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Effects of Coagulant Dosage, Particle Size, and Settling Time on Pond Water Treatment with Cactus Pads and Watermelon Seeds

Mahir M Said[1]*and Neema O Msuya[2]
Department of Chemical and Process Engineering, University of Dar es Salaam
P. O. Box 35131 Dar es Salaam, Tanzania
[1]mahir@udsm.ac.tz, [2]nmsuya@udsm.ac.tz
**Corresponding author: mahir@udsm.ac.tz*
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Abstract

Most Tanzanians who live in villages still struggle to get enough drinking water due to limited supply, so they use pond water for drinking and household purposes. Treatment of this water is crucial especially during the rainy season to reduce its turbidity. The performance of two natural coagulants (i.e., Cactus pads and watermelon seeds) was evaluated in their effectiveness in purifying pond water. The jar test method was used to analyze the effects of coagulant particle size, dosage, and settling time on the treatment of pond water. Attenuated Total Reflectance Fourier Transform Infrared spectroscopy (ATR-FTIR) was used for characterizing the functional groups of the coagulants. The presence of proteins and carboxylic acid groups in both coagulants demonstrates their potential for use in water purification. The effectiveness of removing turbidity in pond water with Cactus and watermelon seed coagulants was determined to be 78.58% and 94.18%, respectively. For both coagulants, the longer the settling time, the more turbidity was removed. The study indicates that watermelon and cactus pads can be used as coagulants to replace synthetic coagulants.

Keywords: Turbidity; Watermelon seed; Cactus pads; Pond water; Natural coagulants

Introduction

Drinking water can originate from surface water, ground water and storm water. Surface water is usually rain water that collects in surface water bodies, like oceans, lakes, ponds or streams (Gana 2022, Ayers et al. 2017). Pond water is still widely used for drinking and household purposes in developing countries (Bwire et al. 2020, Choudhary and Neogi 2017). Due to limited water supply in Tanzanian villages, people rely on ponds for drinking water. Due to the poor water quality, proper treatment is necessary before use. An increase in diseases like cholera, diarrhea, and typhoid is caused by the improper treatment of pond water (Pringle 2019, Bello et al. 2019).

Pond water turbidity is about 40 NTU (Mramba and Kahindi 2023). During rainy seasons, the turbidity of pond water increases even higher. This indicates the necessity of treating the pond water. The result is that a significant amount of chemicals are needed (Khaliq et al. 2022, Choudhary and Neogi 2017). Purification of drinking water from wells, rivers, and lakes has been the subject of various research studies (Hamza et al. 2018, Varkey 2020, Sun et al. 2020, Patel and Shah 2020). Despite being one of the most common sources of drinking water, purification of pond water is rarely studied.

To get the required quality of drinking water from a pond, several processes are necessary. These processes include coagulation, sedimentation, filtration,

aeration, and chemical treatment (Emelko et al. 2011, Podgórni and Rząsa 2014, Ghernaout 2013, Otieno et al. 2012).
The coagulation process is employed in drinking water treatment to destabilize suspended particles and react with organic compounds in the raw water (Katrivesis et al. 2019, Misau and Yusuf 2016). Synthetic coagulants that are commonly used include mineral additives that contain metal salts, such as aluminum sulphate, ferric chloride, polyaluminum chlorides coagulants, and synthetic polymers (Misau and Yusuf 2016). Due to their high particle removal efficiency, the aluminum series is the most popular choice for coagulants used in drinking water treatment (Katrivesis et al. 2019, Shewa and Dagnew 2020).

Several studies have identified a number of adverse effects associated with the use of aluminum salts. These include Alzheimer's disease, disease of the adynamic bones, brain disease, and peripheral nervous system toxicity (Pietropaoli et al. 2022, Kopanska et al. 2018, Crisponi et al. 2017). As a result of all these negative effects, there has been a lot of interest in developing natural coagulants that are abundant, low-priced, environmentally friendly, and biodegradable (Singh et al. 2022).

The effectiveness of natural coagulants like moringa seeds, cactus pads, watermelon seeds, jatropha seeds and maize starch in water purification has been compared to synthetic coagulants (Nimesha et al. 2022, Owodunni and Ismail 2021, Bello et al. 2019). It has been reported that cactus and watermelon seeds can reduce over 90% of the turbidity in raw water (Bello et al. 2019, Odika et al. 2020, Karnena and Saritha 2021). However, little research has been conducted into analyzing appropriate factors that affect the performance of coagulants in pond water treatment (Okunlola et al. 2020, Husen et al. 2021). This study evaluated the effectiveness of cactus pads and watermelon seeds in pond water treatment, considering coagulant dosage, particle size, and settling time.

