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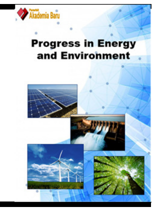

Potential of Banana Peels as Bio-Flocculant for Water Clarification

Research Article

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ABSTRACT

Access to clean water is the major priority in all countries in the world in which millions of humans and living organisms die due to contaminated water-related diseases every year. Flora and fauna particularly urban rivers are losing attraction due to the problem of high turbidity in the water resources. Sedimentation and filtration had been regarded as efficient approaches in tackling high turbidity problem in wastewater. The primary objective of this research is to investigate the performance of banana peels as bio-flocculant for the potential application in turbidity removal in wastewater treatment process compared to alum. The comparison of coagulation-flocculation activities between the extracted bio-flocculant and alum was carried out under different process conditions such as the effects of solution pH, bio-flocculant dosage, temperature and initial wastewater turbidity to investigate the optimum operating conditions in terms of turbidity removal. It was found that the performances of bio-flocculant under different process conditions were almost comparable to alum. The highest turbidity removal percentage could be achieved at solution pH of 4 and 12, 150ml/400ml of bio-flocculant to turbid water dosage, temperature of 40ºC and very high level initial wastewater turbidity (>500NTU). In order to minimize dependency on conventional chemical coagulant, ratio of 50/50 of banana peels bio-flocculant to alum was used to achieve the best turbidity removal percentage in comparison to other ratio combinations. The exploitation of naturally available resources or waste materials into bio-flocculants in this research had shed some lights in the discovery of efficient, biodegradable and green coagulants or flocculants as potential replacement to conventional synthetic chemical coagulants in reducing water turbidity.

Keywords:
Water, Turbidity, Banana peels, Bio-flocculant, Alum

1. Introduction

Industrial effluents are one of the major contributors to water pollution. The industrial effluents are harmful with presence of high chemical oxygen demand (COD), biological oxygen demand (BOD), suspended and colloidal particles and dyes [1]. The dye molecules contained in the water discharge from industrial effluents are highly conjugated and extremely detrimental to human and aquatic life because dyes in the water can inhibit sunlight penetration into the water and subsequently reduce

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photosynthetic reaction of plants in the water [2]. In order to remove contaminants and suspended solids from wastewater, some conventional methods had been extensively applied such as coagulation, flocculation, reverse osmosis and activated carbon adsorption [3, 4]. Yet, reverse osmosis and activated carbon adsorption are not efficient and economically feasible for a large scale wastewater treatment. Therefore, in industrial point of view, coagulation-flocculation remains as the preferable wastewater treatment technology or approach, owing to its advantages such as ease of operation and low operating cost [5].

In the work of Al-Mamun and Ahmad [6] who reported white popinoc as a potential phyto-coagulant to reduce turbidity of river water, they found that rate determining step of the wastewater treatment process was highly dependent on the efficacy of coagulation process in the primary and secondary treatment. Various types of coagulants and flocculants were widely employed in the conventional water treatment processes for this purpose. Among all, chemical coagulants such as aluminium sulphate, polyacrylamide and aluminium chlorohydrate had been widely utilized in regards to their excellent flocculating activity and low processing cost [7]. However, utilization of such chemical coagulants particularly alum in the process is not a good solution in the long run. Potential problems that are associated with them are inclusive of lacking in biodegradability that can lead to environmental hazards and results in the increase of metal concentration or residual of aluminium in the treated water. Pertaining to this problem, it poses a threat and danger to human health that is related to carcinogenic and several neuropathological diseases including percentile dementia and Alzheimer's disease [8, 9].

