THE EFFECTIVENESS OF *MORINGA OLEIFERA* AS PRIMARY COAGULANT IN HIGH-RATE SETTLING PILOT SCALE WATER TREATMENT PLANT

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ABSTRACT

High-rate settling module has long been found to be useful in enhancing the settling of flocs in the water treatment plant. In this study pilot plant test was carried out to assess the effectiveness of high-rate settling module for treatment of synthetic turbid water using alum. The percentage of turbidity removal using high-rate settling module was about 20% better than the turbidity removal without high-rate settling module. Furthermore, the coagulation efficiency of crushed seed kernels from Moringa oleifera Lam. was examined using high-rate settling module pilot plan. The seeds of M. oleifera have shown promise as a coagulant for water treatment. The turbidity after filtration was well below the World Health Organisation's guideline value of <5 NTU for drinking water from the synthetic turbid water of 200 NTU.

Keywords *: moringa oleifera, alum, pilot plant, lamella plates, settling, coagulation*

INTRODUCTION

The presence of unsettleable organic or mineral substances causes some problems in obtaining drinking water. Generally, these substances are in colloid systems, i.e., the dispersed phase is about the particles of small sizes at a few microns. The very significant specific surface area of the particles and the existence of a surface charge on these colloids explain the prevalence of surface forces over volume forces, which stabilize the systems and remove any possibility of elimination by spontaneous settling [1]. In conventional water treatment plants, agitation of the water following the addition of coagulants to reduce the repulsive force between particles in the coagulation and flocculation processes encourages particle collision and flocs formation. The properties of flocs produced from flocculation step prior to solid-liquid separation are crucial in determining the overall efficiency of water treatment process. The bigger the floc, the faster is the solid-liquid separation settling rate [2,3]. In order to enhance the settling rate, the design of the settling tank is paramount important. The usage of high-rate settling module in the sedimentation process is useful to improve the flocs settling. According to Saleh and Hamoda [4], the inclined plate settlers are less affected by overloading in comparison to conventional settlers. The solids removal efficiency increased as the hydraulic residence time increased or as the surface loading rate decreased.

High-rate settling module basically consists of inclined lamella plates or tube settlers in the sedimentation tank. Settling area of the sedimentation tanks can be increased by using plates [5] or tube settlers. For efficient self-leaning, plates are usually arranged with their floors at an angle, α above the horizon. For plated upflow settling tanks having plates with thickness (t), angle of inclination to the horizontal plane (α) and with distance (w), surface loading rate (V'_o) is

$$V'_o = V_o (w + t) / (H \cdot \cos\alpha + w) \quad (1.0)$$

where H (m), is the depth of the sedimentation tank; V'_o (m^3/m^2 time), is surface loading rate with plates; V_o (m^3/m^2 time), is surface loading rate without plates [6]. As it is seen from equation (1.0), surface loading rate decreases by a factor $(w + t) / (H \cdot \cos\alpha + w)$ as the number of plates are added to the system, thereby increasing the sedimentation efficiency. Advantages of plated sedimentation tanks have been compared with conventional sedimentation tanks both theoretically and experimentally by few investigators [7 - 10].

Several studies have reported the performance of *M. oleifera* seeds as an alternative coagulant or coagulant aid [11 - 13] in water treatment. The pilot and full scale trials in Malawi have demonstrated the effectiveness of *M.*

oleifera seed coagulant for the clarification of highly turbid river water (270 – 380 NTU) to below 4 NTU in the finished water [14]. Another pilot treatment plant had been designed to treat 2.5 m^3/day of surface water (60 to 900 NTU) from River Muha near Bujumbura City in Burundi. The plant consists of a grit chamber, flocculation unit, settling tank, a pre filter, two subsequent slow sand filters and reservoir for the storage of treated water. *M. oleifera* seeds (50-140 mg/L) have eliminated the turbidity by the pilot plant in the range of 87 – 98%. The residual turbidity of treated water was between 7 – 9 NTU [15].

In a study by Mohammed [16] *M. oleifera* seed which 0.25% of its oil was extracted was used in a pilot water treatment plant consisted of coagulation tank, flocculation tank, sedimentation tank and rapid sand filter to treat the surface water from the stream. In the conventional treatment, the turbidity removal with *M. oleifera* was 57% for low turbidity water (28 NTU) and 75.2 to 96.9% for moderate turbidity (65.2-261 NTU). However, in the case of the direct filtration the turbidity removal was improved with increase in initial turbidity of the raw water. For the initial turbidity ranged from 32.8–39, 68–95 and 102–185 NTU, the direct filtration gave an average percentage turbidity removal of 75.4, 88 and 96.9%, respectively [16].

