18th International Conference on Environmental Science and Technology

Athens, Greece, 30 August to 2 September 2023

Investigative Study on the Effectivity of Plant-Based Coagulants for the Siltation Pond of an Aggregate Crushing Plant in Southern Luzon, Philippines

ANGUS F., CLEMENTE E.*, BALLESTEROS JR. F.

[1] University of the Philippines Diliman, Quezon City
*corresponding author:
e-mail: edclemente@up.edu.ph

Abstract Water quality and treatment are becoming of increasing concern. It is important to develop renewable bio-coagulants to treat turbid water. This study suggests plant-based coagulants as substitute for chemical coagulants. The plants used were Moringa oleifera (MO), Carica papaya (CP) seeds, and aloe vera (AV) rind which are readily available in most communities. These contain water-soluble substances that have coagulation activity in water. The coagulation efficiency of these plants, at different dose were studied and compared with aluminum sulfate (AS), the most used chemical coagulant.

All coagulants were most effective at 0.40 g/L dose. Among the coagulants used, MO outstands in interface height variation, settling rate and TSS removal of 71.79%. With 98.00%, it also has the highest color removal together with alum. The latter also has the highest turbidity removal with 96.40% and contributed to greater rise in DO levels. However, using alum turned the water acidic. The pH exhibited variations through coagulation, Moringa oleifera yielded to smallest pH variation.

Keywords: water treatment, coagulation, bio-coagulant

1. Introduction

Bodies of water are used as effluent endpoints by many industrial plants. Colloidal particles in water are difficult to remove by sedimentation alone, it can pollute and negatively affect the aquatic life. Wet crushing of raw aggregates transfers some fine particles, causing turbidity in Piña River and making it difficult to use water for industrial uses. Coagulation and flocculation are several dependable approaches for treating water. Chemical coagulants have been employed in traditional treatment but have high cost and detrimental effects on the environment and health [1]. Natural coagulants have gained popularity for its advantages. It offers a promising way to reduce the costs and impacts of synthetic products while creating sustainable and safe water source. MO, CP and AV are various plants used to develop bio-coagulants.

The study aims to characterize the bio-coagulants and find the optimal dose to be used; examine the coagulants' efficiency and determine the most effective based on the settling velocity, TSS, color and turbidity removal, dissolved oxygen, and pH; and analyze the sustainability of these plant-based coagulants in reference to the traditionally used synthetic coagulant.

2. Methodology

2.1. Water Sample Collection

The water samples were obtained from the crushing plant's siltation pond and transported to UPD NEC laboratory.

2.2. Coagulant Preparation and Characterization

MO and CP seeds were de-shelled. AV rinds were removed from the leaf. These were washed and for moisture removal, the seeds were dried in an oven for 6 hrs at 50°C and the rind for 24 hrs at 60°C. These were pulverized using separate grinders. Chemical coagulant used in this study was AS. The coagulants, all in powdered form were sieved through Tyler mesh no. 35. Fine powder was packed with varying weight of 0.4, 0.8, 1.2, 1.6 and 2.0g. Also, 3.0g for each bio-coagulant were sent for FTIR Spectrometry analysis to UPD DMMME Lab.

2.3. Coagulation and Treatability Study

1-L sample was transferred to a beaker. A sample was left as untreated representative. Coagulants in varying doses were added to derive coagulant dose effect. To ensure well mixing to promote particle collision, beakers were agitated using magnetic stirrer: rapid mixing (300rpm) for 3 min and slow mixing (60rpm) for 15 min.

2.3.1. Blanket Height and Settling Velocity Determination

Samples from beaker were transferred to graduated cylinder, allowed to settle for 2 hrs and suspension-liquid interface height was measured at different time intervals.

2.3.2. TSS, Color, Turbidity, DO, and pH Determination

After mixing, at Hr 0, 1 and 2, 100-mL samples were drawn from the beaker. Filter papers were weighed and used to filter the water sample. Wet paper was dried at 103-105°C for 15 mins and reweighed; increase in weight was recorded as the TSS. Remaining procedures used Hanna Hi 96727 Colorimeter, Rcyago

Turbidimeter, Milwaukee M600 DO Meter, and handheld Oakton PCTestr 35, respectively. Measurement procedures for pH determination were done in three trials.