In recent years, a growing research interest had been prompted to study on plant based bio-flocculants and aluminium sulphate (alum) in their respective coagulation-flocculation behavior in the wastewater treatment process. Alum is a chemical coagulant that is being commonly used to remove contaminants in the water such as suspended solid, colloidal particles, COD and BOD. Following that, the turbidity of water will be reduced through coagulation-flocculation and sedimentation processes [9]. In addition to that, residual aluminium in alum treated water also causes phosphorus uptake by the plants from inorganic phosphorus absorption and subsequently leads to aluminium phytotoxicity [8]. Also, on the contrary of the exceptional performance of alum in wastewater treatment, the major drawback associated with chemical coagulant is generation of large volumes of sludge. The treatment process involving alum is also highly sensitive to pH in which according to Sun et al. [4] adjustment of pH in the wastewater is required prior to the wastewater treatment. Plant based bio-flocculants on the other hand, are natural organic flocculants that consist of natural polymers or polysaccharide complexes formed from the sugars of different monosaccharides such as starch, cellulose, chitosan, natural gums and mucilage [8]. The compounds had been widely recognized for their excellent flocculating properties in the wastewater treatment. Polysaccharides are naturally occurring carbohydrate polymers in which monosaccharride residues are linked directly through glycosidic linkage [10].

These polysaccharides exhibit high potential to be further exploited as flocculants due to the availability of reactive functional groups inclusive of hydroxyl, acetamido or amino functions in the polymer chains [11]. Consequently, excellent physico-chemical characteristics namely high chemical stability, selectivity, and reactivity on aromatic compounds and metals are associated with this natural polymer [5]. Due to the constraints posed by chemical coagulant, focuses had been directed to biodegradable flocculants to replace conventional alum because they are more eco-friendly, non-toxic and easily extracted from reproducible agricultural resources [12, 13]. As recently described by Lee et al. [8], bio-flocculants are renewable sources that incur lower cost, demonstrate high removal capability in terms of suspended solids, turbidity and dyes as well as addressing the concerns on public health issues and environmental pollution problems. In regards to the performances of wastewater treatment process by using plant based bio-flocculants, Renault et al. [13] stated that they were not sensitive to pH which indicated that no adjustment of pH was required prior to the wastewater treatment and relatively lower sludge volume was produced as compared to chemical coagulants.

Various successful reports concerning the use of natural coagulants of vegetable or plant origins in treating water with high turbidity has gradually gaining attention in the field of bio-flocculation. For instance, the seed of coccinia [14], the pod of drumstick tree [8], and the mucilage of okra gum [5] had been identified as a potential bio-flocculant that exhibited comparable results to the efficacy of alum in reducing turbidity level in wastewater. The sources of these natural coagulants or flocculants ranged from the seed of various plants to exoskeleton of shellfish have been reported to be effective in water clarification without the generation of excessive sludge volume [8]. Nevertheless, the exploitation of naturally available resources or waste materials into bio-flocculants remained at its infancy with little knowledge on their respective potential in Malaysia. Not much had been done to explore the possibility of converting plant or fruit based waste materials into bio-flocculant, in the effort to discover efficient, biodegradable and green flocculants to reduce the turbidity of water. Therefore, in this study, the coagulation-flocculation activities between conventional chemical coagulant (alum) with banana peel bio-flocculant were investigated using JAR test analysis under different process conditions. Subsequently, the potential of bio-flocculation as coagulant aid to alum was studied which aimed to minimize the residual aluminium concentration in treated wastewater contributed by utilization of alum as the sole coagulant agent in wastewater treatment.

2. Materials and Methods

2.1 *Materials and Chemicals*

Banana peels were collected from the local night market in Taman Connaught, Cheras, Malaysia. Unless stated otherwise, all chemicals (alum, hydrochlocic acid and sodium hydroxide) are of analytical grade and used without pre-treatment.

2.2 *Preparation of Bio-flocculant*

The preparation of bio-flocculant was conducted based on the methods described by Zurina et al. [7] with slight modifications. The banana peel samples were washed with distilled water several times to remove dirt and contaminants, followed by drying in a hot air oven (Memmert UNB 800) at 80 °C for at least 24 hours. The dried samples were then grinded or crushed using pestle and mortar, sieved well in fraction of 150 µm. The powdered sample was then stored in an airtight container prior to bio-flocculant extraction processes. In the preparation of bio-flocculants, dried raw materials were soaked in distilled water at room temperature and stirred for 1 hour using a hotplate magnetic stirrer (Heidolph). The suspension was filtered through muslin cloth and the filtered extract was then used in the subsequent experiments.

