum parameters after coagulation. The experiment involved filling six 1000 mL beakers with 500 mL of Mendana Strait raw water. The turbidity of the raw water was measured before starting the experiment. The coconut husk doses in each beaker were carefully measured. The speed of the stirrer was adjusted, and the test solution was added. Afterward, the stirrer was turned off, and the floc was allowed to settle for one hour. Finally, the final turbidity and pH readings were taken.

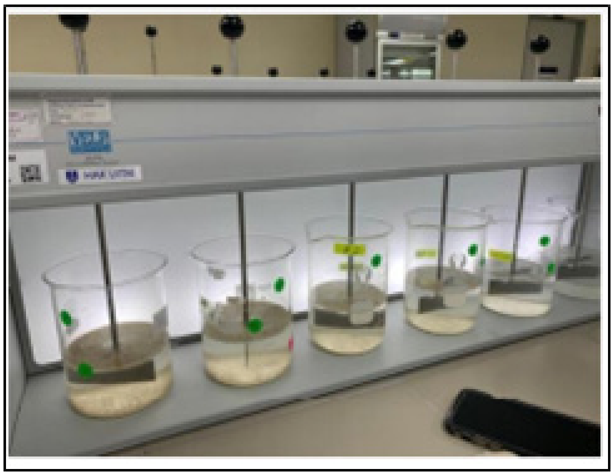

FIGURE 1. Jar test apparatus

The operational conditions for the jar test involved a sequential optimization process. For the coagulant dosage, varying dosages from 0.3 to 1.5 g were employed, while maintaining a consistent agitation speed of 150 rpm and an initial contact time of 60 minutes. This range was chosen based on preliminary screening trials and common practices in coagulation studies. The contact time was then optimized. An optimal dosage of 1.2 g of coconut husk (determined from the previous step) was added to the jars containing 500 mL of raw water. The contact time varied from 10 to 50 minutes, with the agitation speed kept at 150 rpm. The optimal contact time was determined to be 40 minutes. Subsequently, for agitation speed optimization, the optimal dosage of 1.2 g of coconut husk was added, and a contact time of 40 minutes (the overall optimal determined) was maintained. The jars were stirred at different agitation speeds ranging from 60 to 140 rpm. The optimum agitation speed was determined based on the highest percentage of turbidity removal calculated. Finally, for pH optimization, an optimal dosage of 1.2 g of processed coconut husk powder was added to the jars containing 500 mL of raw water, with a contact time of 40 minutes and an agitation speed of 80 rpm. Hydrochloric acid (HCl) was added to adjust the pH of the raw water to 3 and 5, respectively, in the first and second jars. In the fourth and fifth jars, sodium hydroxide (NaOH) was added to adjust the pH of the raw water to 9 and 11, respectively. The pH of the raw water in the third jar was kept neutral. The jars were stirred consistently for approximately 40 minutes at an agitation speed of 80 rpm. The pH solution that resulted in the highest percentage of turbidity removal was identified as the best pH solution. The fixed parameters for each variable optimization step were consistent with the previously determined optimal values at that stage of the experimental design.

CHARACTERIZATION ANALYSIS

The synthesized coconut husks underwent characterization using FTIR, SEM and elemental analysis (EA). The goal was to assess the weight percentage of carbon, hydrogen, nitrogen, and sulphur in samples before and after the experiment. For FTIR analysis, potassium bromide (KBr) pellets were utilized, and measurements were recorded on a Bruker Vertex 70 FTIR spectrometer within a resolution range of 4000 to 400 cm^{-1} at room temperature. This aimed to identify the chemical groups present on the surface of the samples before and after the experiment. The morphology of coconut husks before and after the coagulation process in raw water treatment was examined using a JEOL JSM-IT200 SEM. Prior to analysis, samples underwent coating with a gold (Au) film. SEM image analysis provided measurements of diameters and particle size distributions. For EA, carbon, hydrogen, nitrogen, and sulphur content were determined using a Perkin Elmer 2400 Series 2 instrument, involving weighing and combustion of the samples. This process was carried out to estimate the weight percentage of carbon, hydrogen, nitrogen, and sulphur in samples before and after the experiment.

RESULTS AND DISCUSSION

PHYSICAL CHARACTERIZATION OF POLLUTED RIVER WATER

The results of preliminary water quality testing before and after coconut husk absorption are shown in Table 1. The testing includes 5 physicochemical parameters (turbidity, pH, conductivity, Chemical oxygen demands (COD) and biological oxygen demands (BOD).