McConnachie et al. [17] have developed two types of pilot scale flocculators namely horizontal flow channel system and contact flocculation filter. Pilot tests were carried out at Thyolo Water Treatment Work in Malawi to treat the river water using crushed seed kernel from *M. oleifera* Lam and alum respectively. Both coagulants were reported to reduce the initial turbidity of raw water ranging from 15 – 5600 NTU to a value below 5 NTU in both the flocculation system. The results also revealed that turbidity removal after settling stage was better for the case of alum compared to *M. oleifera* due to *M. oleifera* floc having a lower settling velocity.

The aim of this study was to design and evaluate the efficiency of plated sedimentation tank for water treatment using *M. oleifera*. Firstly, synthetic turbid water was treated using alum in the condition with and without lamella plate in the flocculation/settling unit. Secondly, according to the results obtained synthetic turbid water was treated using *M. oleifera* with the existent of lamella plate in the flocculation/settling unit. Turbidity was the main determinant in assessing the effectiveness of the pilot plant processes.

MATERIALS AND METHODS

Preparation of Water Sample

The synthetic turbid water prepared by adding laboratory grade kaolin (R&M, UK) into distilled water. Ten grams of kaolin was added to 1 liter of distilled water. The suspension was stirred slowly at 20 rpm for 1 hour in a jar test apparatus (Stuart Scientific, Flocculator SW1, UK) for uniform dispersion of kaolin particle. The suspension was then let to stand for 24 hours for complete hydration of the kaolin. The kaolin suspension was used as stock solution for the preparation of water samples at high turbidity of 200 ± 10 NTU.

Preparation of Alum Coagulant

The aluminum sulphate [$Al_2(SO_4)_3.18H_2O$] used in present study was of industry grade. The 1% solution of alum was made by adding 1 g of alum in 100 mL distilled water. The alum was totally soluble in the water. A fresh solution was prepared everyday.

Preparation of *M. oleifera* Coagulant

The dry pods of *M. oleifera* were collected from Seri Serdang, Malaysia. The seeds were dried in the oven (Memmert ULE 400, Germany) for 48 hours at 40°C. A rice husk removing machine (Satake Rice Machine THU class 35A, Japan) was used to remove the hulls and wings from the kernels. The kernels were ground into a medium fine powder with domestic food blender (Moulinex, Malaysia). Ten grams of *M. oleifera* powder was mixed with 0.4 L distilled water in a beaker. The mixture was blended using domestic blender (Moulinex, Malaysia) for 1 minute at high speed in order to extract the active ingredient of *M. oleifera*. The suspension was filtered through muslin cloth. The filtrate was then made up to 1 L to give a stock solution of 10,000 mg/l. The stock solution was used for jar test trials to determine optimum dosages. A fresh solution was prepared everyday to run the pilot plant.

Jar Test Protocols

The optimizations for alum and *M. oleifera* were conducted using the jar test apparatus (Stuart Scientific, Flocculator SW1, UK). The apparatus allowed six beakers to be agitated simultaneously. The beakers were filled with 500 ml of synthetic turbid water and were agitated for 4 min at 100 rpm (rapid mix) and 25 min at 40 rpm (slow mix). This was followed by 30 min of sedimentation. All operational variables was set according to previous studies [18]. After settling, 30 ml of the sample was taken from the middle of each beaker using a pipette and placed in small beaker for further analysis.

Analytical Methods

Turbidity measurements were conducted using Turbidimeter (HACH, 2100AN, USA). The pH of samples were measured using Bench pH meter (Cyberscan pH 500, Singapore). The zeta potentials were measured with Zeta-Meter 3.0+ (Zeta-Meter 3.0+, ZM3-001, USA).

Pilot Plant Scale Run

The schematic diagram of the pilot plant operation flow is shown in Figure 1. The pilot plant consists of raw water tank, coagulation tank, flocculation and high-rate settling tank as a combination unit, rapid gravity filter, coagulant dosing tank and treated water tank. The recommended flow velocity is 0.4 L/min as to obtain the retention of 4 min in coagulation tank and 25 min in flocculation/settling tank in accordance to the operating variables of jar test. The flow was controlled by a flow meter and a butterfly valve. The water sample used was synthetic turbid water of 200±10 NTU. Addition of coagulant from the dosing tank to the coagulation tank was controlled by a peristaltic pump at 3.2 mL/min. In the coagulation tank, the water sample was mixed with the coagulant by mechanical flash mixer (vertical shaft with blade) at 120 rpm. Thereafter, the water flowed to the first compartment of the flocculation and settling unit (Figure 2) wherein the slow mixing at 40 rpm was taken place. The mixing caused the collisions and enmeshment of particulates into flocs and consequently settled in the second compartment. The flow from the settling unit subsequently passed through sampling point 1 controlling by a ball valve before reached the rapid sand filter. The sampling point 2 was installed at the outlet of filter. The samples were taken from sampling point 1 after settling and sampling point 2 after filtration at half hourly interval.

