



Effect of Natural Coagulants on the Treatment of Municipal Wastewater

Md. Ashraful Islam^{1, *}, S. M. Adnan Omi², Md. Niamul Bari²

¹Department of Building Engineering & Construction Management, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

²Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

Email address:

ashraful@becm.ruet.ac.bd (Md. Ashraful Islam), adnanomi37.00@gmail.com (S. M. Adnan Omi),

niamulbari@gmail.com (Md. Niamul Bari)

*Corresponding author

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Abstract: Nowadays, the study of the natural coagulants to treat wastewater has become a growing interest to the environmental researchers around the world as its numerous advantages over chemical coagulants. In this study, the effect of banana peel powder and banana stem powder as natural coagulant on the treatment of municipal wastewater was investigated. Wastewater samples were collected from two different primary drains located near Padma garden and Bornali within Rajshahi city corporation area. The collected wastewater samples were characterized based on turbidity, pH, conductivity, TDS, TSS, TS, alkalinity, acidity and organic content and also compared with maximum permissible limits before going treatment. The worst wastewater sample was treated with varying coagulant doses, contact time, speed and pH. The effectiveness of natural coagulants was evaluated based on the percentage removal of turbidity, alkalinity and acidity. The highest removal of turbidity, alkalinity and acidity were obtained 93.5%, 67.3% and 65.5% by banana peel powder and 93.4%, 71% and 72% by banana stem powder respectively. Therefore, the result revealed that both banana peel powder and banana stem powder had capability to treat municipal wastewater as natural coagulant. Higher treatment conditions were not economically feasible because it did not significantly remove the pollutants. The removal of alkalinity and acidity indicated that it was a partial coagulation and partial adsorption process in which both materials also had high adsorption capacities.

Keywords: Natural Coagulants, Coagulation, Adsorption, Banana Peel Powder, Banana Stem Powder, Turbidity, Alkalinity and Acidity

1. Introduction

Water is by far the most essential element among all natural resources. Oceans, seas, rivers, lakes and forests are reshaped by it, thereby contributing to the hydrological cycle that is crucial for ecosystems and human life [27]. By increasing the population, urbanizing, industrializing, sewage from household, institutions, hospitals and so on, water becomes wastewater [17]. In addition to organic and inorganic substances, biological substances, toxic inorganic compounds, and the presence of toxic materials, wastewater can be destructive for the environment [17]. There are approximately 1,500 km³ of wastewater produced globally

each year [29], over 80% of wastewater in developing countries is emitted into the environment without being treated [28], that can pollute a considerable quantity of fresh water sources, which may be used downstream for agricultural purposes. In developing countries, UNESCO estimates that 50% of the citizens rely on contaminated water sources to sustain their livelihoods [23]. A recent study reported more than six million people die of diarrhea every year in the developing countries because of polluted water [4].

Rajshahi is located on the bank of the Padma river and 43lpcd municipal wastewater are discharged into the river without any considerable treatment [31]. As a result, water of the river is being polluted day by day. This increasing

pollution has a great effect on human life as the water is used for irrigation and other purposes. By killing fish and blooming the algae, it causes eutrophication and increases bacterial contamination [11]. Wastewater from municipalities must be treated appropriately immediately before final disposal so as to control the health and environmental risks. Environmental protection and socio-economic concerns are the ultimate objectives of wastewater management [11].

The treatment of wastewater requires many different techniques around the world. Coagulation-flocculation is one of the most regular and important process used for removing suspended particles and reducing water and wastewater turbidity because it is simple and efficient to operate. In coagulation processes, Coagulants are chemicals added to water to dissolve the forces that stabilize colloidal particles, making them suspended in water. Various types of coagulants that could potentially be applied to water treatment and waste water treatment. Coagulants are either chemical or non-chemical in nature. The conventional approach to remove turbidity of water is to used chemical coagulants such as ferric chloride (FeCl_3), alum (AlCl_3), synthetic polymers (polyacrylamide) and polyaluminium chloride [2, 10, 22]. Despite the effectiveness of chemical coagulants for wastewater treatment, they do not have a sustainable life cycle and have numerous disadvantages. When waste water is treated with chemical coagulants, a major problem is the propagation of non-biodegradable sludge [9]. In recent years, natural coagulants have gained in popularity because of their benefits and the fact that they resolve a large number of issues relative to chemical coagulants [3]. Natural coagulants are biodegradable [4], non-corrosive [25], non-toxic, consistent P^{H} level in treated water and eco-friendly because they are originated from plant, microbes and animals. Therefore many plant-based materials such as *Acacia nilotica*, *Moringa oleifera*, *Dolichas lablab*, *Azadirachta Indica*, *Hibiscus Rosa Sinensis*, Banana stem, Banana peels, *Ficus carcia*, Orange peel, papaya seed powder, Roselle seeds, Jackfruit, *Osimum basilicum*, *Plantago ovate*, Neem leaf powder and etc. have been used as natural coagulants in the treatment of water and wastewater [18, 21, 24, 4, 14, 2, 5, 13, 30].

In Bangladesh, bananas (*Musa paradisiaca*, family *Musaceae*) are cultivated almost all year round and are a very popular fruit. The banana peels and banana stems are discarded as waste materials, after consumption of banana. Without proper disposal of banana peels and banana stem, they may negatively impact on the environment. Currently, water and wastewater treatment research is focused on banana peels and banana stem because of availability, high nutritional value, adsorption capacities, low cost and environmental concerns. Banana peels contain high level of lignocelluloses and have a high adsorption potential [15]. Banana stem foliage contained 5.46% hydrogen, 38.3% carbon and 0.42% nitrogen while banana stem juice had 33.42% carbon, 6.17% hydrogen and 0.49% nitrogen [2]. The stem juice of banana comprises of polysaccharide compounds – inulin (1.22016 mg/mL), a natural polymer that

bridges and entraps the micro floc in order to form larger floc which is helpful for the fast settlement of floc in coagulation of wastewater [2]. Therefore, the aim of this study is to experimentally investigate the effect of natural coagulants (banana peel powder and banana stem powder) on the treatment of municipal wastewater of Rajshahi city corporation area so that this treated water becomes suitable to safely discharge into the river Padma or directly use as irrigation water.