TABLE 1. The result of the preliminary water quality test

Parameters	Before water treatment	After water treatment
Turbidity (NTU)	20.70	1.15
pH	7.20	8.48
Conductivity (mS/cm)	11.53	11.41
Chemical oxygen demands, COD (mg/L)	7.70	7.00
Biological Oxygen Demands, BOD (mg/L)	8.41	6.79

From Table 1, the turbidity of the raw water decreases from 20.7 to 1.15 NTU after the experiment because the coconut husk coagulant reduces microbes and organic matter via coagulation-flocculation. The higher turbidity value is caused by organic materials and inorganic particles suspended in the water (Hambali et al. 2024). A lower turbidity value after the experiment indicates that the water sample has become cleaner than before. Coagulation physically removes microorganisms and organic matter, thereby reducing biological activity that might contribute to heat generation in the water. This statement demonstrated that using coconut husk coagulant within the jar test experiment resulted in fewer colloids and bacteria within the raw water (Qingyu Qin 2021).

Following the experiment, the pH of the water increased from 7.20 to 8.48, suggesting a reduction in bacterial activity. This is a noteworthy finding, as it implies that the coconut husk, either through its inherent properties or its interaction with components in the raw water, exerts an alkalizing effect. This observation is consistent with the subsequent identification of an optimal coagulation pH of 11.13. A pH value below 7.0 indicates acidity, whereas values above 7.0 reflect alkalinity, determined by the relative concentrations of free hydrogen and hydroxyl ions in the solution (N.K. Asmel et al. 2021). The observed increase in pH supports the conclusion that the treated water became less acidic after the application of coconut husk coagulant, potentially due to a decline in microbial metabolism, which is commonly associated with acidification of the medium.

Electrical conductivity decreased from 11.53 to 11.41 mS/cm following the treatment. Conductivity in water is directly proportional to its ability to conduct electrical current, which is determined by the concentration of dissolved ions. These ions typically originate from salt and inorganic compounds such as alkalis, chlorides, sulfides, and carbonates, collectively known as electrolytes. A higher ionic concentration results in greater conductivity, whereas reduced ionic presence lowers it. The observed decrease in conductivity suggests the removal of certain colloidal and dissolved inorganic substances during the coagulation process, particularly those contributing charged ions that facilitate electrical flow. This indicates the effectiveness of the coconut husk coagulant in reducing the ionic load of the water sample.

For the COD test, the initial reading decreased from 7.7 to 7.0 mg/L, signifying contaminant removal. In general, the COD value serves as an indicator of both organic and inorganic contaminants in untreated water (Abdol Jani et al. 2022) Tot. It rises with an increase in organic contaminants or complex compounds, while a decrease in COD value signifies the removal of contaminants, either through biological or chemical processes. Subsequently, BOD analysis performs a function like COD analysis, as both assess the quantity of organic compounds in water. Nonetheless, COD analysis is less specific as it gauges all substances subject to chemical oxidation, rather than focusing solely on levels of biologically oxidized organic matter.

Based on the findings, BOD shows a decrease in value indicating that the contaminant within the raw water decreased after the experiment (Samir Sadik Shaikh et al. 2021). It should be reiterated that the decrease in BOD and COD indicates the successful removal of biodegradable and overall organic/inorganic contaminants, respectively, demonstrating a broader water quality improvement beyond just turbidity. The biochemical factors frequently examined to assess water pollution levels involve examining the dissolved oxygen content. This, in turn, offers insights into the easily biodegradable portion of the organic load present in the water. If BOD is higher, it indicates an elevated level of biodegradable organic matter in the water. A higher BOD suggests that there is an increased presence of organic substances that can be decomposed by microorganisms. As these organic materials undergo microbial decomposition, they consume more oxygen during the process. This can lead to a decline in dissolved oxygen levels in the water, which may have detrimental effects on aquatic ecosystems (N Kasmuri et al. 2022).

EFFECT OF COAGULANT DOSAGE

The efficiency of coagulation is significantly influenced by the dosage of the coagulant. In this study, varying coagulant dosages ranging from 0.3 to 1.5 g were employed, while maintaining a consistent agitation speed of 150 rpm and a contact time of 60 minutes. The pattern depicted in Figure 2 demonstrates that the turbidity percentage exhibited a rise as the coagulant dosage increased from 0.3 to 0.9 g. Subsequently, there was a further increase at 1.2 g, followed by a decrease at 1.5 g. The greatest reduction in turbidity, amounting to 90.7% removal, was observed at a coagulant dosage of 1.2 g, while the lowest removal, at 62.7%, occurred at a dosage of 0.3 g.