2.3 *Preparation of Synthetic Turbid Water*

Kaolin was used as the model wastewater. Stock kaolin suspension was prepared by dissolving kaolin in distilled water at room temperature. The suspension was stirred moderately for at least 10 minutes in a jar apparatus to obtain uniform dispersion of kaolin particles. The initial turbidity prior to bio-flocculation was maintained approximately at 220 NTU.

2.4 *Coagulation-Flocculation Properties of Bio-flocculants and Alum*

The coagulation-flocculation testing was performed using JAR floc test (VelpScientifica JLT 6). The study involved stages such as rapid mixing, slow mixing and sedimentation in a batch process. For rapid mixing, agitator was turned on at the speed of 200 rpm for 10 minutes once the bio-flocculant from banana peels was added into a beaker containing 400 ml of synthetic turbid water [6] and alum was added into another beaker containing synthetic turbid water. Following that, slow mixing was conducted at 40 rpm for approximately 20 minutes before the samples were left to sediment for 30 minutes. After sedimentation, a few ml of sample was collected without agitating the sediments at bottom to measure the turbidity using a turbid meter (Hach 2100Q). The coagulation-flocculation properties were evaluated by measuring the treated water pH and turbidity. The percentage of turbidity removal was determined by using Eq. (1):

$$\text{Turbidity removal } \% = \frac{\text{final turbidity-initial turbidity}}{\text{initial turbidity}} \times 100 \quad (1)$$

2.4.1 *Effect of pH*

The effect of pH was studied under constant initial turbidity of synthetic turbid water in the range of 4 to 12 [14]. The pH was adjusted by using 0.5 M of HCl and 0.5 M of NaOH solutions. The coagulation-flocculation study was performed at room temperature and the extracted bio-flocculant and alum dosage of 100ml in 400ml synthetic turbid water was maintained throughout the experiments. Similar procedures as described in Section 2.4 were performed.

2.4.2 *Effect of Coagulants or Flocculants Dosage*

The effect of coagulant or flocculant dosage was studied by fixing the synthetic turbid water pH as the initial pH of the kaolin clay dissolved in distilled water. Various dosages of extracted bio-flocculant and alum were investigated from the range of 50ml to 250ml in 1 L of synthetic turbid water, for the turbidity removal percentage [14]. Similar procedures as described in Section 2.4 were performed.

2.4.3 *Effect of Temperature*

The effect of temperature on the performance of extracted bio-flucculant and alum in turbidity removal was studied by varying the temperature in the range of 25^{o}C to 40^{o}C in the interval of 5^{o}C. The coagulation-flocculation test was performed at a fixed pH of synthetic turbid water. The bio-flocculant and alum dosage of 100ml/400ml was added into the turbid water. Similar procedures as described in Section 2.4 were performed.

2.4.4 *Effect of Initial Wastewater Turbidity*

The effect of the initial turbidity of synthetic turbid water was examined at the room temperature and initial pH of the kaolin clay dissolved in distilled water. Batch experiments on the effect of initial turbidity were performed in 4 different ranges that were inclusive of low turbidity level (< 100 NTU at 85.5 NTU), moderate turbidity level (100 - 200 NTU at 186 NTU), high turbidity level (200 - 500 NTU at 325 NTU), and very high turbidity level (> 500 NTU at 606 NTU). Similar procedures as described in Section 2.4 were performed.

2.4.5 *The Potential of Bio-flocculants as Coagulant Aid*

In this section, the ratio of bio-flocculant to alum was varied from the range of 0 – 100%, respectively to investigate the optimum combination of alum and bio-flocculant for the best turbidity removal percentage. The experiments were conducted as described by Zurina et al. [15] with slight modifications. Different ratio combinations of bio-flocculation to alum at 80/20, 60/40, 50/50, 40/60, 20/80, in percentage were investigated. Similar procedures as described in Section 2.4 were performed. The final turbidity removal percentages obtained under all combinations were compared to the 100 % dosage of bio-flocculant and alum, respectively.