Methodology

a) Water Sample preparation

Samples of raw water were obtained from Mwanalugali area (6°47'26.1"S 39°01'44.9"E) of Pwani region, Tanzania and transported to University of Dar es Salaam laboratories for analysis (i.e., turbidity, pH, Total dissolved solids (TDS), and conductivity were analysed). Figure 1 depicts the location of the pond from which the water was obtained. The Mwanalugali area was chosen for its accessibility and representative nature of water sources in the region.

Figure 1: Location of pond water

In the laboratory, samples of pond water were stored at 4 °C prior to use. This was done to prevent any biodegradation due to microbial activity, which may affect the results during analysis. Before purification pond water was characterized to determine its quality. The parameters (turbidity, pH, TDS, and conductivity) were analyzed. The turbidity, pH, TDS and conductivity were measured by using turbidity meter, pH meter, TDS meter, and EC meter, respectively.

Figure 2 represents the appearance of watermelon seeds and the cactus pads used in this study, which were obtained from Buguruni Market and Golani open space, respectively. The watermelon seeds were chosen for their high protein content, while the cactus pads were selected for their abundant availability and natural coagulant properties.

Watermelon seeds

Cactus pads

Figure 2: Watermelon seeds and Cactus pads

b) Watermelon seeds coagulant preparation

To remove seeds, watermelon was sliced manually using a laboratory knife. The watermelon was divided into two halves. It was stood on its flat side and sliced down through its centre, splitting it in half lengthwise. The other half was split the same way. Then each half was sliced crosswise into half inch wedge. Finally, the seeds were scraped off using the knife.

The seeds were rinsed to get rid of any remaining pulp. Watermelon seeds were dried for 24 hours in a 60 °C oven to reduce moisture and crushed by using a blender. To eliminate the oil from the seeds, 150 g of crushed seeds were rinsed with hot distilled water (80 °C) and the obtained cake was dried in the oven at 40 °C until its weight were no longer varied. The dried cake after cooling was sieved with 100, 150, and 200 µm by using a sieve analyzer to produce a fine powder, which was utilized as a coagulant for treating pond water. The flocculants were made of different sizes, because flocs of different size ranges contribute differently to the decrease of turbidity (Sun et al. 2016).

c) Cactus coagulants preparation

The cactus pads were cut to 1 cm and dried in the oven at 60 °C for 24 hours before being crushed with a mortar and pestle. The crushed sample was rinsed with 10 ml of 60 °C distilled water, precipitated with 15 ml of ethanol. Distilled water and ethanol are used in order to remove impurities and residual chemicals. Then the sample was dried at 60 °C in the oven until its weight no longer varied. After the cake was dried, it was ground in a ball mill and sieved at 100, 150, and 200 µm to remove larger particles from the powder. The ball mill was used instead of other milling machines because it produces more uniform particle size reduction compared to other milling machines, thus resulting in a fine and more consistent final product.

d) Coagulants characterization

The functional groups and infrared spectra of prepared natural coagulants were analyzed using an Attenuated Total Reflectance Fourier Transform Infrared spectroscopy (ATR-FTIR). This analysis aimed to identify the chemical composition and structural characteristics of the coagulants. A total of 32 scans with a wavelength resolution of 4 cm^{-1} were performed on each sample. The spectra were interpreted using the frequency assignment approach. The resolution of 4 cm^{-1} is a high-resolution spectrum, which provides detailed information about the molecular structure of the sample of coagulant.

The potassium bromide (KBr) cell was rinsed with ethanol, cleaned, and dried. 150 mg ground samples were weighed, put on a potassium bromide cell, and then placed in the spectrophotometer's light chamber. The system software automatically removed a KBr reference spectrum to produce the final spectrum of the samples. The absorption spectra of the resulting mull were acquired after a three-minute scan in the 4000–400 cm^{-1} area. Three minutes scan was used since it is a standard for a dispersive spectrometer hence to ensure accuracy.

e) Pond water Purification

The purification method by Singh and Saxena (2020) was adopted and amended. The effect of three factors, particle size, settling time, and coagulants dosage on pond water treatment was evaluated using a 2^n-factorial design. For each experiment, 350 ml of pond water was poured into 500 ml glass beakers, followed by coagulants. The coagulants dosage was varied from 0.2 g/L to 1.6 g/L with the constant addition of 0.2 g/L in each beaker. The mixture was set into Phipps and Bird jar test apparatus (Figure 3) with multiple spindle stirrers and four 500 ml glass beakers. The agitation speed was maintained at 100 rpm for 5 minutes while adding the coagulant dosage and then reduced to 50 rpm for 15 minutes before allowing the samples to settle. After settling, the coagulated water was filtered with filter paper with pore size of 45 µm to separate the flocs from the water cleaned prior to characterization.