This indicates that the performance of flocculation could be influenced by either an insufficient coagulant dosage or an excessive one. Insufficient dosage leads to inadequate particle destabilization and insufficient floc formation (Teh et al. 2016). Conversely, excessive dosage can lead to the destabilization of particles due to charge reversal (if charge neutralization is the primary mechanism) or steric hindrance, thereby diminishing the coagulant's efficacy (Teh et al. 2016). The observed "bell-shaped" curve strongly suggests that the mechanism for coconut husk is sensitive to the concentration of active sites or polymeric chains. This points towards either charge neutralization (if the husk releases charged species) or interparticle bridging (if it releases polymeric chains) as primary mechanisms, both of which can be hindered by over-dosing. The discussion should explicitly link the observed dosage effect to these potential mechanisms, providing a more profound understanding of the optimal dosage. The impact of coagulant dosage on particle collisions is substantial, and the addition of coagulants should be based on the requirement to facilitate floc formation. Insufficient coagulant dosage diminishes particle collisions, making it challenging to establish flocs. Conversely, excessive coagulant dosage hinders proper floc formation, potentially leading to the resurgence of turbidity (Wetri Febrina et al. 2020).

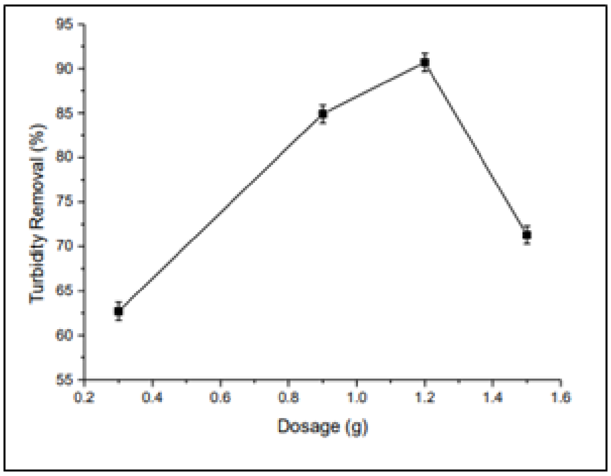

FIGURE 2. Illustration of dosage against the percentage of turbidity removal

EFFECT OF CONTACT TIME

Evaluating various contact time intervals ranging from 10 to 50 minutes, the impact of contact time on the percentage of turbidity was investigated, while keeping the coconut husk powder dosage at 1.2 g and the agitation speed at 150 rpm as constant parameters. Figure 3a illustrates that the percentage of turbidity removal increased from 10 to 40 minutes but decreased when the contact time was extended to 50 minutes. The peak percentage of turbidity removal, 94.43%, was observed at 40 minutes, while the lowest, 85.8%, occurred at 10 minutes (Figure 3b).

Consequently, the optimal contact time was determined to be 40 minutes. The initial increase in turbidity removal with increasing contact time is attributed to sufficient time for effective particle collision and floc formation (Teh et al. 2016). The decrease in turbidity removal beyond this point was attributed to floc breakage due to prolonged and excessive agitation, even if gentle, leading to a diminished capacity of the coagulant to adsorb colloids as the coagulation-flocculation process duration increased (Sun et al. 2019). The optimal contact time (40 minutes) represents a critical balance between allowing sufficient time for floc growth (Orthokinetic Flocculation) and preventing shear-induced floc breakage (Teh et al. 2016). Balance is crucial for maximizing floc size and strength, which directly impacts sedimentation efficiency in practical applications. This highlights the importance of precise control over mixing duration in water treatment plants to ensure optimal flocculation and subsequent removal efficiency. According to earlier research, increasing the mixing duration increases micro-flocs breakup in primary particles, which decreases flocs growth during flocculation (Yanmei Ding et al. 2019). Time plays a crucial role in the coagulation process because enough time must be set aside to allow for the creation of particles large enough to be efficiently removed during the flocculation process (V. Saritha et al. 2017). Thus, 40 minutes was the optimum time in this experiment as the flocs might break down if it was longer than that.