3. Results and Discussion

The comparison of coagulation-flocculation activities between bio-flocculant and alum was carried out under different process conditions in which the initial water turbidity was maintained in the range of 210 NTU – 260 NTU to investigate the effects of solution pH, temperature and bio-flocculant dosage. At the same time, the speed of agitation for different stages such as high speed coagulation (150rpm), low speed flocculation (40rpm), mixing time for coagulation (10 minutes), mixing time for flocculation (20 minutes) and sedimentation time were remained constant throughout the research. Initial solution pH, temperature (°C), initial water turbidity (NTU) and bio-flocculant or alum dosage (ml) were the manipulated valuables for comparing the performance of alum and bio-flocculant in the wastewater treatment process. The major consideration for comparison of the coagulation-flocculation activities was the percentage of turbidity removal in final synthetic turbid water.

3.1 *Effect of pH*

In this study, the pH of turbid water was altered within the range of pH 4 to 12, by addition of either hydrochloric acid or sodium hydroxide. The degree of pH, either acidity or alkalinity, is one of the vitally important factors that may affect the coagulation and flocculation process occur in wastewater treatment [16]. In addition, surface charges of particles in the solution were greatly influenced by the pH value. Therefore, identification of the optimum pH range of value to attain the highest turbidity removal percentage was of utmost importance in coagulation-flocculation activities.

In **Fig. 1**, the result clearly indicated that the removal percentage decreased significantly as the solution pH was increased from 4 – 8, but increased drastically beyond pH 8. The turbidity removal profiles were consistent between both alum and banana peels bio-flocculant. It demonstrates that the lowest performance of both coagulants andflocculants occurred in the solution pH of 8. Dual optimum pH ranges both in acidic and alkaline conditions could be achieved in this study. The highest turbidity removal at 93.44 % and 98.34 % was attained when bio-flocculant and alum was administered into the turbid solution at pH 12, respectively. On the other hand, the highest percentage removal in acidic range was obtained at pH 4 in which the removal as high as 81.42 % and 86.68 % was recorded for bio-flocculant and alum, respectively.

A similar result was reported by Luvuyo et al. [17], in which the utilization of *Methylobacterium sp. Obi* and *Actinobacterium sp* as bio-flocculants, resulted in dual optimum pH ranges both in acidic and alkaline conditions consistent with the results in the present study. One of the most plausible explanations for this observation was due to the complexibility structure of bio-flocculant extracts which may contain amphoteric ions. As reported by Yuliastri et al. [16], turbidity removal mechanism involving coagulants and flocculants could be associated with one or more mechanisms at a time. Depending on the solution pH, the rate limiting or turbidity removal determining step could be dominated by different mechanisms of either charge neutralization or polymerization bridging effect or electrostatic patch. These mechanisms led to the reduction of particles surface charge and destabilization of electrical repulsion forces between colloid particles, and subsequently binding to form larger flocs [18].

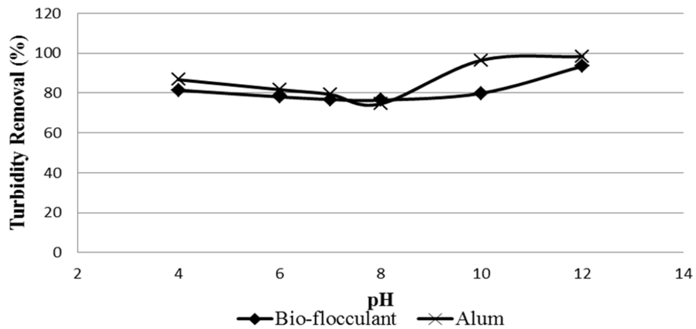


Fig. 1. The effect of pH on turbidity removal percentage

3.2 *Effect of Coagulants or Flocculants Dosage*

Coagulants or flocculants dosage into turbid water for turbidity removal was another important variable affecting the turbidity removal efficiency. The result shown in **Fig. 2** revealed that residual turbidity in treated water decreased when the dosage of alum and banana peels bio-flocculant used were increased from 50ml up to 150ml. However, beyond the dosage of 150ml, a decreasing profile in the turbidity removal percentage was observed for both alum and the banana peels bio-flocculant. Slight increase in the final residual turbidity was resulted when the dosage was further increased from 150 to 250ml. Therefore, in this study, the optimum turbidity removal performance occurred at 150ml for both alum and banana peels bio-flocculant, which resulted in 85.69 % and 71.34 % turbidity removal percentage, respectively, in the treated water.

