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Utilization of *Moringa oleifera* as Natural Coagulant for Water Purification

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ABSTRACT: The plant-based natural coagulant has the potential to substitute the chemical coagulant in the water treatment process. In this work, the potential of plant-based natural coagulants in the ability of turbidity removal was identified. The *Moringa oleifera* seed was selected for the batch analysis test such as pH, contact time, agitation, and dosage. The high alkaline water decreases the effectiveness of plant-based natural coagulants. The agitation and contact time show the importance of the coagulation process. The optimum turbidity removal rate in pH is 4, the contact time is 60 seconds and 3000 seconds for coagulation and flocculation, respectively, the agitation is 300 RPM and 30 RPM for coagulation and flocculation, and lastly, the dosage is 10 g of *Moringa oleifera* seed. Finally, the plant-based natural coagulants demonstrated the ability to remove turbidity and could be used in place of chemical coagulants.

KEYWORDS: plant-based natural coagulant; *Moringa oleifera* seed ; turbidity removal; water purification

1. Introduction

Water is one of the major elements of life, and about 70% of the human body is water. Therefore, water is a necessary and indispensable substance for life. Although the water covers more than 70% on the Earth's surface, 97.5% of the water on the earth consider is seawater, and fresh water only contribute for 2.5%. In this 2.5% of fresh water, 70% is frozen in polar glaciers, leaving nearly 30% in deep groundwater source. Therefore, only less than 1% of fresh water is available for direct use. In short, only about 0.025% of all water is the water that can be used. Fresh water resources are very rare and precious [1,2]. Typical water treatment are physical treatment and chemical treatment. The physical method includes use of different filter materials with different pore sizes to achieve the filtration effect. The adsorption method is used to exclude the impurities in water with activated carbon. The physical method is allowed the water pass through the filter material, so the bulky impurities are blocked and thus the fresh water is obtained. The chemical method is using various chemicals to convert the impurities in water into less hazard effect to human body or concentrate the impurities [3].

The identification potential of animal-based coagulants and plant-based natural coagulants was challenging due to a lack of awareness and information about the chemical composition of tissue behavior on coagulation effect [4]. Some plant-based natural materials were studied, such as *Moringa oleifera* (MO) and common beans, which contain cationic compounds, while anionic compounds were found in cactus and okra mucilage [5]. Thus, the different composition of the plant-based natural coagulant requires a critical investigation of its applicability. To satisfy the demand for clean water for humans and the environment, the plant-based natural coagulant is the alternative sustainable water purification method to achieve the sustainability development initiative. The aim of this study was to investigate some plant-based natural coagulants for water purification.

2. Materials and Methods

2.1. Materials

The materials used in this experiment were raw water from Curtin Lake and different natural coagulants such as MO seed, okra seed, papaya seed, soybean and water hyacinth. There are three major steps in extracting the plant-based natural coagulants in this experiment, which are the primary processing step, secondary processing step, and tertiary processing step. The simplest of these three-processing steps is the primary processing step. The primary processing steps include extracting the different parts of the plant, such as its seeds, leaves, stems, kernels, fruits, and other structures as a coagulant. The primary step is easy to apply without any advanced technology. Some of the plant-based natural coagulants can be point of use in water treatment, such as soybean and MO seed. In the secondary processing step, some chemicals are required to perform the extraction of the contaminant from the plant-based natural coagulant. This process offers the opportunity to remove the compounds that impact the efficiency of coagulation. The tertiary process is the most expensive and complex.

2.2. Extraction protein from plant-based natural coagulants

The extraction of protein from plant-based natural coagulants was conducted according to modified previous methods [6,7]. The dried plant-based natural coagulants were sieved into fine powder through a sieve shaker. The sieve size for this work was 400 µm to 150 µm. To eliminate the non-coagulant compound from the dried plant-based natural coagulants, the 1.0 M sodium chloride (NaCl) was prepared by dissolving 58.5 g in 1 litre of distilled water because the 1.0 M NaCl was able to extract the protein from the plant-based natural coagulant tissue. Next, the fine powder form of plant-based natural coagulants was added into the NaCl solution and stirred by the magnetic stirrer for 30 min at a room temperature of 25 °C. The suspension was filtered with filter paper and dried in the drying and heating chamber at 70 °C for 12 h. The extracted dry, fine powder was used as the primary coagulant in the jar test experiment.