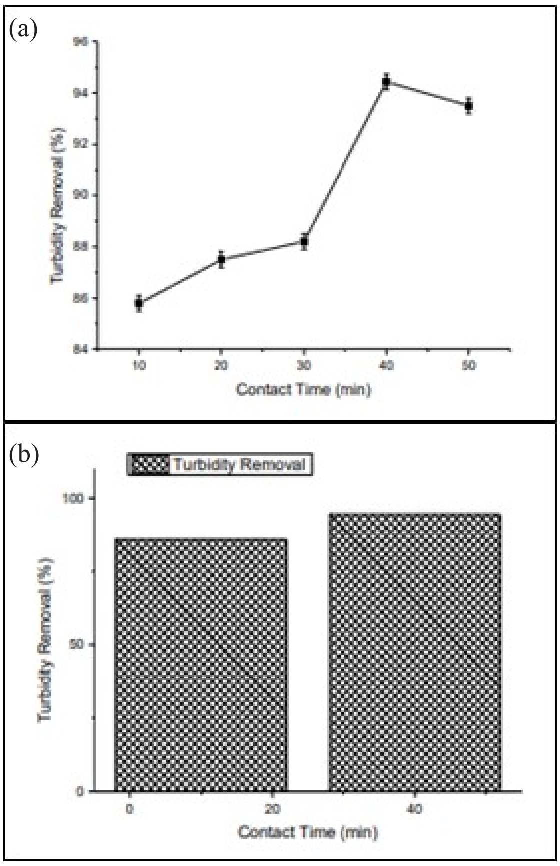

FIGURE 3. Illustration of contact time (a) against the percentage of turbidity removal; and (b) at the highest and lowest percentage of turbidity removal

EFFECT OF AGITATION SPEED

One of the most important factors in getting a larger percentage of turbidity removal is agitation speed. With the optimal contact time set at 40 minutes and an optimum coagulant dosage of 1.2g, the impact of agitation speed within the range of 60rpm to 140rpm was investigated. Figure 4a indicates an increase in the percentage of turbidity between 60 and 80 rpm, followed by a decrease between 90 and 140 rpm. Subsequently, Figure 4b illustrates that the highest percentage of turbidity removal, 89.46%, was achieved at 80 rpm, while the lowest, 81.94%, occurred at 140 rpm.

The fundamental role of agitation in promoting particle collisions, necessary for the formation of larger aggregates (flocs), should be discussed. This decline in turbidity removal percentages with increasing agitation speed was attributed to the susceptibility of the flocs formed during the coagulation-flocculation process to breakage, leading to reduced effectiveness as the agitation speed approached the maximum for the reaction. The optimal agitation speed (80 rpm) is a critical balance point for orthokinetic flocculation (Teh et al. 2016). It provides enough kinetic energy for efficient particle collision and aggregation without introducing destructive shear forces that would break apart the newly formed flocs. This reinforces the importance of controlled mixing for efficient flocculation. This parameter is highly specific to the coagulant, water matrix, and floc characteristics, underscoring the need for empirical optimization for each application. According to the results, the best agitation speed was 80 rpm, which eliminated 89.46% of the turbidity. The efficiency of turbidity removal has been demonstrated to be higher at intermediate mixing speeds, indicating that the increased intensity led to greater flocculation of small particles until it reaches 120 rpm, and the speed itself starts to disturb the process of flocculation (S.W. Bin Ahmed et al. 2020).

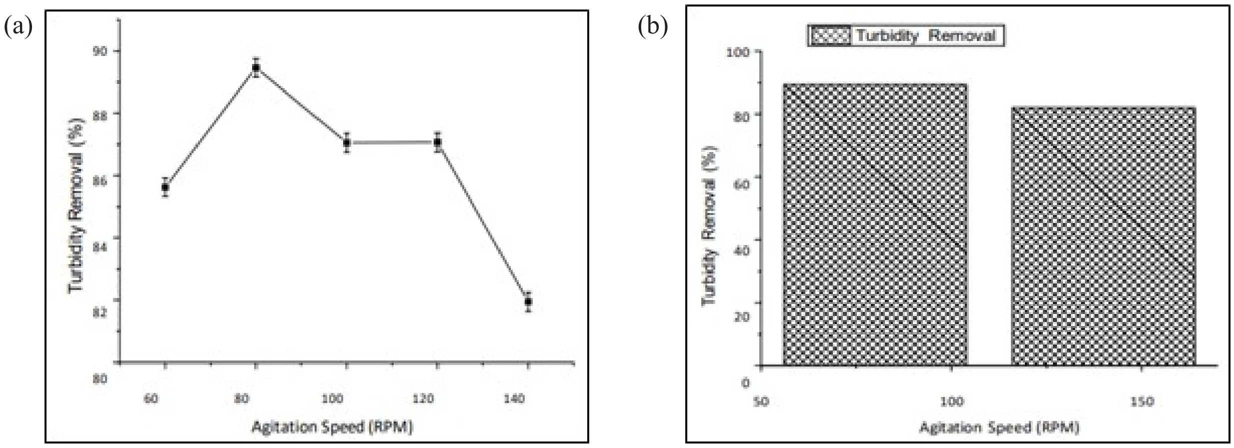

FIGURE 4. Illustration of agitation speed (a) against percentage of turbidity removal; and (b) at the highest and lowest percentage of turbidity removal