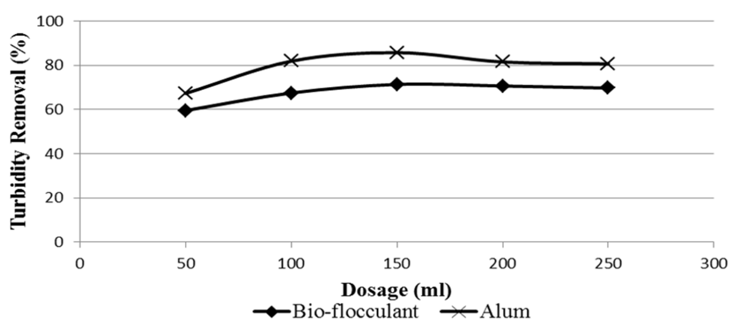


Fig. 2. The effect of different coagulants or flocculants dosage on turbidity removal percentage

Generally, larger dosage enhanced the turbidity removal process by inducing greater interaction between the coagulants or flocculants, which promoting the separation of suspended solid particles or contaminants from the water. Nevertheless, according to Nourmoradi et al. [19] and Ariffin et al. [20], it was not a guarantee that positive correlation would always be the relationship between coagulants or flocculants dosage with the turbidity removal percentage. This was because either inadequate dosage or overdosing of coagulants or flocculants could also result in low turbidity removal in coagulation-flocculation process. Okaiyeto et al. [21] further elaborated that inadequate dosage might cause inefficient charge neutralization of negative charges on kaolin particles. In contrast, over dosing could be leading to saturated polymer bridge sites, causing re-stabilization of the destabilized particles due to insufficient number of suspended particles to form more inter-particle bridges [22].

3.3 *Effect of Temperature*

The effect of temperature on the turbidity removal in the use of bio-flocculant and alum had been investigated in the range of 25 – 40°C. Tolerance level of polymers towards temperature, is an important information in the selection of suitable coagulants and flocculants in all wastewater treatment [23]. Based on literature review, temperature-related researches in coagulation-flocculation processes were generally associated with either thermal stability of bio-flocculant [17, 21] or thermal solubility of alum [24].

Fig. 3 depicts the turbidity removal profiles for both alum and banana peel bio-flocculants. As the temperature was increased from 25°C to 40°C, the highest turbidity removal of bio-flocculant was observed at 40°C with 75.18 % while the lowest turbidity removal was recorded at 25°C with 71.67 %. A different removal pattern was obtained for alum. The highest percentage turbidity removal of alum was achieved at the temperature of 30°C with 80.93 % removal while the lowest percentage turbidity removal was recorded at 25°C with only 65.93 % percentage turbidity removal. For banana peels bio-flocculant, the performance in turbidity removal could be related to the thermal stability of the polysaccharide backbone of the peel itself since the major constituents of banana peels were consisted of carbohydrates, protein, organic matters and crude fibre [21]. The rise in temperature could also provide the suitable driving force to raise the mobility of polymers and suspended kaolin particles thereby increased the interaction with binding sites which enhanced the turbidity removal efficiency. Besides, for chemical coagulant, the rate of formation of the metal hydrolysis products and the solubility of metal hydroxide precipitate were very much affected by temperature [24]. In low temperature, the solubility of chemical coagulant would affect the coagulation process due to higher viscosity of water and interrupted the kinetics of hydrolysis reactions and particle coagulation. Therefore, this explained the lowest percentage of turbidity removal was achieved at 25°C with 65.93 % removal.