Figure 3: Jar test apparatus

f) Water quality characteristics

Turbidity, pH, Total Suspended Solid (TSS), and Total Dissolved Solid (TDS) were all determined before and after treatment. The standard methods of water and wastewater treatment were used (Rice et al. 2012). Three runs for each experiment were performed and the average value was reported. Turbidity and pH were measured using a turbidity meter and an electronic pH meter, respectively.

Each experiment used a 100 ml beaker filled with Pond water for TSS measurement. Before filtering the sample water, the weight of a dry filter paper was measured. After filtration, the filter paper was dried at 35-40

°C in the oven. Then the weight of residue was computed.

The weight of the empty porcelain dish was recorded in an analytical balance using a clean porcelain dish to determine total dissolved solids (TDS). A funnel lined with filter paper was used to filter 100 ml of the sample after it was thoroughly mixed. The water was evaporated after pouring 75 ml of filtered sample into a porcelain plate at 104 °C for 2 hours. The residue and porcelain were placed in a desiccator to cool, and then they were measured and recorded. The TDS was calculated using Equation 1.

$$TDS = \frac{B - A}{V} \quad (1)$$

Where, A is a weight of empty porcelain dish; B is a weight of residue and porcelain dish; and V is a volume of sample.

g) Performance analysis

Performance analysis was used to assess the effectiveness of two coagulants in removing pre-existing characteristics of drinking water, such as turbidity and chemical characteristics. Equation 2 was used to analyze the results.

$$Perfomance = \frac{T_B - T_S}{T_B} \times 100\% \quad (2)$$

Where T_B is the initial parameter of water and T_S is the final parameter of drinking water after purification.

h) Statistical Data Analysis

Minitab Software Version 20 was used to design the experiment and analyze the results. A 2^3 factorial design with one replicate and five centre point was employed to analyze the effects of three factors: particle size, settling time, and coagulant dosage on pond water treatment. Statistical analyses by ANOVA tables were used to determine the significance of the results. Main and interaction plots were utilized to analyze the effects of the factors.

Results and Discussion

a) Characterization of pond water

The characteristics of unpurified pond water are shown in Table 1.

Table 1: Characteristics of unpurified pond water

Parameters	Value	Standard value (TBS 2008)
Turbidity (NTU)	99.63	<25
pH	7.85	6.5-8.1
TDS (g/L)	193	<0.5
Conductivity (µs/cm)	450	1335

The turbidity of the pond water exceeded the drinking water standards, which require a turbidity of less than 25 NTU (TBS 2008), as shown in Table 1. TSS, dissolved organics, algae, and bacteria are potential contributors to high turbidity levels, highlighting the importance of water treatment.

b) Characterization of Prepared Coagulants

i.) Characteristics of Cactus Coagulants

The ATR-FTIR spectrum of cactus coagulants is presented in Figure 4. Several peaks were identified, including bands corresponding to the antisymmetric and symmetric COO- stretch found in carboxylic salts that deprotonate cellulose's carboxylate functional group, observed at 1369.66 cm^{-1} and 1316.00 cm^{-1}, respectively. The band 1316.00 cm^{-1} reveals the presence of non-ionic carboxyl groups (-COOH, $-COOCH_3$) in pectin molecules and uronic acid. This is an oxidized version of galacturonic acid with carboxyl groups at C1 and C6. The identification of carboxylic (COO-) functional groups and the presence of uronic acid confirm the existence of galacturonic acid, which is an active group in cactus coagulants. The peaks are attributed to various functional groups as shown in Table 2.

Table 2: Summary of FTIR spectra for cactus coagulants

SN	Wavenumber (cm^{-1})	Bond	Functional Group
1.	3997.4121	OH bonded	Hydroxyl
2.	3993.1641	N-H stretch	1°, 2° amines, amides
3.	3330.1641	C-H stretch	Aromatics
4.	2922.03	C-H Stretch	Alkanes
5.	1738.48	C=O stretch	Aldehydes, saturated aliphatic
6.	1610.18	N-H bend	1° amines
7.	1369.66	C-H rock Antisymmetric and symmetric COO-	Alkanes carboxylic acid
8.	1316.00	CO stretch	Alcohols, carboxylic acids, esters, ethers, aromatic amine
9.	1231.45	C-N stretch	Aliphatic amines
10.	1026.1	C-N strech	Aliphatic amine
11.	889.43	C-H "oop"	aromatics
12	824.12	=C-H bend	alkenes

ii.) Characteristics of watermelon seed

The ATR-FTIR spectrum of the watermelon seed coagulants is shown in Figure 5 with different functional groups identified by the highlighted peaks. Table 3 summarizes the functional groups that are attributed to watermelon seed.