EFFECT OF PH

Coagulation experiments were first conducted to determine the optimal conditions for turbidity removal using coconut husk. The best performance was achieved with a coagulant dosage of 1.2 g, a contact time of 40 minutes, and a mixing speed of approximately 80 rpm. To evaluate the effect of pH, the sample pH was adjusted using 1.0 mol/L HCl and NaOH. As shown in Figure 5a, turbidity removal increased with a rising pH, with a marked improvement observed when the pH exceeded 7.5. The highest turbidity removal (95.16%) occurred at pH 11.13, while the lowest (82.3%) was recorded at pH 3.13. This suggests that coconut husk performs more effectively in alkaline conditions, unlike conventional coagulants such as alum, which typically work best at pH 6–8.

The enhanced performance at high pH is likely due to structural and chemical changes in the coconut husk. As a lignocellulosic material, coconut husk contains lignin and cellulose, which may undergo partial hydrolysis, swelling, or unfolding in alkaline environments (Liu et al. 2024). These changes expose functional groups such as hydroxyl, carboxyl, and phenolic groups that can bind with colloidal particles via hydrogen bonding, electrostatic attraction, or complexation. Additionally, alkaline conditions may cause the release of soluble organic compounds (polysaccharides, proteins, lignin fragments) into the water. These macromolecules can act as natural coagulants by neutralizing surface charges or bridging particles together. In some cases, the released compounds may form precipitates that trap suspended particles, forming sweep flocs (Teh et al. 2016).

Supporting evidence from FTIR, SEM, and CHNS analyses further confirms the chemical and structural modifications that occur under high pH conditions. These characterizations provide a more robust scientific explanation of the interaction mechanisms between coconut husk and contaminants during coagulation. The high turbidity removal observed at pH 11.13 underscores the effectiveness of coconut husk as a natural coagulant in alkaline environments. Its performance is attributed to pH-induced alterations in surface chemistry and the release of active components, positioning it as a promising candidate for high-pH water treatment applications. However, further studies are necessary to ensure the treated water meets the standard pH range of 6 to 9, which remains a key limitation of this study.

(a) (b)

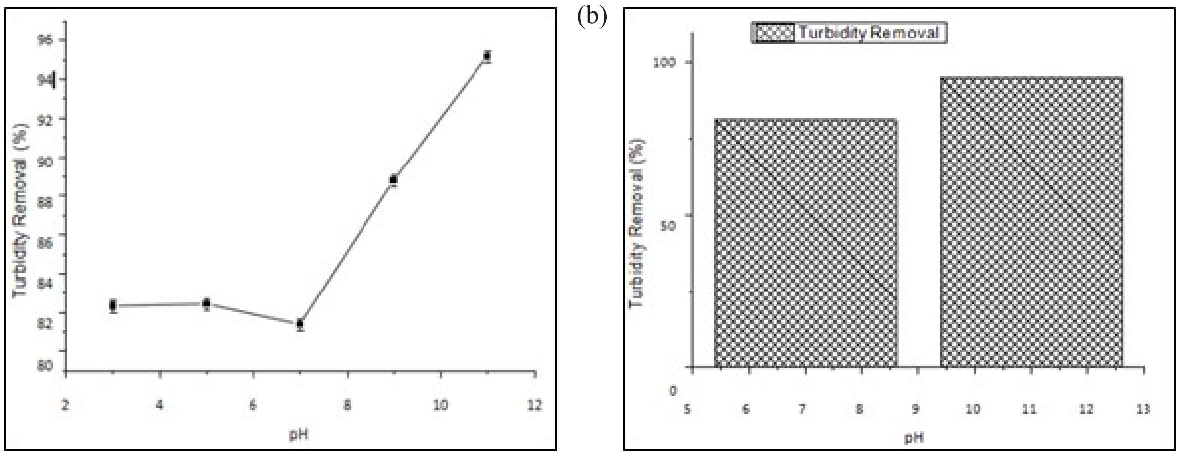

FIGURE 5. Illustration of pH (a) against the percentage of turbidity removal; and (b) at the highest and lowest percentage of turbidity removal