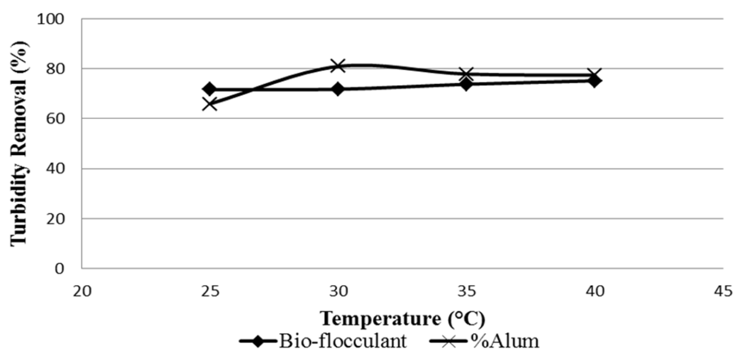


Fig. 3. The effect of temperature on turbidity removal percentage

3.4 *Effect of Initial Wastewater Turbidity*

The effect of initial turbidity on the turbidity removal efficiency was also another notable factor that required proper investigation because wastewater streams generated from different industries or sources could be of different strengths. By comparing the turbidity removal capability between the extracted banana peels bio-flocculant with the conventional chemical coagulant (alum) in turbid water with different initial turbidities, it would be helpful in determining the possibility of substituting the utilization of alum with the banana peels bio-flocculant in wastewater treatment process. Batch experiments on the effect of initial turbidity were performed in 4 different ranges that were inclusive of low turbidity level (< 100 NTU), moderate turbidity level (100 - 200 NTU), high turbidity level (200 - 500 NTU), and very high turbidity level (> 500 NTU).

The results of the turbidity removal percentage by banana peels bio-flocculant and alum, are presented in **Fig. 4**. It was observed that the percentage of turbidity removal increased with increasing initial turbidity in turbid water from low to very high level. This could be probably due to higher particle concentration in water with high turbidity level that increased the frequency of collisions between the suspended particles with coagulants thus promoting better coagulation-flocculation process. With enhancement in the contact and interaction between the coagulating and suspending particles, bigger and denser flocs would be formed which led to higher rate of sedimentation in the treatment process [25]. As the initial turbidity was varied from low to high level, the highest turbidity removal by banana peels bio-flocculant was achieved when the turbid water was at very high level turbidity with 83.33 % removal while the lowest turbidity removal was recorded at low level turbidity with only 43.16 % recorded. Likewise, a similar removal pattern was obtained for alum. It was obvious that from **Fig. 4**, a drastic enhancement in the turbidity removal efficiency was observed as the removal percentage increased from 63.75% to 87.14 % when the initial turbidity in turbid water was varied from low to very high level.

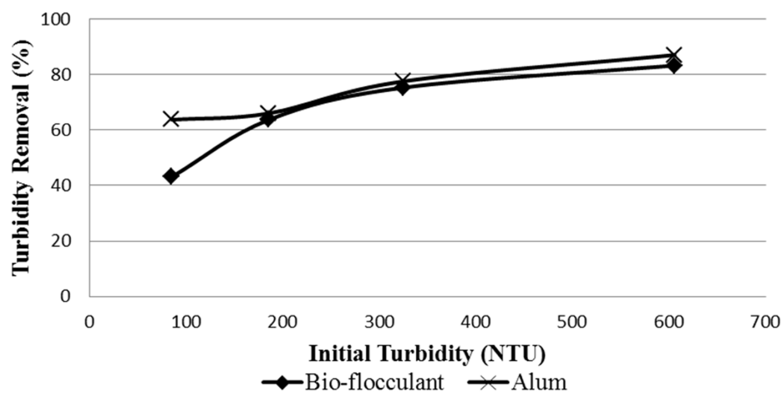


Fig. 4. The effect of initial turbidity on turbidity removal percentage

The results were in agreement with the research conducted by Asrafuzzaman et al., [26] that three different types of bio-flocculant extracts were used to investigate the performance of turbidity removal percentage in different levels of turbidity. The author reported that the turbidity removal efficiency using *Moringa oleifera*, *Cicer arietinum*, and *Dolichos labla,* increased as the level of turbidity varied from low to high level where the percentage of turbidity removal is shown in **Table 1** at 100mg/l dosage of bio-flocculant used.