2.4. Effectivity and Sustainability Analysis

Coagulants' effectivity at optimal dose was assessed and sustainability analysis was also done to understand their environmental and economic impact.

3. Results and Discussions

3.1. Coagulant Characterization

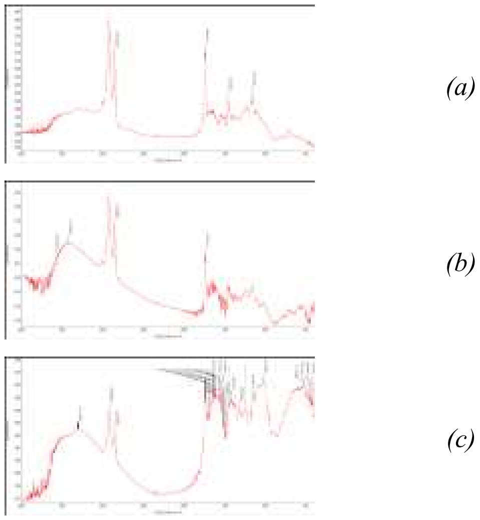

Figure 3.1. Fourier Transform Infrared Spectrum of (a) MO seed, (b) CP seed, and (c) AV rind powder.

A broad band observed at beginning of *Fig. 3.1a* may be related to MO seeds' water-soluble flocculating protein which acts an active coagulation agent. The C–H bond of alkane groups at 2926.00, 2853.96, 1464.48 cm^{-1} aids turbidity removal while C=O bond of esters at 1747.08 and 1163.13 cm^{-1} provides metal ion adsorption sites.

For CP at *Fig. 3.1b*, H–bonded alcohols and phenols at 3572.30 and 3425.41 peaks, C–H bond of alkane groups at 2926.00 and 2853.74 cm^{-1} and C=O bond of esters at 1745.21 cm^{-1}, indicate functional groups enabling protein to be an efficient polyelectrolyte and potential to adsorb wide range of contaminants, removing suspended solids.

For AV at *Fig. 3.1c*, O–H stretch of alcohol is linked at 3307.74, 1418.14; C–H bond of alkane at 2923.62, 2852.77, 1488.67; and other functional groups indicate potential to absorb a wide range of contaminants.

3.2. Coagulation and Treatability Study

3.2.1. Blanket Height

Coagulation deals with blanket height and settling rate, which are inversely related. Treated samples displayed enhanced slope of interface height vs. time. Settling occurs more quickly at 0.40 g/L which had largest slope and lower height difference. As concentration rises, hindered settling becomes more prominent and results in velocity drop [2].

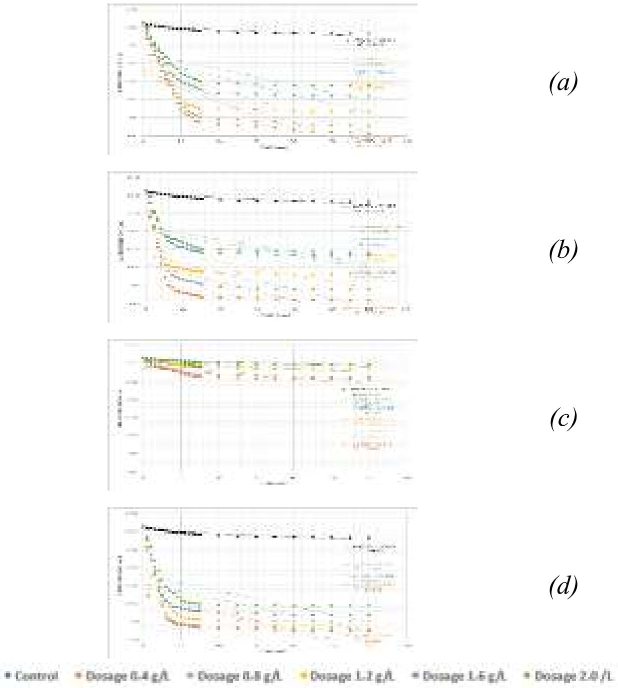

Figure 3.2. Blanket Height vs. Time for Control and (a) MO, (b) CP, (c) AV, and (d) AS at different doses