The experiment was carried out under three different conditions, which are stated as below:

a) Coagulation of synthetic turbid water in the presence of lamella plate using alum.
b) Coagulation of synthetic turbid water without lamella plate using alum.
c) Coagulation of synthetic turbid water in the presence of lamella plate using *M. oleifera*.

RESULTS AND DISCUSSION

Alum as Coagulant

The results of the jar test in Table 1 reveals that the optimum dosage of alum is 6 mg/L. At optimum dosage, turbidity decreased from 201 NTU to 6.9 NTU corresponding to a turbidity removal of 96.5%. The pH value of the water samples treated with alum decreased from 6.6 to 5.6, which means that in practical terms, further chemical addition is necessary in order to correct the pH of the finished water to values between 6.5 and 8.5.

The usage of alum at the optimum dosage of 6 mg/l increased the value of zeta potential from –16 mV to +5.8 mV in the treated water. The positive value of zeta potential indicated the occurrence of polymerisation undergoing further hydrolytic reactions which yield to higher hydroxides complexes and leading to formation of positively charged complex ions and the hydroxide precipitates. However, excessive aluminium dosage (>6 mg/L) caused restabilisation of colloids and incremental in turbidity parameter.

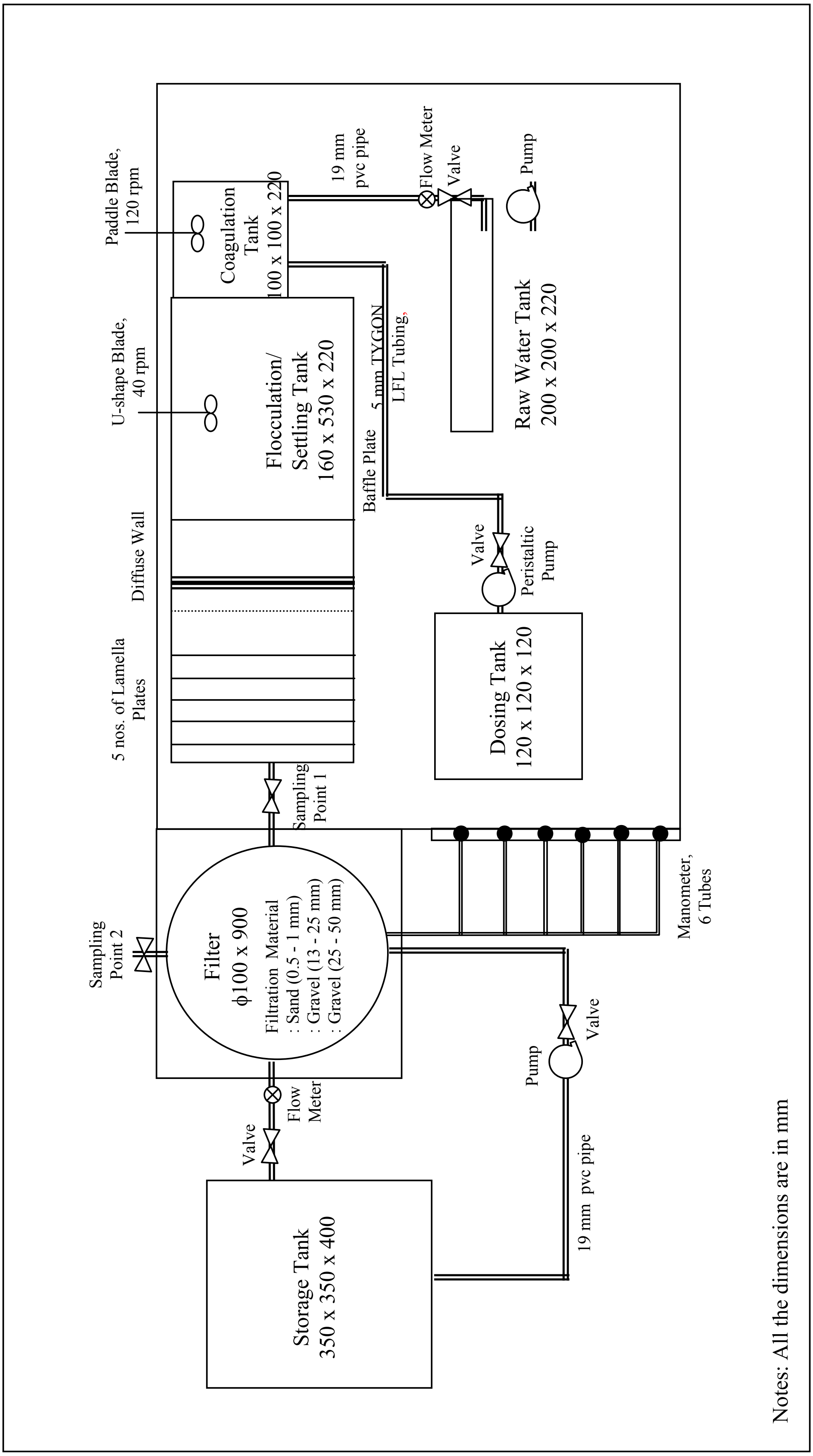

Figure 1: Schematic Diagram of the Pilot Plant Operation Flow

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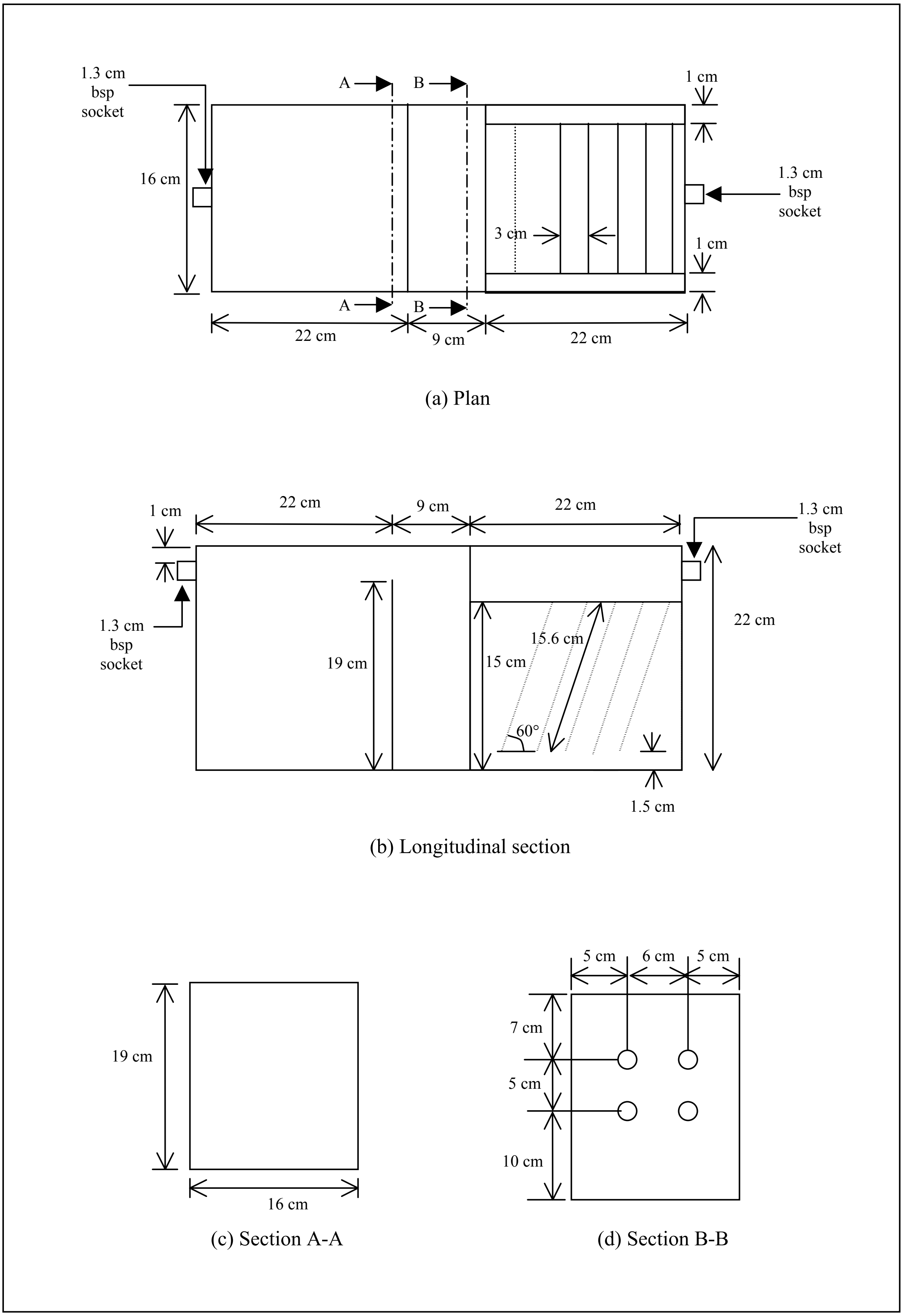

Figure 2: Schematic View of the Flocculation and High-rate Settling Tank

Table 1: Optimization of alum dosages for coagulation of high turbid water using jar test

Alum Dosage (mg/L)	Parameter			Turbidity Removal (%)
	pH	Turbidity (NTU)	Z.P. (mV)	
4	6.16	88.4	-12.0	56.1
5	6.07	18.6	-9.0	90.8
6	5.93	6.9	5.8	96.5
7	5.79	10.7	9.7	94.7
8	5.74	45.8	11.5	77.2
9	5.58	98.5	13.2	50.9