COCONUT HUSKS CHARACTERIZATION

FOURIER TRANSFORM INFRARED (FTIR) ANALYSIS

The FTIR spectra of coconut husk before and after coagulation are presented in Figure 6. Both coagulant samples were analyzed to identify the presence and potential transformation of functional groups involved in the coagulation process. Prior to the experiment (Figure 6a), a broad and intense absorption band was observed at 3292.25 cm^{-1}, corresponding to O–H stretching vibrations, which are typically associated with hydroxyl groups (Lazim et al. 2015). Additional bands at 2925.22 cm^{-1} and 2855.73 cm^{-1} were attributed to C–H stretching, while a peak at 2675.08 cm^{-1} further confirmed the presence of –CH groups. The prominent peaks at 1744.27 cm^{-1} and 1711.85 cm^{-1} were indicative of C=C stretching vibrations, characteristic of alkene groups. Peaks at 1459.78 cm^{-1} and 1238.15 cm^{-1} were assigned to carboxylate C–CH_3 stretching and aromatic ring vibrations, respectively. The phenolic O–H groups likely formed intermolecular hydrogen bonds with suspended solids, enhancing the coagulation process. Weak bands observed at 1417.72 cm^{-1} and 1374.66 cm^{-1} were due to C–CH_3 bending vibrations. The presence of alkene moieties provided potential adsorption sites for suspended particles (Hettiarachchi, Eshani, and Perera et al. 2015). In the range of 1200–800 cm^{-1}, the spectral features correspond to aliphatic ether C–O stretching and O–H vibrations from alcohol groups. A distinct peak near 700 cm^{-1} was attributed to O–H out-of-plane bending associated with C–OH groups.

Comparative analysis of the spectra before and after coagulation reveals slight variations in transmittance, particularly in peak intensity, broadening, and positional shifts. These spectral changes suggest that specific functional groups, especially hydroxyl and carboxyl were actively involved in binding colloidal particles during the coagulation process. The reduction in O–H peak intensity, for example, may indicate consumption of hydroxyl groups, while peak shifts imply the formation of new chemical interactions. Collectively, these changes reflect alterations in the chemical structure and surface properties of the coconut husk, confirming its functional role in coagulation.

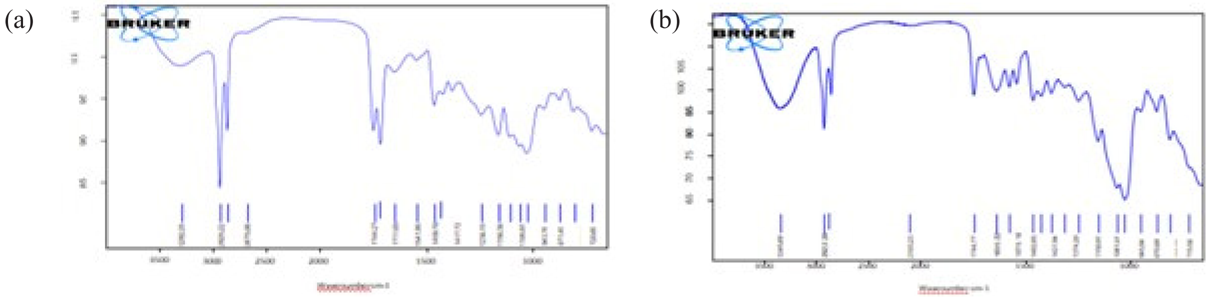

FIGURE 6. FTIR results for coagulation (a) before treatment; and (b) after treatment with coconut husk

SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS

A scanning electron microscope (SEM) was utilized for the surface morphological analysis of coagulants to characterize their particle shapes and elemental distributions. Figure 7 displays SEM images of coagulant grains (coconut husk) at a scale of 100 µm, with a magnification of 1000x and a landing energy capacity of 20 kV. The images highlight the distinctions between the coconut husk before and after the jar test experiment. From the figures, it could be observed that before the process of removing colloids from the Mendana Strait, the surface of coconut husk was rough, and complex compared to the figures after the process. These morphological changes strongly support the idea that the coconut husk surface is actively involved in particle adsorption and floc entrapment. The husk material undergoes physical changes (like swelling, partial dissolution, or conformational changes) that facilitate its role as a coagulant, potentially exposing more active sites or allowing for better entrapment of flocs. This observation aligns well with the high optimal pH findings, where such surface modifications might be promoted. Compare this to the finding observed by Nawel Adjeroud-Abdellatif et al. 2020, in their study using OFI mucilage as a coagulant removing turbidity of water. In addition, this process helped to loosen the wrinkles, thereby reducing internal resistance and increasing the coagulation power of the coagulants. Meanwhile, figures 7e and 7f show the structure of flocs with a magnification of 100x and 1000x produced by the samples of river water, respectively.