3.2.2. Settling Velocity

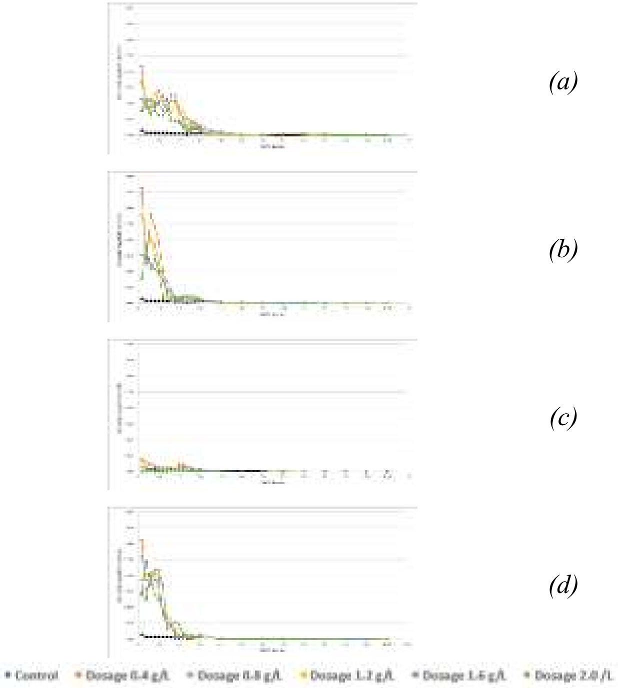

Figure 3.3. Settling Velocityy vs. Time for Control and (a) MO, (b) CP, (c) AV, and (d) AS at different doses

Large reduction in blanket height resulted in faster settling. Average settling rates were observed rapid for first 30 mins, and decreased for the remaining observation time. Settling curves exhibit the same patterns, separated into three portions: first segment, with a constant settling velocity; followed by transitional-settling period, with a decreasing settling velocity; and compression settling near the end marked by a very low variation of the interface [3].

3.2.3. Total Suspended Solids

Fig. 3.4 indicates notable TSS reduction and the violet trendline (time vs dose) shows final TSS increases with dose. Adding more natural polymer beyond the optimum point reduces TSS removal. The surface become saturated with too many polymer particles, causing charge reversal, and reducing TSS removal. Zeta potential affects flocs' size and density. Higher TSS produces more sludge because of particle pushing and crowding which increase density until it approaches a critical distance causing more rapid flocculation. Low zeta potential reduces electrostatic interactions and resulting in more compact flocs [4].

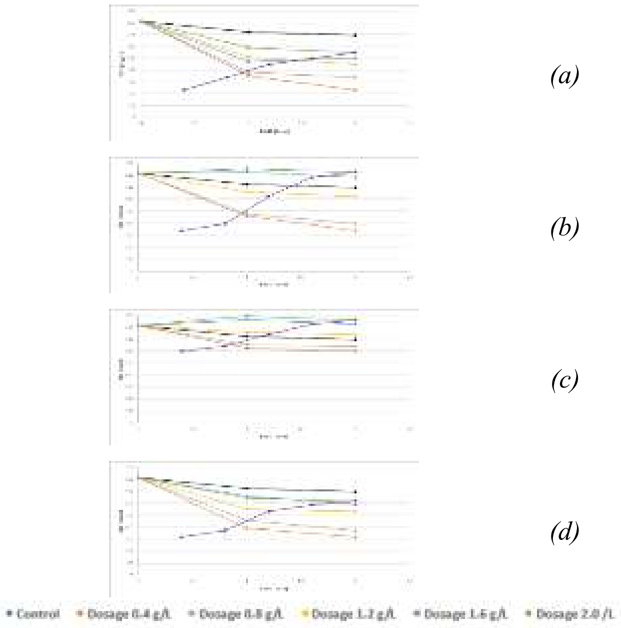

Figure 3.4. TSS vs. Time for Control and (a) MO, (b) CP, (c) AV, and (d) AS at different doses

3.2.4. Color

Strong positive association between color and TSS was observed; color also decreased after treatment. Impurities present in colloidal form cause high color. As already noted, adding natural polymer over the recommended level reduces TSS removal, which leads to increased solids in the water and changes the water's color.