Therefore according to the results obtained 5 mg/L and 6 mg/L alum dosage was selected for the high rate settling (with attendant of lamella plates) pilot plant operation. Fig. 3 showed that the average residual turbidities in the flocculation/settling tank were 91.0 NTU and 72.9 NTU corresponding to the turbidity removal efficiency of 55.8% and 63.9% for 5 mg/L and 6 mg/L alum, respectively. The zeta potential of the water samples increased from the initial average of –17.8 mV to –11.7 mV and +8.4 mV after application of 5 and 6 mg/L of alum dose, respectively. The results indicated that, 6 mg/L of alum induced higher turbidity removal efficiency, however, the corresponding zeta potential of the water treated using the optimum dosages gave positive values. The finding showed that an overdosage of coagulant had reversed the zeta potential to positive value, however, it did not cause the destabilization of the colloids, as the residual turbidity was low.

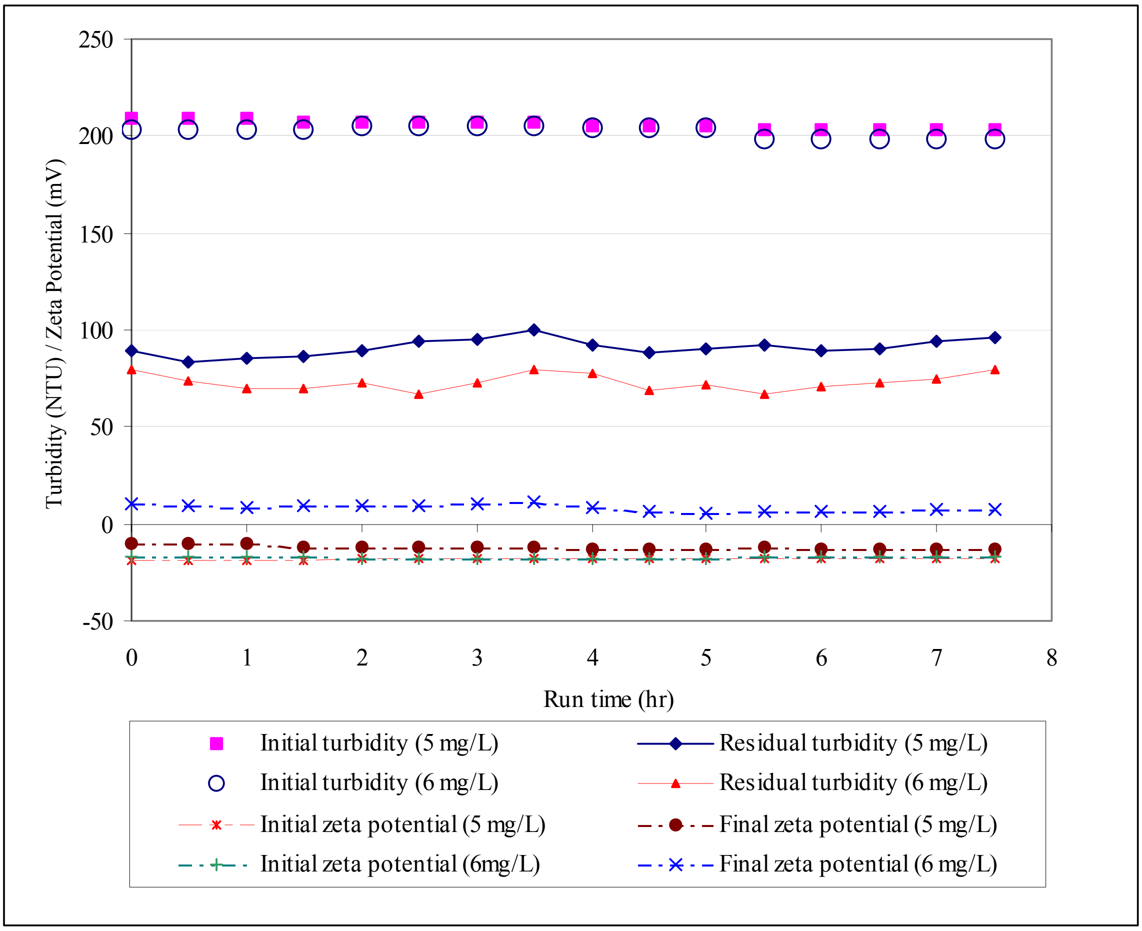

Figure 3: Relationship between Residual Turbidity and Zeta Potential of Water Samples (Sampling Point 1) Coagulated with 5 mg/L and 6 mg/L Alum in Pilot Plant Run