2.3. Delipidation and purification extraction process

The plant-based natural coagulant may contain contaminants, non-coagulant compounds that affect coagulation efficiency, such as lipid, dust, ash, minerals, carbohydrates, and other proteins.Therefore, the delamination and purification extraction were performed to eliminate those non-coagulant compounds. The excessive natural organic matter loading is a major setback in the use of natural extracts in water treatment. Therefore, the purification method aims to address the challenge of water quality degradation with natural extract treatment. The fine powder of plant-based natural coagulants was defatted through a delipidation process by using hexane in an electro-thermal or water bath Soxhlet extractor. In this work, the electro-thermal device was applied. The electro-thermal device for the Soxhlet extractor was operating at 60 °C and the best efficiency for extraction was 1% w/v of plant-based natural coagulant sample with hexane. Next, the residues from the electro-thermal Soxhlet extractor were taken out and dried at room temperature, 25 °C. To complete the extraction cycle for delipidation, the color of the extracted liquid should turn transparent [8,9].

2.4. Jar test

The jar test is the common process for running the water treatment test [10]. The fundamental principle of the jar test is adding coagulant into the untreated water or contaminated water. The coagulant is an electrolyte and it will form micelles in water, and the colloidal substance in the water will be neutralized, thus forming floc and settling down. The plant-based natural coagulant in defatted and fine powder form will be added to the water during the rapid mixing process. The coagulation and flocculation processes were completed with selective RPM and contact time. The requirements for coagulation are fast and uniform. When a plant-based natural coagulant is added to water, it hydrolyzes and produces an iso-charged colloid, which interacts with the colloid and suspended matter in the water to form floc.Then the mixing speed was reduced to allow the floc to form larger particles and settle down. This process is called flocculation. After the flocculation process, the beaker was removed from the equipment and allowed to stand undisturbed to settle for 1 hour. The treated surface water in the beaker was obtained by using a syringe and run for turbidity and pH tests by using a turbidity meter and a pH meter. The condition of batch studies can be summarized in Table 1. The percentage of turbidity can be calculated using an equation as follows:

$$\text{Turbidity removal (\%)} = \frac{T_i - T_f}{T_f} \times 100\%$$

where T_i is initial turbidity of the water and T_f is the final turbidity after the jar test.

Table 1. The condition of batch studies

Parameters	Dosage (g)	Contact time (s)		Agitation (rpm)		pH
		Coagulation	Flocculation	Coagulation	Flocculation	
Effect of dosage	1-10	20	1200	150	15	7
Effect of contact time	2	10-60	600-3000	150	15	7
Effect of agitation	2	20	1200	75-300	7-23	7
Effect of pH	2	20	1200	150	15	4-9

3. Results and Discussion

3.1. Screening of the plant-based natural coagulant

The screening experiment was conducted to determine the highest removal rate of turbidity among all the plant-based natural coagulants, including MO seed, okra seed, papaya seed, water hyacinth, and soybean. The plant-based natural coagulant with the highest removal rate was chosen to proceed with the batch analysis experiment in which different parameters such as pH, contact time (s), and agitation (rpm) were tested. For the screening experiment, the initial dosage of each extracted plant-based natural coagulant was kept at 5 g. The contact time for coagulation and flocculation was kept at 20 s and 1200 s, respectively, while the agitation speed for coagulation and flocculation was kept at 150 rpm and 15 rpm. The degree of pH was kept at 7.50.3 without any adjustment for pH because, based on Yin (2010), the plant-based natural coagulant will not alter the final pH of the water after the purification process [11]. Based on Figure 1, both MO extract and okra seed achieved a high turbidity removal rate of more than 80%, which satisfied the water treatment standard as outlined in the National Water Quality Standard for Malaysia (NWQS). The highest turbidity removal rate was achieved by using *Moringa oleifera* extract as a plant-based natural coagulant, in which it exhibited at least 91.59%, followed by okra seed, with a result of 84.59%. Meanwhile, the soybean exhibited the lowest turbidity removal rate, which was 7.89%. The water hyacinth achieved a 45.88% turbidity removal rate, followed by papaya seed, which achieved 53.92% turbidity removal. Hence, the MO was selected to proceed to the batch analysis test and dosage (g) was examined. Based on the existing studies available online, the soybean is exceedingly one of the plant-based natural coagulants with an average turbidity removal rate ranging from 80–95%. However, salt solution extraction and delipidation have destroyed the protein structures of the soybean. The soybean contained a large fraction of lipid and the delipidation removed the lipid from the soybean. Thus, the effectiveness of coagulation was not functioning well [12]. Moreover, the electrostatic interactions between the cations and the soybean protein led to an increase in turbidity. The direct point-of-use of soybean as the plant-based natural coagulant is preferred without any purification of its plant structure [9].