2. Materials and Methods

2.1. Materials Collection and Preparation

Fresh banana and banana stem were purchased from local market, Shaheb Bazar, Rajshahi. After consumption of banana, banana peels were collected. To remove external dirt from the banana peels, we cut them into small pieces and rinsed them thoroughly with tap water. The banana stem was also cut into small pieces. In order to dry the washed banana peels and stem pieces were air-dried in the sunlight for 2 weeks then oven-dried for 24 h at 105°C . A mortar pestle was used to grind the dried banana peels and stem into fine powder.



Figure 1. Banana peels and Banana stem.



Figure 2. Banana peel powder and Banana stem powder.

2.2. Wastewater Sample Collection and Characterization

Wastewater samples were collected in PET bottle in sufficient quantity by following standard procedure from two different primary drains located near Padma garden and Bornali within Rajshahi City Corporation area. All the samples were brought as early as possible to the laboratory and kept in chiller below 4°C temperature to protect from the physical, chemical and biological changes. The collected Wastewater samples were characterized based on turbidity,

pH, conductivity, TDS, TSS, TS, alkalinity, acidity and organic content before going for treatment.

2.3. Selection of Sample

Based on the characterization results, the worst wastewater samples were selected for treatment.

2.4. Treatment of Selected Wastewater Sample

After preparation of materials selected sample was treated using different natural coagulants separately through coagulation process. The treatment was carried out to reduce the concentration of pollutants. The treatment process was divided into four parts and these are variation in coagulant doses, variation in contact time, variation of speed and variation of pH. During treatment only one factor could be varied at a time and others must be constant. The treatment efficiency was determined based on removal of turbidity, alkalinity and acidity.

2.5. Experimental Instruments

The turbidity of wastewater before and after the treatment was measured by using a turbidity meter (Turbidimeter-TN-100) from Eutech Instrument. The pH values of the wastewater samples were measured by using DZB-718 Multi-Parameter Analyzer. HACH conductivity meter was used to measure the conductivity of the sample. The bench top Jar-Tester (Model: SF6 and power 220V, 50Hz) was used for coagulation experiment.

3. Results and Discussion

3.1. Characteristics of Raw Wastewater and Comparison with Maximum Permissible Limits (MPL)

The collected wastewater was characterized based on turbidity, conductivity, pH, TSS, TDS, TS, alkalinity, acidity and organic content. Table 1 summarizes the results.

Table 1. Characteristics of raw wastewater collected from different municipal drains and comparison with maximum permissible limits [26].

Parameters.	Sample of Outfall to Padma river.	Sample of Bornali.	MPL for discharging into natural water bodies	MPL for using for irrigation
Turbidity (NTU)	31.10	28.60	35	35
Conductivity (μ mhoes/cm)	1500	1380	2250	2250
pH	6.98	6.07	5.5-9.0	5.5-9.0
TSS (mg/l)	130	95	100	200
TDS (mg/l)	680	702	2000	2000
TS (mg/l)	810	797	2100	2200
Alkalinity (mg/l)	472	397	600	600
Acidity (mg/l)	250	234	200	200
Organic content (mg/l)	96	82	250	200

From table 1 it is revealed that most of the parameters with in the maximum permissible limit and both samples are slightly polluted. Considering the all parameters, it is found

that sample collected from the primary drain near the Padma garden is more polluted compared to sample of Bornali. So the sample of outfall to Padma river is chosen for treatment.

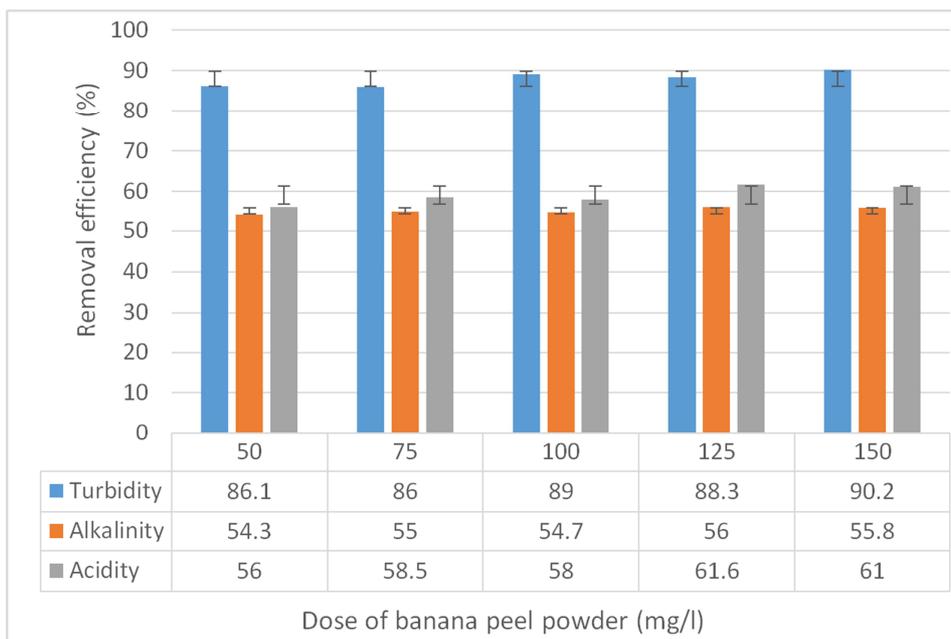


Figure 3. Removal of turbidity, alkalinity and acidity with variation of coagulant doses in forward direction for Banana peel powder.