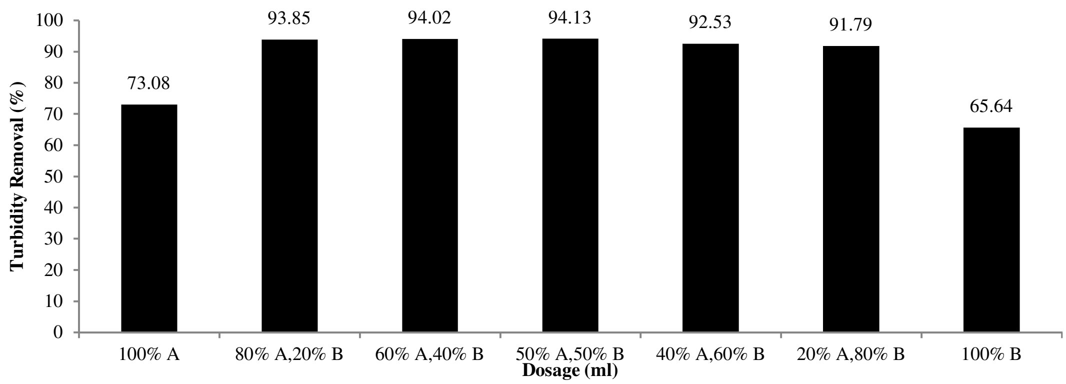
Table 1 Type of natural flocculants with their respective turbidity removal percentage from low to high level initial turbidity (Asrafuzzaman et al. [26])

Natural flocculants	**Turbidity removal (%)**		
	Low level	Medium level	High level
Moringa oleifera	60	68.37	94.1
Cicer arietinum	71.29	81.63	95.89
Dolichos labla	60.85	68.16	88.9

3.5 *The Potential of Bio-flocculants as Coagulant Aid*

The optimization study on the ratio of banana peels bio-flocculant extracts to alum dosage was carried out under the process conditions of pH 7, turbidity ranging from 210 – 260 NTU, temperature at 25 ºC. Ratio of bio-flocculant to alum was varied from the range of 0 – 100%, respectively, to investigate the optimum combination of alum and bio-flocculant for the best turbidity removal percentage.

Based on **Fig. 5**, the percentage of turbidity removal of synthetic turbid water using alum and banana peels bio-flocculant alone was 73.08 % and 65.64 %, respectively. The ratio of 60/40 and 50/50 of alum to bio-flocculant demonstrated the highest percentage of turbidity removal which was more than 94 %. No significant difference was observed between the performances of these two ratios, thus the ratio 50/50 of alum to bio-flocculant was identified as the best combination as it resulted in the maximum percentage of turbidity removal among all combinations. The utilization of 50 % bio-flocculant could be regarded as a greener solution or alternative in wastewater treatment since a reduction of 50 % in the utilization of chemical-derived coagulant could be achieved. This approach would be a tempt to the industry for wastewater treatment as the demand on alum could be reduced, which in turn indicating the possibility to reduce the cost of the treatment yet still maintaining the high efficiency of turbidity removal.



**A = Alum ; B = Banana Peels Bio-Flocculant*

Fig. 5. The effect of varying ratio of bio-flocculant to alum as coagulant aid

4. Conclusion

The comparison of turbidity removal efficiency between the conventional chemical coagulant with bio-flocculant in different process conditions was determined in this study. Under the effect of pH, the optimum turbidity removal percentage for bio-flocculant was 93.44 % at pH 12. Besides, it was found that 150ml was the best dosage for the optimum turbidity removal percentage at 71.34 % demonstrated by bio-flocculant. Under the effect of temperature, it was proven that the optimum temperature for the highest turbidity removal showed by banana peel bio-flocculant was at 40°C with 75.18 % turbidity removal percentage. Also, the banana peel bio-flocculant extracts achieved the highest turbidity removal percentage at very high turbidity level (>500NTU) with 83.33%. Lastly, the potential of extracted banana peels bio-flocculant to be used as coagulant aids to alum was investigated. The maximum turbidity removal percentage was recorded at 94.13 % with the ratio of alum to bio-flocculant at 50:50. The utilization of banana peels bio-flocculant helps to reduce the health and environmental concerns on chemical coagulants. The use of renewable sources of low cost agricultural or household waste biomass which might requires little processing to produce bio-flocculant is considered as a better choice.

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