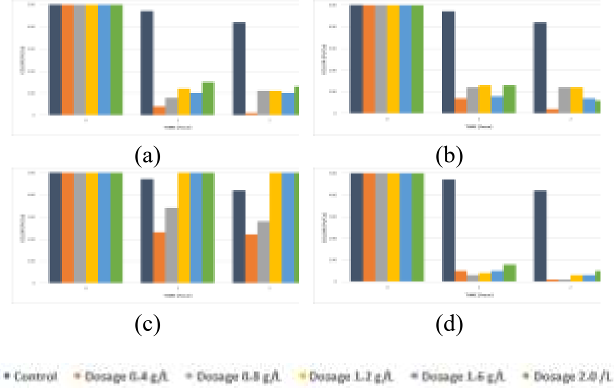

Figure 3.5. Color vs. Time for Control and (a) MO, (b) CP, (c) AV, and (d) AS at different doses

3.2.5. Turbidity

Turbidity follows same trend with TSS and color. Higher turbidity is a result of significant amounts of suspended and dissolved solids, produced by adding doses above what is optimal; polymer particles cause particle restabilization and obstructs removal of suspended solids.

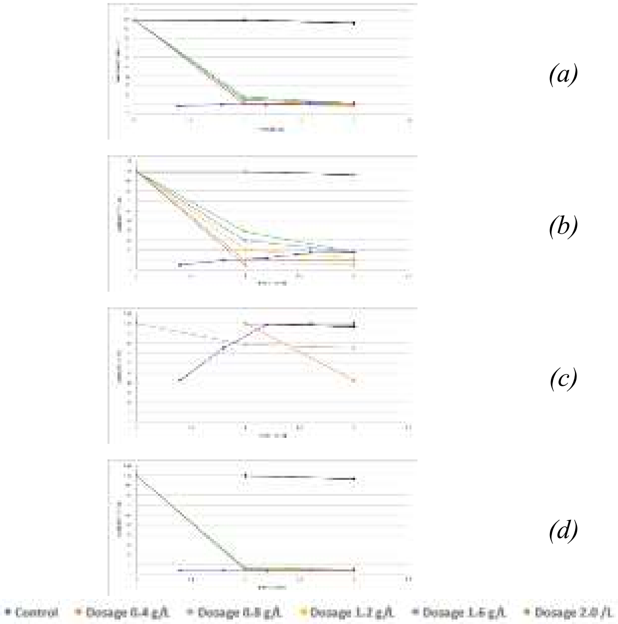

Figure 3.6. Turbidity vs. Time for Control and (a) MO, (b) CP, (c) AV, and (d) AS at different doses

3.2.6. Dissolved Oxygen

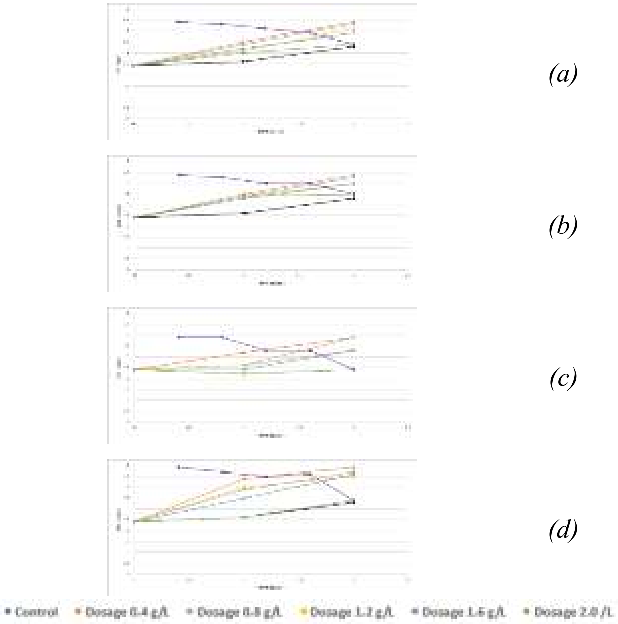

Figure 3.7. DO Velocityy vs. Time for Control and (a) MO, (b) CP, (c) AV, and (d) AS at different doses

DO evidently decreased with increased dose. This is due to the interaction of active site of coagulant with oxygen atom in water. Thus, high turbid water had lesser DO. Turbidity lowers sources of DO, as it inhibits gas exchange with the environment and light penetration. Also, the degradation of the organic content or reduction of suspended solids decreases turbidity, which in turn uses up DO.