3.2. Treatment of Selected Wastewater Sample

3.2.1. Effect of Doses of Coagulants

The coagulation activity (turbidity removal efficiency) depends on the doses of coagulants. It depends on the type and level of incoming turbidity whether the dose is increased or decreased for each type of coagulant [1]. Higher turbidity and low temperature generally increase the dose [7]. Effects of varying doses of both materials banana peel powder and banana stem powder as a natural coagulant on the removal of turbidity, alkalinity and acidity are shown in Figures 3 to 7. The other parameters contact time, stirring speed and pH were maintained at 60 minutes, 100 rpm and 6.98 respectively.

From Figure 3 it is observed that the banana peel powder as a natural coagulant is capable to remove turbidity, alkalinity and acidity. The removal capacity is also almost same in every dose level. The maximum removal of turbidity, alkalinity and acidity are 90.2%, 56% and 61.6% at doses 150 mg/l, 125 mg/l and 125 mg/l respectively by banana peel powder in forward direction. It is observed that the trend of removal efficiency is increasing with increase of coagulant doses. However, 86.1% removal was achieved at 50 mg/l dose while to increase only 4.1% removal additional 100 mg/l dose is required which is not economically feasible. Therefore, 50 mg/l could be the selected dose for the treatment.

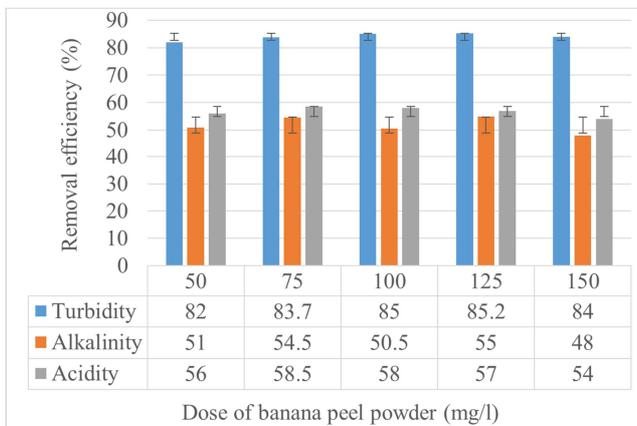


Figure 4. Removal of turbidity, alkalinity and acidity with variation of coagulant doses in backward direction for Banana peel powder.

Figure 4 illustrates that the maximum removal of turbidity, alkalinity and acidity are 85.2%, 55% and 58.5% at doses 125mg/l, 125mg/l and 75 mg/l respectively by banana peel powder in backward direction. It is observed that removal capacity is almost same in every dose level and higher doses of coagulant negatively affect the coagulation activity. However, 82% removal was achieved at 50 mg/l dose while to increase only 3.2% removal additional 75 mg/l dose is required which is not economically feasible. Therefore, 50 mg/l could be the selected dose for the treatment. It is also observed that the effect of the direction of stirring is insignificant where only 4.1% removal efficiency decreases

in backward direction at the selected dose (50 mg/l).

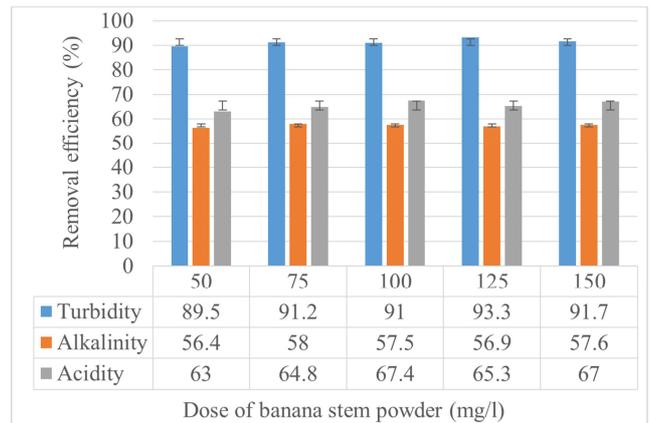


Figure 5. Removal of turbidity, alkalinity and acidity with variation of coagulant doses in forward direction for banana stem powder.

The banana stem powder as a natural coagulant is shown in figure 5 to be capable of removing turbidity, alkalinity and acidity. The maximum removal of turbidity, alkalinity and acidity are 93.3%, 58% and 67.4% at doses 125mg/l, 75mg/l and 100 mg/l respectively by banana stem powder in forward direction. It is clearly observed that the trend of removal efficiency is increasing with increase of coagulant doses upto 125 mg/l and the incremental rate of removal is insignificant at doses higher than 125mg/l. However, 89.5% removal was achieved at 50 mg/l dose while to increase only 3.8% removal additional 75 mg/l dose is required which is not economically feasible. Therefore, 50 mg/l could be the selected dose for the treatment.

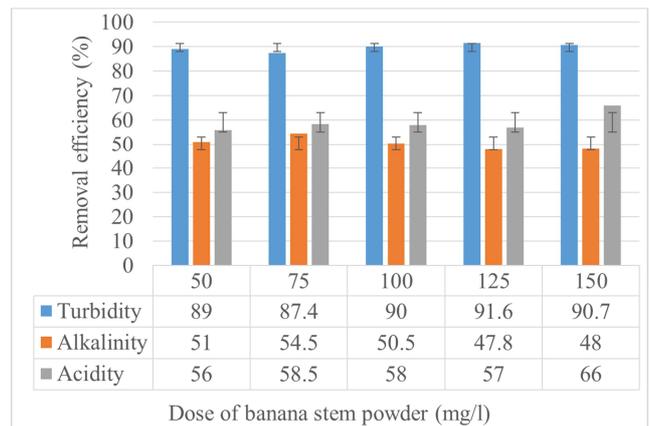


Figure 6. Removal of turbidity, alkalinity and acidity with variation of coagulant doses in backward direction for banana stem powder.

Figure 6 shows the maximum removal of turbidity, alkalinity and acidity are 91.6%, 54.5% and 66% at doses 125mg/l, 75mg/l and 150 mg/l respectively by banana stem powder in backward direction. It is observed that the trend of removal efficiency is increasing with increase of coagulant doses and the incremental rate of removal is insignificant at doses higher than 125mg/l that indicates higher doses of coagulant negatively affect the coagulation activity. However,

89% removal was achieved at 50 mg/l dose while to increase only 2.6% removal additional 75 mg/l dose is required which is not economically feasible. Therefore, 50 mg/l could be the selected dose for the treatment. It is also observed that the removal efficiency is almost same in both direction at selected dose (50mg/l).