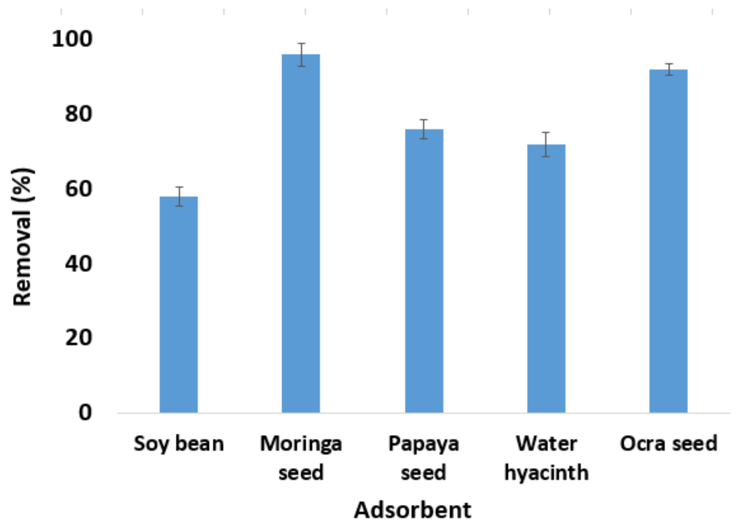

Figure 1. The graph of screening result.

3.2. The effect of pH

This experiment has been conducted to determine the effect of pH on the turbidity removal rate. The initial pH of the raw water from Curtin Lake Site was adjusted with sodium hydroxide (NaOH) and hydrochloric acid (HCl) to 4, 6, and 9 for each 500ml of water. At 2 g of plant-based natural coagulant, agitation was set to 150 rpm for coagulation and 15 rpm for flocculation, with contact time set to 20 s for coagulation and 20 min for flocculation. Figure 2 shows that the MO extract turbidity removal rate for turbidity under different pH conditions. The result shows that a higher pH value has a lower turbidity removal rate. Different pH values were employed to test the stability of protein in plant-based natural coagulants. The turbidity removal rate was decreased when the pH value was more alkaline. The highest turbidity removal rate was 64.25% in the condition of pH 4, while the lowest was 27.90% in the condition of pH 9. Based on Figure 2, it can be concluded that the degree of pH is inversely proportional to the turbidity removal rate. The protein stability decreases with alkaline conditions; therefore, the removal rate is decreased. However, it is not practically possible to treat the water in such a low pH condition because it requires additional resources by local authorities to adjust the pH to achieve the acceptable pH level of 6.5 to 7.5.

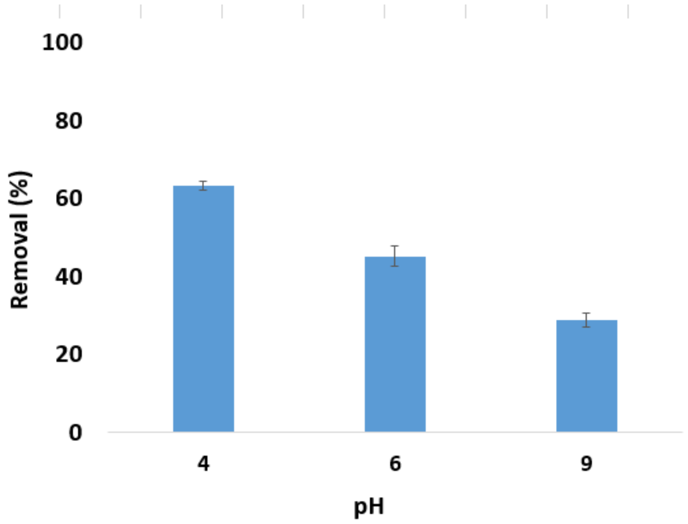

Figure 2. The effect of pH on turbidity removal rate by *Moringa oleifera* extract.