The presence of functional groups at 3447.68, 1633.08, and 1741.26 cm^{-1} demonstrate the existence of protein and carboxylic functional groups. The protein molecules are represented by large biomolecules (also known as macromolecules). Proteins are large biomolecules (macromolecules) composed of long chains of amino acid residues containing carbon, hydrogen, and oxygen. Watermelon seeds possess coagulation properties because their proteins are hydrophobic and able to bind to other molecules.

The band at 3736.41 cm^{-1} indicates the presence of aluminum, which is bonded to hydroxyl groups. Silicon was detected in the band at1419.62 cm^{-1}, which is bonded to a methyl group. These indicate that water melon seeds can precipitate particles in raw water during treatments.

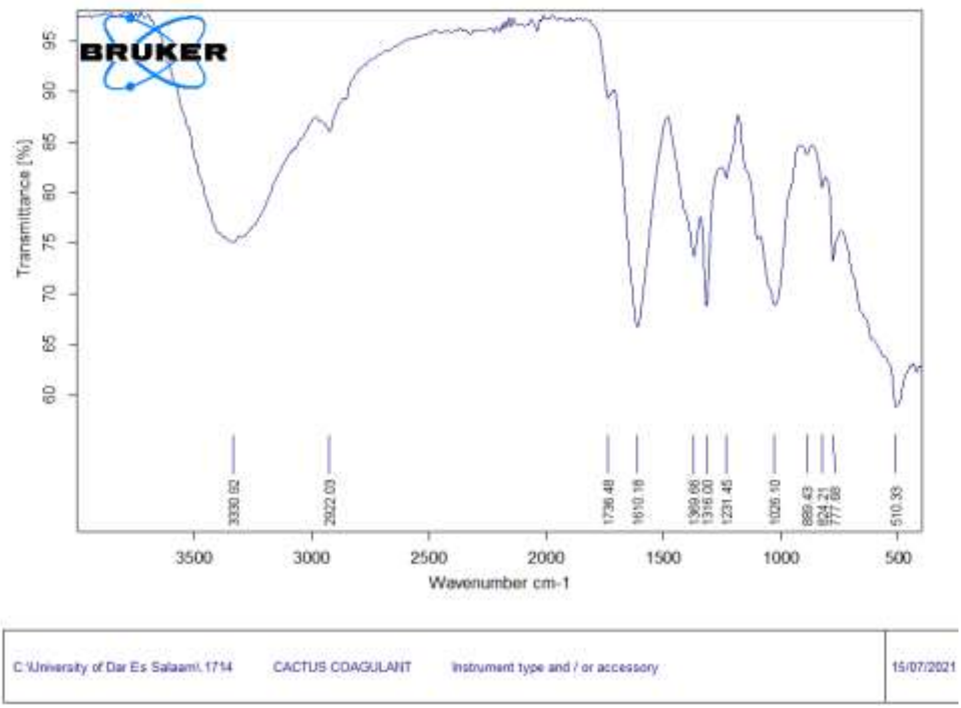

Figure 4: FTIR Spectra of Cactus Coagulants

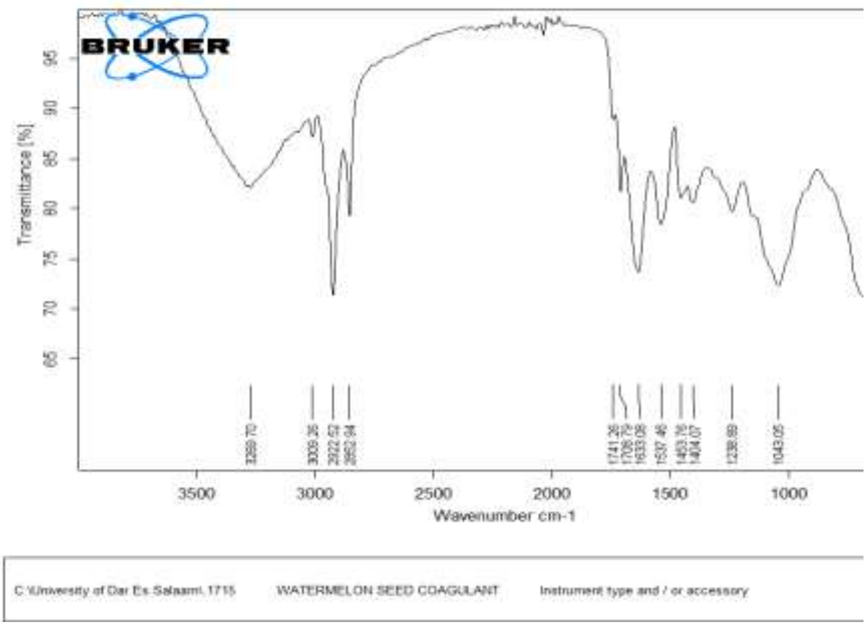

Figure 5: FTIR spectrum for watermelon seed Coagulants

Table 3: FTIR Summary for watermelon seed coagulants

SN	Wavenumber (cm^{-1})	Bond	Functional Group
1.	3736.41	AlO-H (-OH stretching)	Hydroxyl
2.	3447.68	R-C(O)-NH-RCH_3-R N-H symmetric stretching	Amide
3.	3269.7	O-H stretch	Carboxylic acids
4.	3009.26	C-H stretch	Aromatics
5.	2922.52	C-H stretch	Alkanes
6.	2854.13	Si-H symmetric stretching	Silane
7.	2852.94	C-H stretch	Alkanes
8.	1741.26	C=O stretch	Carboxylic acids, esters and saturated aliphatic