Natural coagulants based reseaches are topical and materials from plants and renewable resources have been studied as potential sources. A study by Maurya and Daverey [18] investigated four natural plant-based coagulants (banana stem juice, banana peel powder, neem leaf powder and papaya seed powder) to municipal wastewater treatment. Different dosages were applied and maximum turbidity removal efficiency of papaya seed powder (0.8 g/l dosage), banana peel powder (0.4 g/l dosage), neem leaf powder (1.0 g/l dosage), and banana stem juice (10 ml/l dosage) were found to be 41.89%, 59.6%, 43.96%, and 18.78%, respectively [18]. With a dose of 0.4 g/l, banana peel powder showed the maximum coagulation activity of 59.6% [18]. The authors also found, higher coagulant doses negatively affected coagulation activity. when banana peel powder dosage was increased from 1.2 to 1.4 g/l, the coagulation activity was reduced from about 59% to 14.6% [18]. Result were similar when neem leaf powder and papaya seed powder [18]. Bari, et al. [5] taken an attempt to check the effectiveness of natural coagulants such as *Moringa oleifera*, banana stem, *Acacia nilotica*, *Ficus carcia* and banana peels on the treatment of municipal wastewater. The maximum turbidity removal efficiency of *Acacia nilotica*, *Moringa oleifera*, banana stem, banana peels and *Ficus carcia* were 95.31%, 93.87%, 96.42%, 94.4% and 96.04% at dose 100mg/l, contact time 30 minutes and 70 rpm stirring speed respectively. They observed that higher coagulant doses increase coagulation activity. Kukic, et al. [16] performed wastewater treatment using natural coagulants derived from common beans. It was obtained that the highest coagulation activity (49.8%) was achieved at dose of 0.4 ml/ among other doses tested [16]. Alwi, et al. [2] studied that banana stem juice has 98.5% turbidity removal efficiency at 90ml/l dosages for treatment of spent coolant wastewater. Saravanan, et al. [21] used locally available natural coagulants as *Moringa Oleifera*, *Dolichas lablab*, *Hibiscus Rosa Sinensis* and *Azadirachta Indica* to treat wastewater. The maximum turbidity removal efficiency at optimum doses of *Moringa Oleifera*, *Dolichas lablab*, *Hibiscus Rosa Sinensis* and *Azadirachta Indica* were 31.47% (3g/l) 37.45% (16g/l), 12.95% (1g/l) and 63.01% (6.5g/l) respectively [21]. While using the conventional alum (Alumnium Sulfate) as coagulant, the optimum dosage was 0.8 g/l which gave 75.01% turbidity removal efficiency [21]. Subashree, et al. [24] investigated whether banana and lemon peel powder are capable of coagulating water. They observed that removal increased as the mass of coagulant dosage was increased and dose at 0.25g/l maximum removal was obtained.

In the present study, more than 82% removal of turbidity was achieved at dose 50 mg/l by banana peel powder and banana stem powder respectively. It is observed that the trend

of removal efficiency is increasing with increase of coagulant doses and also indicates that coagulation activity is negatively affected by higher doses of coagulant. Further the study revealed that greater dosages were not economically feasible and did not significantly remove the pollutant. So, it can be concluded that at the selected dose (50 mg/l) the percentage removal efficiency is excellent and economically feasible. At optimum doses of coagulant, high turbidity reduction is achieved by neutralizing and precipitating all colloids, and when the coagulant concentration exceeds the optimum dosage, turbidity increases. If excess coagulants added to water, turbidity increased itself and did not interact with colloidal particles as they already flocculated earlier.

3.2.2. Effect of Contact Time

Contact time is a vital parameter for coagulation activities. Contact time was varied from 30 to 70 minutes at an interval of 10 minutes. The removal efficiency of turbidity, alkalinity and acidity with variation of contact time are presented in Figures 8 to 11 where other parameters like coagulant dose, stirring speed and pH were maintained at 125 mg/l, 100 rpm and 6.98 respectively.

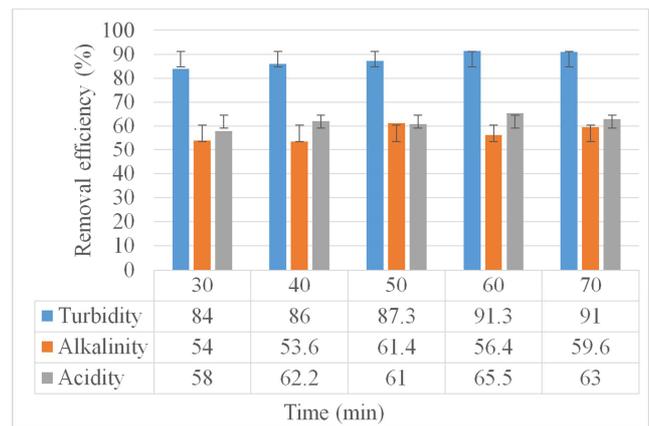


Figure 7. Removal of turbidity, alkalinity and acidity with variation of contact time in forward direction for Banana peel powder.

Figure 7 shows the maximum removal of turbidity, alkalinity and acidity are 91.3%, 61.4% and 65.5% at contact time 60 minutes, 50 minutes and 60 minutes respectively by banana peel powder in forward direction. It is observed that the removal percentage increases gradually as the time is increased upto 60 minutes and a slight decrease on the percent removal at time 70 minutes. However, 84% removal was achieved at time 30 minutes while to increase only 7.3% removal additional 30 minutes time is required which is time consuming and not economically feasible. Therefore, 30 minutes could be the selected time for the treatment.