According to the above mentioned results 6 mg/L alum was selected for treatment of synthetic high turbid water (197-205 NTU) in the pilot plant to evaluate the effectiveness of presence of lamella plates in the flocculation/settling tank. Results are presented in Fig. 4. In the case of flocculation/settling tank with lamella plates, the turbidity removal in the range of 59 to 67% was recorded. The residual turbidity after coagulation and sedimentation was in the range of 67 to 80 NTU. Whilst, in the case of non-existent of lamella plates in the flocculation/settling tank, the turbidity removal varied between 31 to 52% corresponding to the residual turbidity of 95.7 to 137 NTU. The results indicated that the utilization of lamella plates increased the turbidity removal efficiency by 21% in average. By using the lamella plates, surface area could be greatly increased and low flow-through velocity could be maintained in each plate. At low surface overflow loading, the occurrence of scouring reduced and the hydraulic residence time increased in the sedimentation tank thus enhanced the settling of flocs [19].

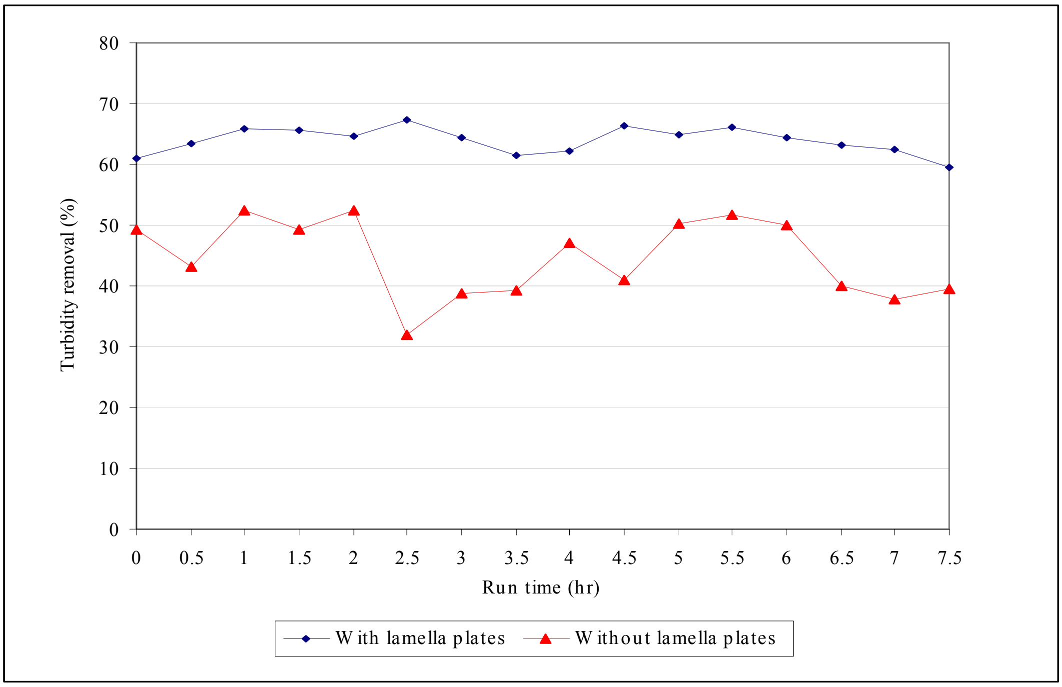

Figure 4: Coagulation of Synthetic Turbid Water (200±5 NTU) Using 6 mg/L Alum in the Pilot Plant With and Without Lamella Plates

M. oleifra as Coagulant

The results of the dosage optimization of *M. oleifera* using jar test is presented in Table 2. The result indicated that at the optimum dosage of 80 mg/L, *M. oleifera* reduced the turbidity from 201 to 13.9 NTU, corresponding to a turbidity removal of 93%. The pH values revealed that *M. oleifera* did not significantly affect the pH of the treated water, which remained almost constant at 6.4 and 6.5 for all dosages tested.

The values of the zeta potential increased from –20.0 mV to –2.1 mV after coagulation at optimum dosages of 80 mg/l *M. oleifera*. The result indicated that there was a substantial charge neutralization [12]. Doses of more that 100 mg/L led to overdosing which resulted in the increasing of zeta potential to positive value in the range of +9.1 to +21.9 mV. The increasing dosages of *M. oleifera* led to charge reversal and subsequent restabilization of the destablilized particles. Therefore, higher residual turbidity was obtained when *M. oleifera* was overdosed. Therefore according to the results obtained the *M. oleifera* dosages selected for the pilot plant operation were 80 and 100 mg/L. The effective dosage of *M. oleifera* in the pilot plant operation and the relationship between the residual turbidity and zeta potential of water samples after flocculation/settling are illustrated in Figure 5.