Moreover, the result was supported by Jones (2017) with a turbidity result of 98%, 65%, and 56% at pH 4, 6, and 9. This section examined the relationship between the effect pH and the buffering effect of the reaction between carboxyl-COOH-and amino (NH_2) in the plant-based natural coagulant seed protein. The buffer capacity is estimated to be 0.017 for MO extract [13]. A minor change in final pH after the water treatment may also be due to the balancing of hydrogen ions in the plant-based natural coagulant seed with the raw water hydroxide ions [14]. Although some previous studies have shown that the most effective turbidity removal rate for coagulation by the effect of pH is above the neutral pH value [15]. This section is to investigate the effects of different pH values on the performance of Moringa seed extract. Conventional water treatment methods use chemical coagulants such as ferric sulfate [$Fe_2(SO_4)_3$] to remove the turbidity in raw water intake. The chemical coagulant applied could affect the residual colloids in the water, which will affect the pH in the treated water and increase the residual health effects on humans. However, the use of plant-based natural coagulants has been reported in many studies and research that it does not affect the final pH of the water [11]. The pH value is one of the factors that affects the result of the coagulation and flocculation processes. Each of the plant-based natural coagulants has a different optimum pH value. Based on the studies, the optimum pH for MO extract as a plant-based natural coagulant was somewhere between pH 6 and 8. At the optimum pH value, the protein from MO will ionize to produce carboxylate ions and protons to attract colloids to form neutral groups that will eventually become floc [16].

3.3. The effect of dosage

The water treatment process in the jar test contains two primary destabilization mechanisms, which are charge neutralization and sweep flocculation. The coagulation mechanism is dependent upon the plant-based natural coagulant dosage. In the charge neutralization, the positive charged of protein from plant-based natural coagulants is attracted to the negative charge colloid via electrostatic interaction. The dosage of the plant-based natural coagulant has significant effect on the optimum capacity of turbidity removal. Moreover, insufficient dosage of plant-based natural coagulant will not effectively destabilize the particles in the water while excessive dosage of plant-based natural coagulant can result in detrimental impact. This experiment has been conducted to determine the effect of dosage on the turbidity removal rate. The dosage of MO extract as plant-based natural coagulants added into the raw water were chosen to be 1 g, 3 g, and 10 g. Each of the MO extract was added into 500ml of water for jar test experiment with the agitation speed of 150 rpm for coagulation and 15 rpm for flocculation; while the contact time was decided to be 20 s for coagulation and 1200 s (20 min) for flocculation. Figure 3 represent the effect of dosage on the turbidity removal rate by the MO extract. The overall turbidity removal rate achieved were more than 90%. The effect of plant-based natural coagulant dosage was evaluated during the jar test experiment with different dosage of MO extract from 1 gram, 3 grams and 10 grams. The turbidity removal rate for Curtin Lake Site water was increased from 90.58% to 94.89%. The 10 g of MO extract achieved the highest turbidity removal rate of 94.89% while 3 g of MO extract achieved 93.29% of turbidity removal rate and lastly 1 g of MO extract achieved lowest turbidity removal rate of 90.58%.

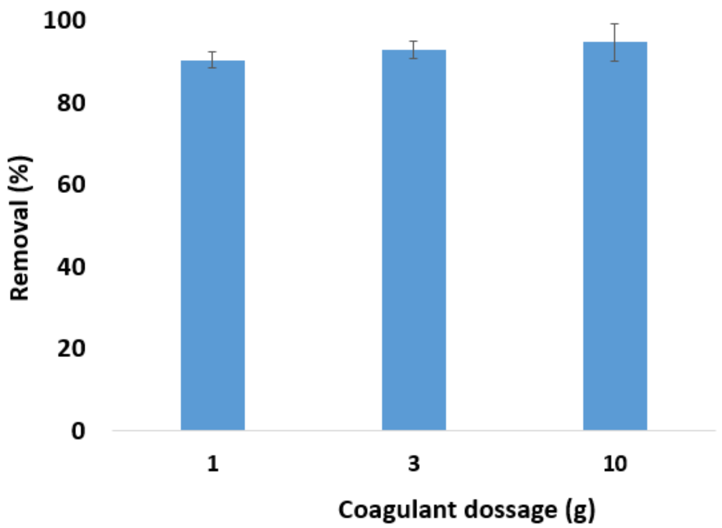

Figure 3. The effect of coagulant dosage on turbidity removal rate.