Figure 8 shows the maximum removal of turbidity, alkalinity and acidity are 86.1%, 51.7% and 56.5% at contact time 50 minutes, 50 minutes and 70 minutes respectively by banana peel powder in backward direction. It is clearly observed that the percentage removal is almost same in every varied contact time. However, 84.3% removal was achieved at time 30 minutes while to increase only 1.8% removal

additional 20 minutes time is required which is time consuming and not economically feasible. Therefore, 30 minutes could be the selected time for the treatment. It is also observed that the removal efficiency is almost same in both direction at selected contact time (30 minutes).

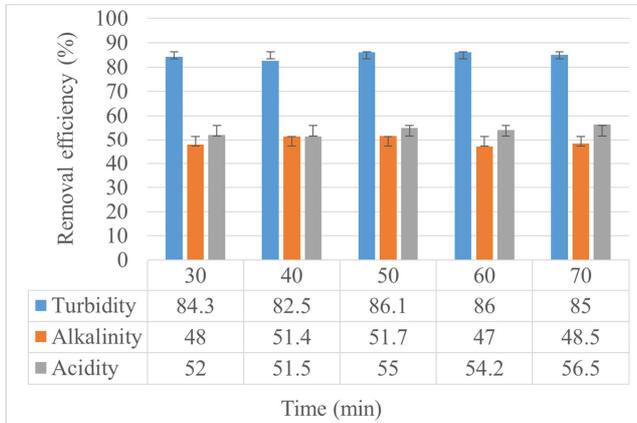


Figure 8. Removal of turbidity, alkalinity and acidity with variation of contact time in backward direction for Banana peel powder.

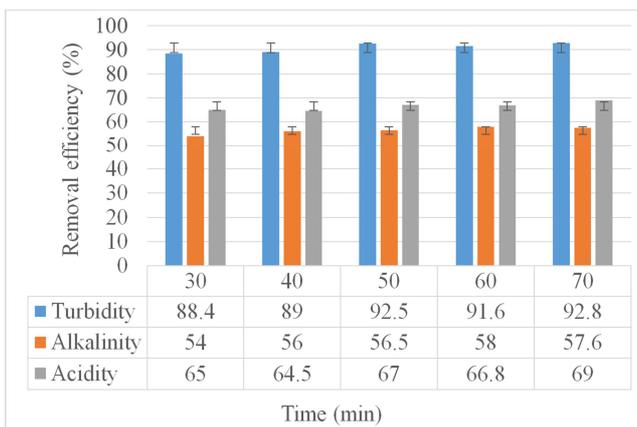


Figure 9. Removal of turbidity, alkalinity and acidity with variation of contact time in forward direction for banana stem powder.

Figure 9 shows the maximum removal of turbidity, alkalinity and acidity are 92.8%, 58% and 69% at contact time 70 minutes, 60 minutes and 70 minutes respectively by banana stem powder in forward direction. It is observed that the removal percentage increases gradually as the time is increased. However, 88.4% removal was achieved at time 30 minutes while to increase only 4.4% removal additional 40 minutes time is required which is time consuming and not economically feasible. Therefore, 30 minutes could be the selected time for the treatment.

Figure 10 shows the maximum removal of turbidity, alkalinity and acidity are 93.4%, 57% and 69% at contact time 70 minutes, 60 minutes and 70 minutes respectively by banana stem powder in backward direction. It is observed that the removal percentage increases gradually as the time is increased. However, 86% removal was achieved at time 30 minutes while to increase only 7.4% removal additional 40 minutes time is required which is time consuming and not economically feasible. Therefore, 30 minutes could be the

selected time for the treatment.

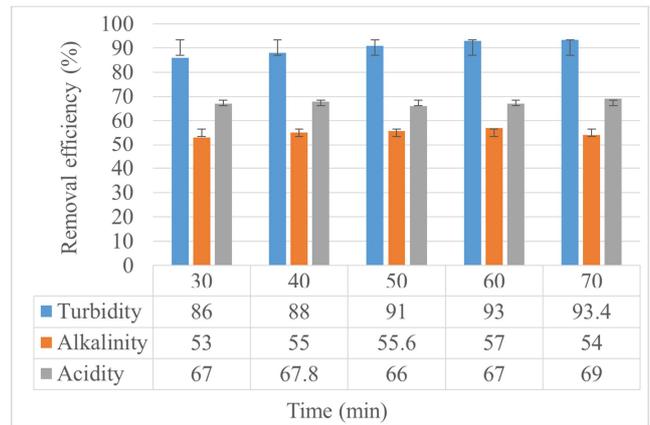


Figure 10. Removal of turbidity, alkalinity and acidity with variation of contact time in backward direction for banana stem powder.

In the present study, more than 84% removal of turbidity was achieved at mixing or contact time 30 minutes by banana peel powder and banana stem powder respectively. Further the study revealed that higher mixing time was not economically feasible because it did not significantly remove the pollutant. It was found from other researchers that the optimum contact time varies from 15 to 90 minutes for various doses of different coagulants [4, 14, 2, 18, 16, 5, 24]. So, it can be concluded that the percentage removal efficiency at selected contact time (30 minutes) is significant and economically feasible.

3.2.3. Effect of Speed

In addition to time, mixing speed also determined the efficiency of coagulation. In order to achieve shorter mixing times, faster speed is required. The removal efficiency of turbidity, alkalinity and acidity with variation of stirring speed are presented in Figures 12 to 15 where other parameters like coagulant dose, contact time and pH were maintained at 125 mg/l, 60 minutes and 6.98 respectively.

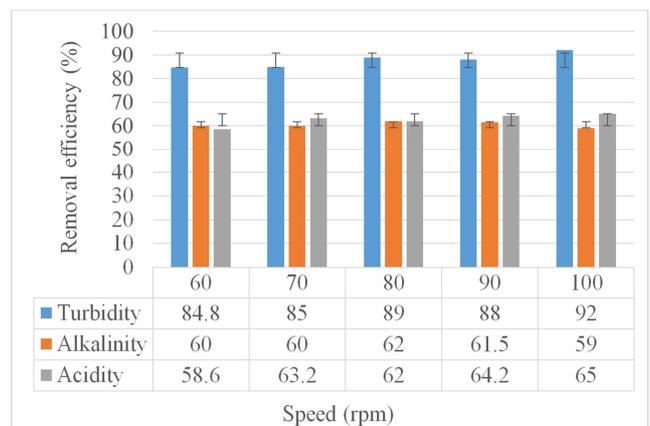


Figure 11. Removal of turbidity, alkalinity and acidity with variation of speed in forward direction for Banana peel powder.