Table 2: Optimization of M. oleifera dosages for coagulation of high turbid water using jar test

M. oleifera Dosage (mg/L)	Parameter			Turbidity Removal (%)
	pH	Turbidity (NTU)	Z.P. (mV)	
60	6.39	18.5	-6.5	90.8
80	6.44	13.9	-2.1	93.1
100	6.37	28.8	9.1	85.7
120	6.42	30.5	10.6	84.8
140	6.39	49.3	11.3	75.3
160	6.45	129.1	21.9	35.2

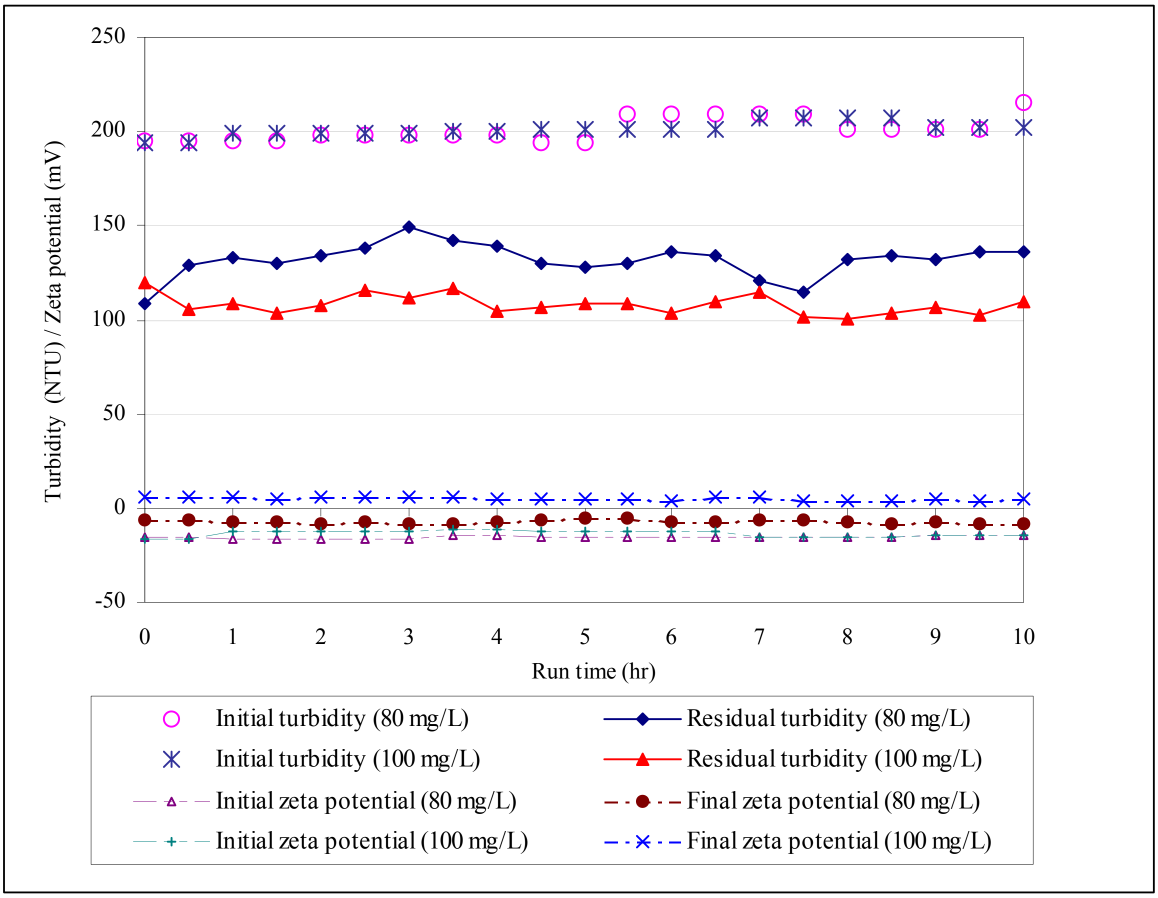

Figure 5: Relationship Between Residual Turbidity and Zeta Potential of Water Samples (Sampling Point 1)
Coagulated With 80 mg/L and 100 mg/L M. oleifera

As presented in Figure 5 the average residual turbidities recorded for *M. oleifera* dosage of 80 mg/L and 100 mg/L were 131.8 NTU and 108.5 NTU corresponding to average turbidity removal of 35% and 46%, respectively. The zeta potential of the water samples treated with 80 mg/L and 100 mg/L *M. oleifera* increased from –13.9 mV to –7.3 and +5.1 mV, respectively. Higher turbidity removal efficiency was obtained for 100 mg/L *M. oleifera*. The corresponding positive zeta potential of the treated water showed that an overdosage of coagulant had reversed the zeta potential to positive but it did not result the destabilization of the colloids, as the residual turbidity was low. This result is coincided with the study reported by Ndabigengesere et al. [12]. They have documented that overdosage of *M. oleifera* reversed the zeta potential of kaolin suspension at around +4 mV but it did not cause the restabilization of colloids.