It can be concluded that the dosage of plant-based natural coagulants is directly proportional to the turbidity removal rate. The increasing dosage can achieve a higher turbidity removal rate. The amount of MO extract is increasing the number of proteins in the water, thus increasing the binding between the flocs. The number of proteins has increased the effectiveness of charge neutralization in the water; thus, the turbidity removal has increased [17]. Based on Figure 4, the 10 g of MO extract has a fine and soft precipitate. However, the 1 g of MO extract has a coarse precipitate. It can be concluded that the insufficient dosage of plant-based natural coagulant was not able to destabilize all the particles in the water. A previous study showed that the relationship between the number of dosages of plant-based natural coagulant and the turbidity removal rate in which the turbidity removal rate was achieved was all more than 90% for dosages of 5 to 35 g of plant-based natural coagulants [18]. Moreover, it is important to study the effect of dosage to save the cost of preventing over-dosing in coagulant applied in water treatment. Not only that, the high amount of dosage in plant-based natural coagulant applied in water treatment poses a great possibility in the destabilized particles in which re-stabilization will likely occur due to the high concentration of the polymer bridge [17].

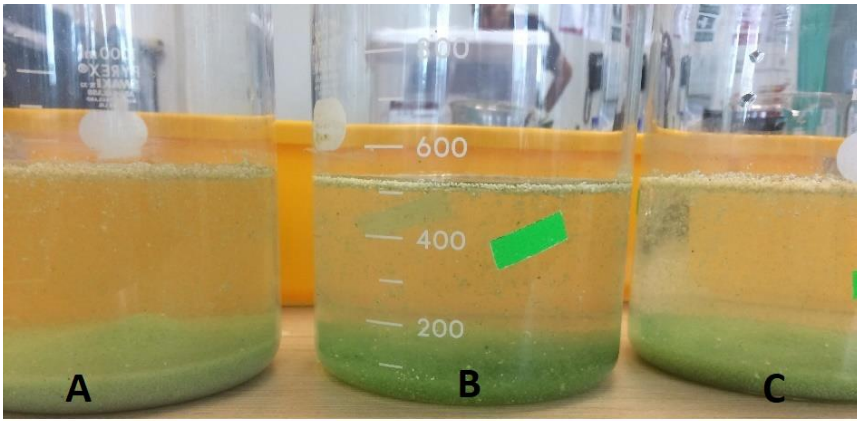

Figure 4. The effect of dosage: (A) 10 g of MO extract (B) 1 g of MO extract (C) 3 g of MO extract.

3.4. The effect of agitation

The agitation speed is one of the factors that affects the coagulation-flocculation process efficiency during the jar test experiment. The jar test was performed to evaluate the agitation effect on the turbidity removal rate of Curtin Lakeside water by the MO extract as a plant-based natural coagulant. The dosage for each set was kept at 2 g of MO extract as a plant-based natural coagulant, while the contact time for coagulation and flocculation was kept constant at 20 s and 1 min (20 min) for each set. The degree of pH remained neutral. This test is to determine the optimum agitation speed for the stability of the protein charge of MO extract to form floc. The effect of agitation speed was evaluated with different set-ups. It is noted that set 1 with the agitation speed of 75 rpm and 7 rpm exhibited zero effect on the turbidity removal rate. Based on Figure 5, since the result from set 2 was close to the result from set 3, it can be concluded that the optimum agitation speed for the turbidity removal rate was between the range of 225 to 300 for coagulation and 23 to 30 for flocculation. It can be concluded that the specific agitation speed had a significant effect on the turbidity removal rate by the plant-based natural coagulant.

Therefore, the large floc was so fragile that instead of binding together, they constantly repelled each other and tended to float in the water. Previous studies stated that the minimum agitation speed required for plant-based natural coagulant was 80 rpm for coagulation in order to prevent floc fragility that causes loss of effectiveness in turbidity removal [19,20]. Another study showed that the increase in agitation speed also increases the efficiency of turbidity removal rate, with a result of 98% for the MO extract [21]. However, the dosage applied in their research was 0.2 g per liter of MO extract, with 0.2 l of 1 g/l sorbate solution to run the experiment. Furthermore, Jaoudi and Amdouni stated that the low agitation speed could result in floc fragility with an agitation speed of less than 80 rppm. The floc formed during the jar text experiment was easily broken and the turbidity removal rate was decreased [20].