Figure 11 shows the maximum removal of turbidity, alkalinity and acidity are 92%, 62% and 65% at speed of 100

rpm, 80 rpm and 100 rpm respectively by banana peel powder in forward direction. It is clearly observed that the percentage removal is increasing with increase of mixing speed. However, 84.8% removal was achieved at mixing speed 60 rpm while to increase only 7.2% removal additional 40 rpm speed is required which is loss of energy and not economically feasible. Therefore, 60 rpm mixing speed could be the selected speed for the treatment.

Figure 12 shows the maximum removal of turbidity, alkalinity and acidity are 93.5%, 67.3% and 65% at speed of 90 rpm, 90 rpm and 80 rpm respectively by banana peel powder in backward direction. It is observed that the removal percentage increases gradually as the mixing speed is increased upto 90 rpm and a slight decrease on the percent removal at speed 100 rpm. However, 86% removal was achieved at mixing speed 60 rpm while to increase only 7.5% removal additional 30 rpm speed is required which is loss of energy and not economically feasible. Therefore, 60 rpm mixing speed could be the selected speed for the treatment.

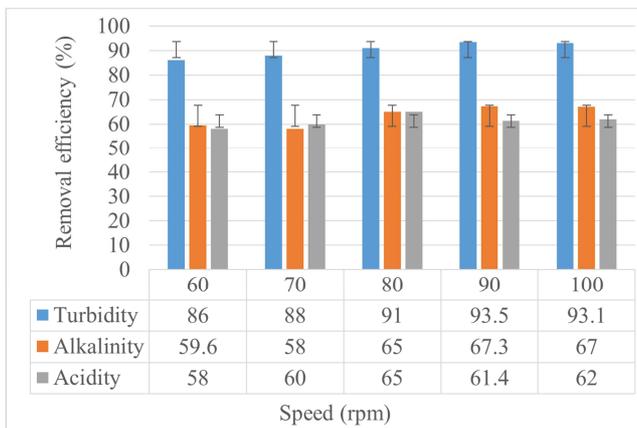


Figure 12. Removal of turbidity, alkalinity and acidity with variation of speed in backward direction for Banana peel powder.

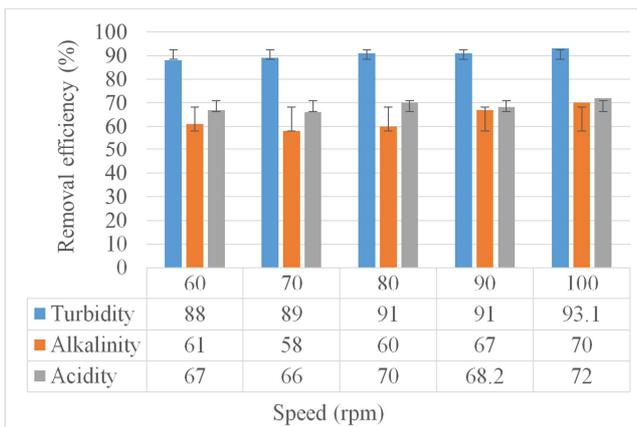


Figure 13. Removal of turbidity, alkalinity and acidity with variation of speed in forward direction for banana stem powder.

Figure 13 shows the maximum removal of turbidity, alkalinity and acidity are 93.1%, 70% and 72% at speed of 100 rpm, 100 rpm and 100 rpm respectively by banana stem powder in forward direction. It is clearly observed that the removal percentage increases gradually as the mixing speed

is increased. However, 88% removal was achieved at mixing speed 60 rpm while to increase only 5.1% removal additional 40 rpm speed is required which is loss of energy and not economically feasible. Therefore, 60 rpm mixing speed could be the selected speed for the treatment.

Figure 14 shows the maximum removal of turbidity, alkalinity and acidity are 92.1%, 71% and 70% at speed of 100 rpm, 100 rpm and 80 rpm respectively by banana stem powder in forward direction. It is clearly observed that the removal percentage increases gradually as the mixing speed is increased. However, 81% removal was achieved at mixing speed 60 rpm while to increase only 11.1% removal additional 40 rpm speed is required which is loss of energy and not economically feasible. Therefore, 60 rpm mixing speed could be the selected speed for the treatment.

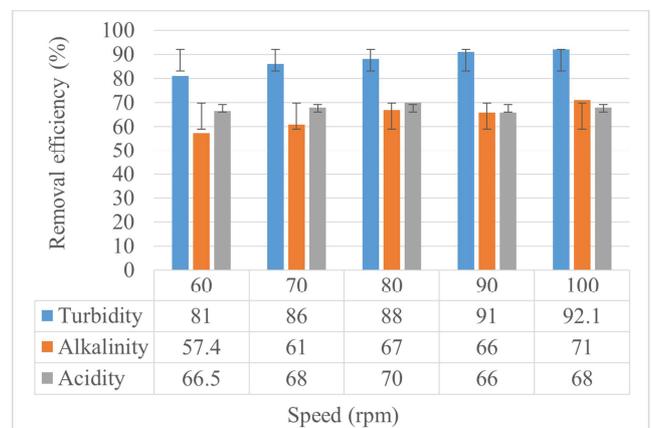


Figure 14. Removal of turbidity, alkalinity and acidity with variation of speed in backward direction for banana stem powder.