According to results obtained in pilot plant process, the 100 mg/L *M. oleifera* was found to be the optimum dosage. Nevertheless the effective dosage of *M. oleifera* at 100 mg/L was slightly overdosing as it reversed the zeta potential to positive value. The result indicated that a higher dosage of coagulant is required to run the pilot plant at optimum mode.

The effectiveness of *M. oleifera* (100 mg/L) as the primary coagulant in the pilot plant operation is illustrated in Figure 6. The average turbidity removal efficiency of 100 mg/L *M. oleifera* in the flocculation/settling tank was recorded as 46%. During the experiment, *M. oleifera* flocs formation was evident but the floc tended to be small, compact and light which resulted in reduction of settling velocities, significantly. Therefore the usage of lamella plate was paramount important to increase the sedimentation efficiency by reducing the surface loading rate. After the sand filtration stage, the percentage of turbidity removal was 99% where the final effluent quality was consistently close to or below 1 NTU and thus substantially below the WHO guideline for drinking water of <5 NTU [20]. This result is in accordance to those reported by Bhuptawat and Chaudhari [13]. They have documented the turbidity of filtrate about 2 NTU for *M. oleifera* and 4 NTU for alum.

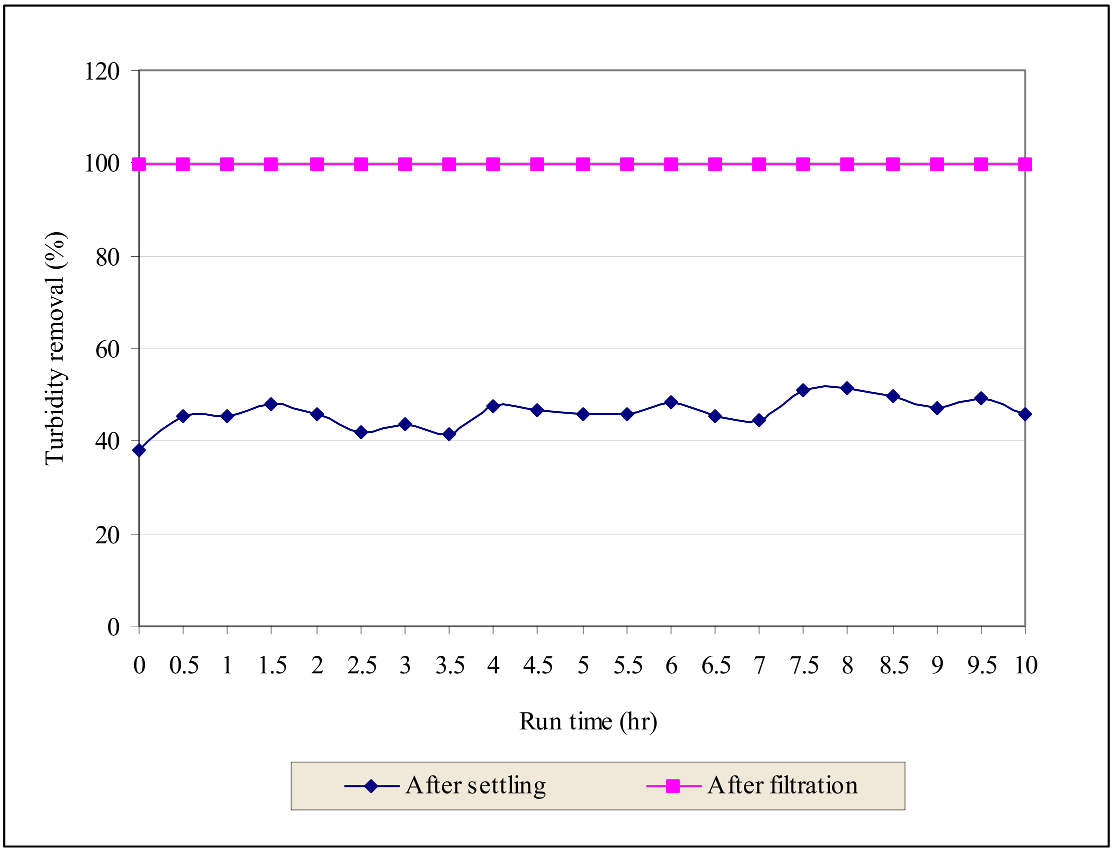

Figure 6: Coagulation of Synthetic Turbid Water (200±10 NTU) Using 100 mg/L M. oleifera in the High-rate Settling Pilot Plant

CONCLUSION

Lamella plate was found to be able to increase turbidity removal efficiency significantly in the flocculation/settling tank by reducing the surface loading rate and increasing the retention time. The application of *M. oleifera* in the pilot plant showed that it can be used effectively as coagulant for water treatment. The quality of water treated using *M. oleifera* was well below the WHO guideline for drinking water of <5 NTU after filtration.

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