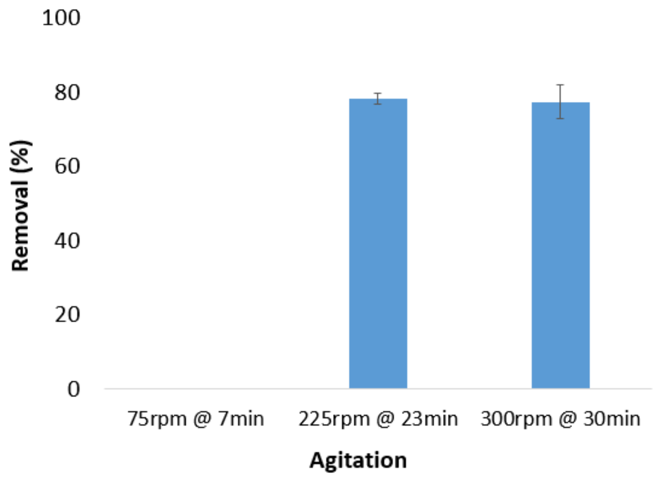

Figure 5. Effect of agitation on Turbidity removal rate.

3.5. The effect of contact time

Contact time is a parameter for determining the equilibrium time required for the coagulation and flocculation processes in the jar test experiment. The jar test was performed to evaluate the contact time effect on the water turbidity removal rate by the MO extract as the plant-based natural coagulant. The variables were decided to be 3 sets in which contact time was 10 s for coagulation and 600 s (10 min) for flocculation; 40 s for coagulation and 1800 s (30 min) for flocculation; and 60 s for coagulation and 3000 s (50 min) for flocculation, accordingly. This test is to determine the optimum contact time for the formation of floc. The effect of contact time was evaluated during the jar test experiment. The turbidity removal rate for the Curtin Lake Site increased with the contact time. Set 1 exhibited a zero-turbidity removal rate, while sets 2 and 3 exhibited significant positive effects on the turbidity removal rate with 57.97% and 69.11%, respectively. The highest turbidity removal rate was obtained in set 3, which was 69.11%, while the lowest turbidity removal rate was obtained in set 1, which was 0%. Moreover, based on Figure 6, it can be concluded that rapid mixing requires a minimum amount of contact time to prevent insufficient mixing. However, increases in contact time will improve the effectiveness of the coagulation process.

The short time for coagulation was not enough to disperse the protein from Moringa oleifera. Thus, the effectiveness of the neutralization of charge in the water was greatly affected by insufficient mixing, as stated by Cai and Chang [22]. Therefore, set 1 exhibited no significant effect on the turbidity removal rate due to the fragility of the floc formation. Sasikala and Muthuraman proved that the increases in settling time for flocculation will result in an increased turbidity removal rate [18].

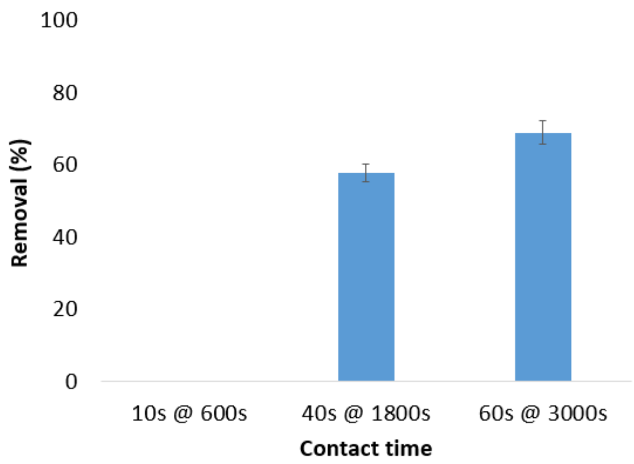

Figure 6. Effect of contact time on the turbidity removal rate.

4. Conclusions

The plant-based natural coagulants showed the ability to remove turbidity. However, only 2 plant-based natural coagulants achieved more than an 80% turbidity removal rate. The water quality was achieved at a class IIA standard, which means the turbidity was lower than 50 NTU according to the National Water Quality Standards for Malaysia. The effect of different parameters on the relationship between the turbidity removal rate An increase in plant-based natural coagulant dosage will increase the efficiency of the turbidity removal in the water. The high alkaline water decreases the effectiveness of plant-based natural coagulants. The agitation and contact time show the importance of the coagulation process. The coagulation process requires rapid mixing at more than 80 rpm and the contact time should not be less than 20 s. Use of plant-based natural coagulants for water purification did not affect the final degree of pH because the plant protein is an amphoteric substance. Therefore, it can eliminate the need for additional pH adjustment for the treated water.

Acknowledgments

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Competing Interest

There is no competing interest to declare.

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