In the present study, more than 81% removal of turbidity was achieved at mixing speed 60 rpm by banana peel powder and banana stem powder respectively. It is observed that the removal capacity is almost same with the various mixing speed. However, it is remarkable that higher mixing speed was not economically feasible because it did not significantly remove the pollutant. It was found from other researchers that the optimum mixing speed varies from 30 rpm to 120 rpm for various doses of different coagulants [14, 4, 2, 18, 16, 5]. Therefore, the selected mixing speed (60 rpm) the percentage removal efficiency is excellent and economically feasible.

3.2.4. Effect of pH

Enhancement of coagulation is affected by coagulation pH [6]. The characteristics of treated water and both the type and concentration of the coagulant used influence the optimum pH value [19]. The actual pH of sample was 6.98 in stable condition. The pH was controlled using 3N HCl and 0.02 NaOH solution. It was varied as 5, 6.5, 6.98, 7.55 and 8.5 where other parameters like coagulant dose, contact time and stirring speed were maintained at 125 mg/l, 60 minutes and 100 rpm respectively. Figures 16 to 19 shows the effect of pH on the coagulation of the municipal wastewater treatment using banana peel powder and banana stem powder as natural

coagulant where it determines the removal of turbidity, alkalinity and acidity.

Figure 15 shows the maximum removal of turbidity, alkalinity and acidity are 88.3%, 56% and 61.6% at pH 6.98 by banana peel powder in forward direction. It is found that the removal percentage increases gradually as the pH is increased upto pH 6.98. However, a slight decrease on the percent removal at pH greater than 6.98. Therefore, pH 6.98 could be the optimum pH for the treatment. It can be clearly understood from the trend of removal efficiency that the acidic condition of sample (i.e. pH ranges 5-6.98) is favourable for achieving maximum removal efficiency.

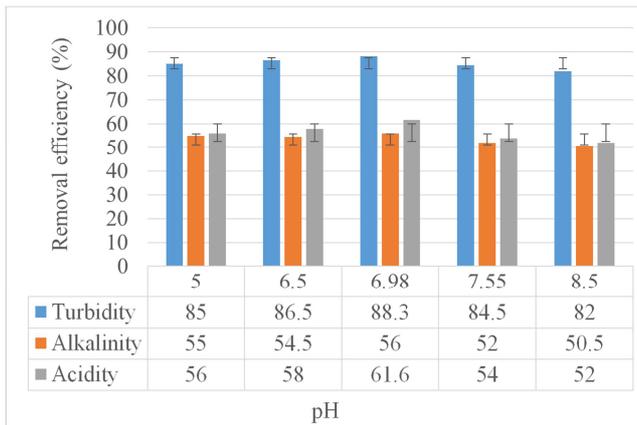


Figure 15. Removal of turbidity, alkalinity and acidity with variation of pH in forward direction for Banana peel powder.

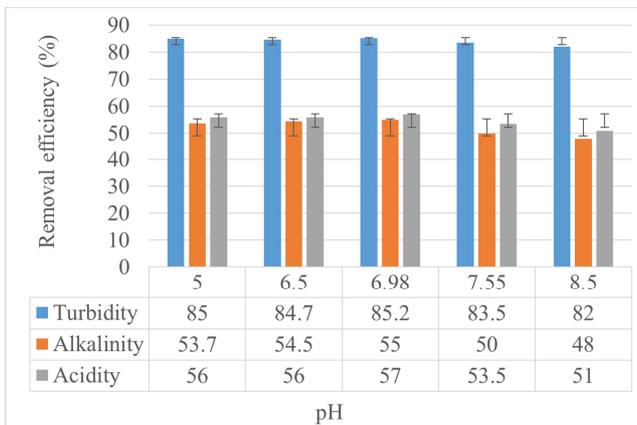


Figure 16. Removal of turbidity, alkalinity and acidity with variation of pH in backward direction for Banana peel powder.

Figure 16 shows the maximum removal of turbidity, alkalinity and acidity are 85.2%, 55% and 57% at pH 6.98 by banana peel powder in backward direction. It is observed that the percentage removal is almost same in every varied pH level. It is also showed that the removal percentage increases gradually as the pH is increased upto pH 6.98 and a slight decrease on the percent removal at pH greater than 6.98. Therefore, pH 6.98 could be the optimum pH for the treatment.

Figure 17 shows the maximum removal of turbidity, alkalinity and acidity are 93.3%, 56.9% and 65.3% at pH 6.98 by banana stem powder in forward direction. It is found that the removal percentage increases gradually as the pH is

increased upto pH 6.98. However, a slight decrease on the percent removal at pH greater than 6.98. Therefore, pH 6.98 could be the optimum pH for the treatment. It can be clearly understood from the trend of removal efficiency that the sample with high acidity (i.e. pH ranges 5-6.98) attain the best removal percentage.

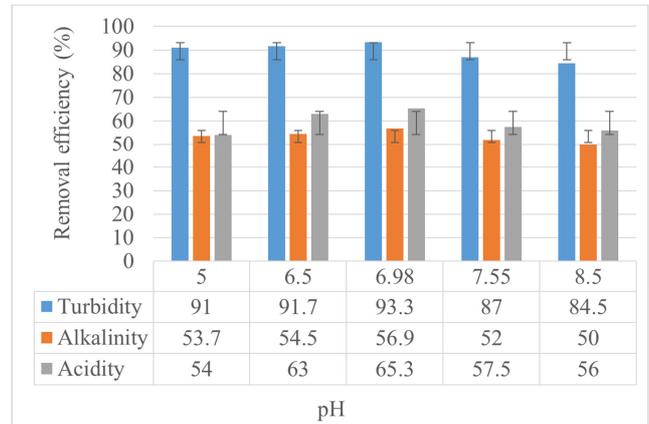


Figure 17. Removal of turbidity, alkalinity and acidity with variation of pH in forward direction for banana stem powder.