3.2.7. pH

Water basicity is neutralized b addition of coagulants. pH decreased with increasing coagulant dose, impact on pH was contained within the pH range of 5.50 to 8.00 Out from the data gathered, below is a table generated from ANOVA (analysis of variance) in Excel.

Table 3.1. Analysis of Variance of the pH measurements

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.35	3.00	0.78	5.37	0.01	3.10
Within Groups	2.92	20.00	0.15			
Total	5.27	23.00				

F>Fcrit denotes a significant difference on pH. P-value of 0.01<0.05 confidence level denotes difference between how coagulants affect pH. Since pH is a crucial component for aquatic life, pH preferably remains unchanged to ensure existing organisms in the water continue to grow.

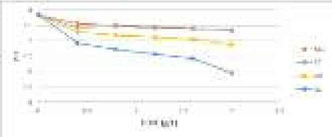

Figure 3.8. Final pH vs. Concentration for Control and different coagulants at different doses

3.3. Effectivity Analysis

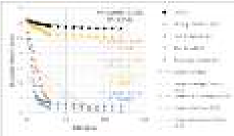

Figure 3.9. Blanket Height vs. Time for Control and different coagulants at 0.40 g/L

At 0.4 g/L, MO, CP, AV and AS yield a height difference from the unsettled solution of 0.7771, 0.9015, 25.4896, and 2.3935 cm, respectively. MO has largest slope and smaller interface height; followed by CP, AS and AV; making AV the least effective based on the blanket height.

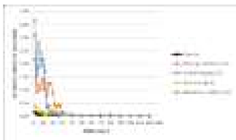

Figure 3.10. Setling Velocity vs. Time for Control and different coagulants at 0.40 g/L

Settling rate followed same coagulant ranking with blanket height, as expected from results shown in previous graphs.

Figure 3.11. TSS vs. Time for Control and different coagulants at 0.40 g/L

Fig 3.11 and *Table 3.2* show that most effective coagulant in terms of TSS reduction is MO has the largest slope.

Table 3.2. Effect of the coagulants on TSS removal at optimal conditions

COAGULANT	CONCENTRATION (g/L)	TSS (mg/L)		% Removal Efficiency
		Initial Conc	Final Conc	
Control	–	816.33	695.52	14.80
Moringa Oleifera	0.40	816.33	230.27	71.79
Carica Papaya	0.40	816.33	339.24	58.44
Aloe Vera	0.40	816.33	599.27	26.59
Aluminum Sulfate	0.40	816.33	319.23	60.89

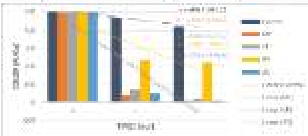

Figure 3.12. Color vs. Time for Control and different coagulants at 0.40 g/L

Table 3.3. Effect of the coagulants on Color removal at optimal conditions

COAGULANT	CONCENTRATION (g/L)	COLOR (PtCo)		% Removal Efficiency
		Initial Conc	Final Conc	
Control	–	500.00	420.00	16.00
Moringa Oleifera	0.40	500.00	10.00	98.00
Carica Papaya	0.40	500.00	20.00	96.00
Aloe Vera	0.40	500.00	220.00	56.00
Aluminum Sulfate	0.40	500.00	10.00	98.00

Color reduction is shown in *Fig. 3.12* and *Table 3.3.* MO and AS were the most efficient in terms of this parameter.