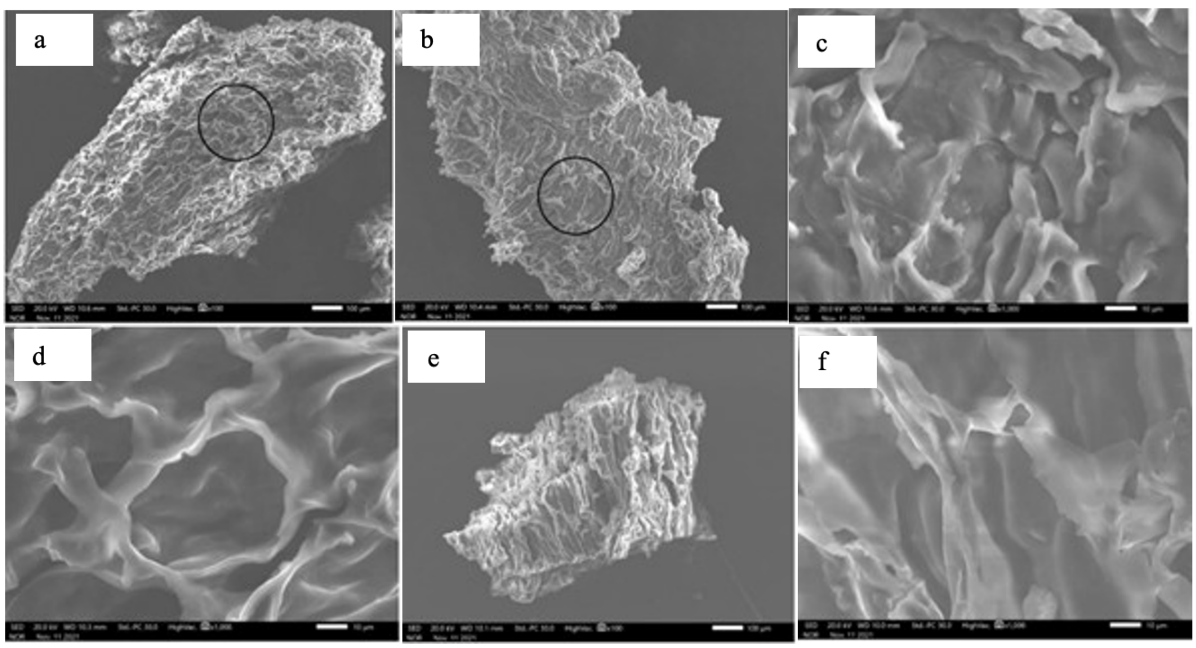

FIGURE 7. SEM images of (a) coconut husk before absorption 100x; (b) coconut husk after absorption 100x; (c) coconut husk before absorption 1000x; (d) coconut husk after absorption 1000x; (e) floc 100x and (f) floc 1000

ELEMENTAL ANALYZER (CHNS)

The EA results presented in Table 2 were used to quantify the presence of C, H, N and O in the coagulant sample before and after treatment. The data indicate a decrease in the percentages of carbon and hydrogen following the experiment. This reduction may be attributed to the interaction between the coagulant and suspended particles in the raw water, which led to the disruption or transformation of carbon- and hydrogen-containing functional groups during the coagulation process. Nitrogen, a naturally occurring nutrient in aquatic ecosystems (Chan et al. 2017), exhibited a notable increase in concentration post-treatment. The rise in nitrogen content suggests that nitrogenous compounds such as proteins, organic nitrogen, or ammonium ions present in the raw water were successfully adsorbed onto or incorporated into the coagulated flocs. This provides direct elemental evidence of the removal of nitrogen-based contaminants from the water. Importantly, this finding highlights an additional water quality improvement beyond turbidity reduction and underscores the dual role of coconut husk in both coagulation and adsorption mechanisms.