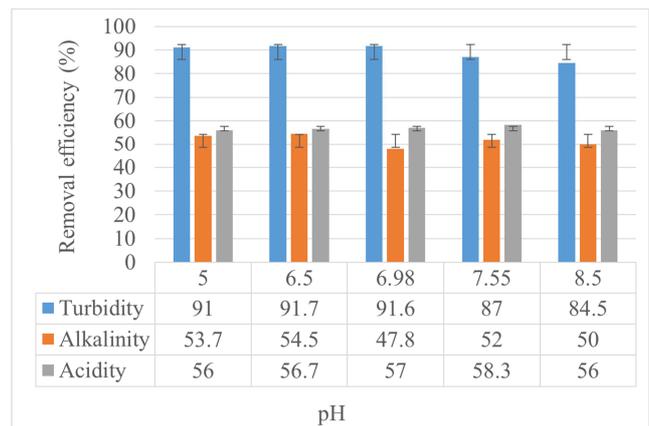


Figure 18. Removal of turbidity, alkalinity and acidity with variation of pH in backward direction for banana stem powder.

Figure 18 shows the maximum removal of turbidity, alkalinity and acidity are 91.7%, 54.5% and 57% at pH 6.5, 6.5 and 6.98 respectively by banana stem powder in backward direction. It is observed that the percentage removal is almost same in acidic condition (i.e. pH ranges 5-6.98) and a slight decrease on the percent removal at pH greater than 6.98. Therefore, the acidic condition of sample (i.e. pH ranges 5-6.98) is favourable for achieving maximum percentage removal efficiency.

Many others researchers found that pH affects the coagulation process to treat wastewater by using natural coagulants. Alwi, et al. [2] obtained maximum removal of turbidity, COD and suspended solids are 98.5%, 80.1% and 88.6% at pH 7 using 90ml/l banana stem juice dosage. Garde, et al. [13] obtained 54% removal of TSS for coffee fermented wastewater at pH 5-7 using 2-3g/l *Moringa oleifera*. Removal of turbidity and E. coli was also found by the application of 50mg/l *Moringa oleifera* at pH 7. Banana pith

was able to remove 80% turbidity at an optimum dosage of 0.1kg/m³ and pH 4 [30]. Subashree, et al. [24] investigated that maximum removal occurs between pH 6-8 for lemon and banana peels in wastewater treatment.

In this study, optimum pH for the maximum removal of turbidity is 6.98 for banana peel powder and banana stem powder respectively by comparing both direction. It can be clearly understood from the trend of removal efficiency that the acidic condition of sample (i.e. pH ranges 5-6.98) is favourable for achieving maximum percentage removal efficiency. The density of positive charges in the surfaces of coagulants hydrolysates is quite high in acidic condition [6]. This may be the main reason for both of the coagulants achieved optimum removal efficiency when pH ranges 5-6.98. However, it is remarkable that excellent turbidity removal was obtained at pH 6.98 which indicated that at pH 6.98, maximum amount of coagulant is converted to solid phase flocs particles [2]. Therefore, it can be concluded that pH affects treatment of wastewater by coagulation process using natural coagulants.

3.3. Justification of Partial Coagulation and Partial Adsorption Process

Adsorption, neutralization of charges, and particle-to-particle attachment are the principal mechanisms of natural coagulants [12]. Banana peels contain high level of lignocelluloses and have a high adsorption potential [15]. In banana peel FTIR analysis, the presence of carboxylic acid, aliphatic amine and hydroxyl have been implicated in flourishing coagulation-flocculation by neutralizing the charge of impurities in water [18]. The stem juice of banana comprises of polysaccharide compounds – inulin (1.22016 mg/mL), a natural polymer that bridges and entraps the micro floc in order to form larger floc which is helpful for the fast settlement of floc in coagulation of wastewater [2]. Therefore, both the materials have natural coagulant properties and adsorption capacities. In this study, it is found that wastewater produced a thick gelatinous precipitate after coagulants were dissolved in it and thoroughly mixed. This precipitate called a floc is capable of capturing suspended impurities within wastewater by forming this floc upon descending. Thus, this process is called coagulation process.



Figure 19. Coagulation process (Floc formation).

Natural coagulants showed an advantage over synthetic coagulants that increased turbidity removal ratios after treatment without significantly altering pH and alkalinity

[12]. Due to its highly charged surface, it has a high ability to coagulate [12]. This may be the main reason for without altering pH. Caldera, et al. [8] have been reported that after coagulation, *Moringa* seed extracts consistently removed more than 90% of turbidity of water without significantly changing pH and alkalinity. Randive, et al. [20] applied natural coagulants (*Cactus opuntia*, Kidney bean and *Cicer arietinum*) for the treatment of water and have been reported that reduction in the alkalinity of water is seen consistent, thus an inference can be drawn that natural coagulants are less efficient in reducing Alkalinity. But in this study, about 47% to 71% removal of alkalinity and 51% to 72% removal of acidity was achieved by both types of materials used as natural coagulants that indicates it is a partial coagulation and partial adsorption process in which both materials also have high adsorption capacities.

4. Conclusions

It can be concluded that municipal wastewater of Rajshahi City Corporation area is slightly turbid (28.60 to 31.10 NTU) due to the presence of suspended (95 to 130 mg/l) and dissolved solids (680 to 702 mg/l). The maximum elimination of turbidity, alkalinity and acidity are obtained 93.5%, 67.3% and 65.5% by banana peel powder and 93.4%, 71% and 72% by banana stem powder respectively. So, both banana peel powder and banana stem powder have capability to treat municipal wastewater as natural coagulant. Higher treatment conditions were not economically feasible because it did not significantly remove the pollutant. It is also observed that the effect of the direction of stirring is insignificant to remove the pollutant from wastewater by coagulation process. The selected dose, time, speed and pH are obtained to be of 50 mg/l, 30 minutes, 60 rpm and 6.98 for both types of materials used as natural coagulants for the treatment. Both of the coagulants are capable of removing excellent turbidity at pH 6.98 that indicates coagulants are converted to the highest amount of solid phase flocs particles at pH 6.98. In this study, about 47% to 71% removal of alkalinity and 51% to 72% removal of acidity was achieved by using natural coagulants that indicates it is a partial coagulation and partial adsorption process in which both materials also have high adsorption capacities.

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