Figure 3.13. Turbidity vs. Time for Control and different coagulants at 0.40 g/L

Table 3.4. Effect of the coagulants on Turbidity removal at optimal conditions

COAGULANT	CONCENTRATION (g/L)	TURBIDITY (NTU)		% Removal Efficiency
		Initial Conc	Final Conc	
Control	–	100.00	92.70	7.30
Moringa Oleifera	0.40	100.00	8.30	91.70
Carica Papaya	0.40	100.00	5.00	95.00
Aloe Vera	0.40	100.00	42.30	57.70
Aluminum Sulfate	0.40	100.00	3.60	96.40

AS exhibited the largest turbidity reduction, followed by CP, MO and AV with 96.40%, 95.00%, 91.70% and 56.00%, respectively; making the latter the least effective.

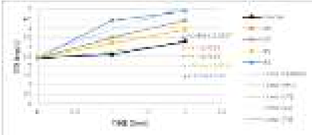

Figure 3.14. DO vs. Time for Control and different coagulants at 0.40 g/L

From initial DO of 2.40, resulting DO were 4.40, 4.40, 3.90 and 4.90 mg/L for MO, CP, AV and AS, respectively.

Then, pH was initially measured 7.85. MO did not affect raw water so much, had smallest pH decrease to 7.57; CP and AV to 7.43 and 7.28, respectively. While water became acidic with AS, had final pH 6.92, making it most compromising coagulant if alteration of pH be considered.

3.4. Sustainability Analysis

Chemical coagulants lack in green chemistry. Coagulation with alum results to pH decrease. Chemical coagulants in general, produce non-biodegradable sludge which uptake phosphorus in plants and result in aluminum phytotoxicity. It is also relatively difficult to dewater [1]. Treating severely turbid water also requires the use of proteolytic chemicals in addition to alum, making it expensive and challenging to implement.Due to these, it is necessary to consider plant-based coagulants to protect environment and public health. They are cost-effective as they are readily available; require low dose and easy preparation process; and produce lower sludge volume which can be used as backfill as they are biodegradable. No additional sludge treatment and no pH adjustments are needed which suggest its economic and environmental advantage. Natural coagulants are also non-corrosive [5], so worries about pipe erosion can be eliminated.

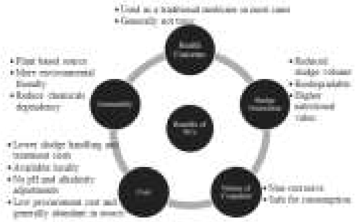

Figure 4.15. Advantages of natural coagulants (*Sourced from Choy et.al. through Journal of Environmental Sciences, 2014*)

4. Conclusions

Bio-coagulants can be paradigm shift in water treatment. This study emphasizes the use of these coagulants for effective siltation pond water treatment. From FTIR analysis, presence of many functional groups in plant-based coagulants indicates potential for coagulation and removal of colloidal particles. 0.40 g/L was the optimum efficiency for all coagulants. For interface height, MO has fastest settling rate which resulted to greatest change with a difference of 0.78 cm. TSS, color and turbidity removal efficiency of 71.79%, 98.00%, and 91.70%, respectively; and least pH alteration are the highlights for MO. AS has same color removal, highest turbidity removal of 96.40% and greater DO rise. However, it's the most compromising coagulant considering non-alteration of pH and it produces non-biodegradable and toxic residual sludge [5]. Thus, with time, interest in plant-based coagulants has grown due to their biodegradability and eco-friendliness, making it more sustainable choice.

References

[1] Aizawa, T. (1990). Problems with introducing synthetic polyelectrolyte coagulants into the water purification process. *Water Supply* 8, 27–35.

[2] Guibai, L., & Gregory J. (1991). Flocculation and sedimentation of high-turbidity waters. *Water Research,* 25, 1137–1143.

[3] B. Fitch, "Sedimentation of flocculent suspensions: state of the art," AIChE Journal, vol. 25, pp. 913–930, 1979.

[4] Panalytical, M. (2019). Water Treatment and Role of Zeta Potential in Water Treatment Process Control. Retrieved on January 21, 2023 from https://www.azonano.com/article.aspx?ArticleID=1237.

[5] Choy, S., Prasad, K., Wu, T., Raghunandan, M., & Ramanan, R. (2014). Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification. *Journal of Environmental Sciences,* 26, 2178-2189. https://doi.org/10.1016/j.jes.2014.09.024