TABLE 2. THE EA FOR BEFORE AND AFTER TREATED WITH COCONUT HUSKS

Sample	C%	H %	N%	O%
Coagulant before treated	48.17	8.34	7.81	35.68
Coagulant after treated	42.71	8.33	8.28	40.68

COMPARATIVE EVALUATION OF COCONUT HUSK WITH OTHER NATURAL COAGULANTS

To place the performance of coconut husk in context, a comparative analysis with other natural coagulants is presented in Table 3. This comparison highlights the turbidity removal efficiency, optimal dosage, and pH conditions reported in recent literature. The coconut husk coagulant used in this study achieved a removal efficiency of 95.16% at an optimal dosage of 1.2 g and pH 11.13, which is among the highest reported for natural coagulants.

Salazar Gámez et al. (2024) reported removal efficiencies of 88.9% for Moringa oleifera, 83.3% for Yausa (Abutilon insigne), and 67.2% for Breadfruit (Artocarpus altilis). While these coagulants demonstrated good performance, the current study's optimized use of coconut husk surpasses them, particularly under alkaline conditions. Additionally, a previous study using coconut husk reported a lower turbidity removal of 78.96%, further underscoring the improved performance achieved through parameter optimization in the present work. Cicer arietinum (chickpea) achieved a slightly higher removal efficiency of 95.89% (Md Asrafuzzaman et al. 2011), serving as a strong benchmark among natural coagulants. However, its optimal dosage was lower (100 mg/L), and pH conditions were not reported. Similarly, yam starch extracted using an alkaline method showed 92.48% efficiency (Angel Villabona-Ortíz, et al. 2023), reinforcing the finding that alkaline extraction or application enhances coagulant performance.

The higher efficiency of coconut husk observed in this study may be attributed to its surface modification and release of active organic compounds at high pH, as previously discussed. These findings emphasize not only the potential of coconut husk as a sustainable and locally available coagulant but also the importance of optimizing process conditions to achieve superior performance.

This comparative analysis strengthens the argument for coconut husk as a competitive natural coagulant, offering an effective, low-cost, and eco-friendly alternative for turbidity removal in water treatment applications.

TABLE 3. Comparative Turbidity Removal Performance of Natural Coagulants

Coagulant type	Source Material	Optimal Dosage	Optimal pH	Turbidity Removal Efficiency (%)	Reference
Coconut Husk	*Cocos nucifera*	1.2 g	11.13	95.16	This study
Moringa Oleifera	*Moringa oleifera*	62.5 mg/L	Not reported	88.9	Salazar Gámez et al. (2024)
Yausa	*Abutilon Insigne Planch*	10 mg/L	Not reported	83.3	Salazar Gámez et al. (2024)
Breadfruit	*Artocarpus Altilis*	7000 mg/L	Not reported	67.2	Salazar Gámez et al. (2024)
Coconut Husk	*Cocos nucifera*	Not reported	Not reported	78.96	Siti Nur Hidayah Sani et al. (2024)

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Cicer arietinum	*Cicer arietinum*	100 mg/L	Not reported	95.89	Md Asrafuzzaman et al. (2011)
Yam Starch	Yam	250 ppm	Maintained in range	92.48	Angel Villabona-Ortíz, et al. (2023)

CONCLUSION

Based on the experimental results employing coconut husk as a natural coagulant, it can be inferred that the jar test experiment effectively removes colloids. The four key parameters such as dosage, contact time, agitation speed, and pH have been identified as optimal factors, indicating the efficacy of coconut husk in eliminating colloids from the raw water sample through the coagulation-flocculation process. These optimal parameters, which are optimal dosage at 1.2g, contact time 40 minutes, medium agitation speed (80 rpm), and pH of 11.13, were determined based on achieving the highest efficiency with various manipulated variables within each parameter.1 It should also be briefly mentioned that the comprehensive characterization analyses (FTIR, SEM, CHNS) successfully provided valuable insights into the changes in the coconut husk material and its likely involvement in the coagulation mechanism. Consequently, the use of coconut husk as a natural coagulant proves beneficial in enhancing raw water turbidity removal up to 95.16% and color, improving clarity, and successfully achieving the objective of colloid removal.

Future studies should consider crushing the coconut husk into a finer powder and sieving it using a 125 µm mesh. Reducing particle size increases the specific surface area, thereby enhancing the availability of active sites for adsorption and interaction with suspended particles. This could improve coagulation efficiency and potentially lower the coagulant dosage required, contributing to more cost-effective treatment processes. It is also strongly recommended that pilot-scale studies be conducted to validate the optimal parameters established under laboratory conditions. Such studies are essential to assess the scalability, robustness, and performance of the coagulant in real-world scenarios. This step addresses the limitations of laboratory generalizability and is critical for transitioning from experimental findings to practical implementation in water treatment systems.

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DECLARATION OF COMPETING INTEREST

None.

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