9.	1708.78	C=O stretch	α, β - Unsaturated aldehydes, ketones
10.	1633.08	N-H bend	1° amines
11.	1537.46	N-O asymmetric stretch	Nitro compounds
12	1419.62	Si-CH_3 Stretch	Silane

c) Pond Water purification by using watermelon seed coagulants

i. Effect of Watermelon seed on Pond Water Purification

Table 4 reports the results of the study on the effects of watermelon seed dosage, particle size, and settling time on pond water purification.

Table 4: ANOVA Table for factors considered during Pond water purifications

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	572.530	143.132	7156.62	0.009
Linear	3	541.328	180.443	9022.13	0.008
Settling Time	1	78.943	78.943	3947.16	0.010
Particle size	1	427.869	427.869	21393.46	0.004
Dosage	1	34.51	34.516	1725.78	0.015
Curvature	1	31.202	31.202	1560.09	0.016
Error	1	0.020	0.020		
Total	5				

The results show that all the main factors are significant at p-value (p = 0.05). The characteristics are well elaborated in the plots, depicting the trends of each factor in Figures 6 and 7.

Settling time and particle size show an inverse relationship with turbidity retention in the water, while increasing coagulant dosage increases turbidity. The interaction between those factors and the resulting effect can be seen in Figure 7.

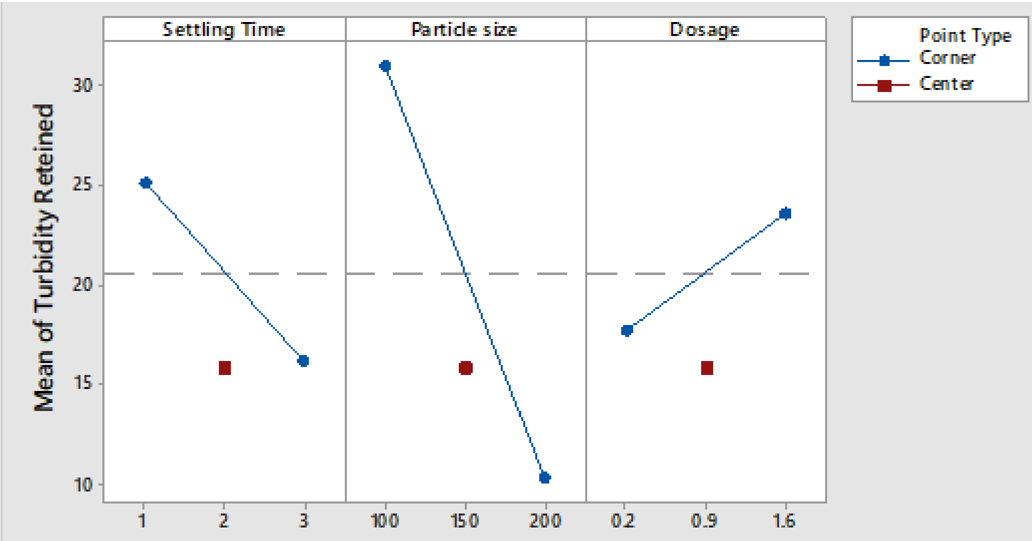

Figure 6: Turbidity retained during pond water treatments

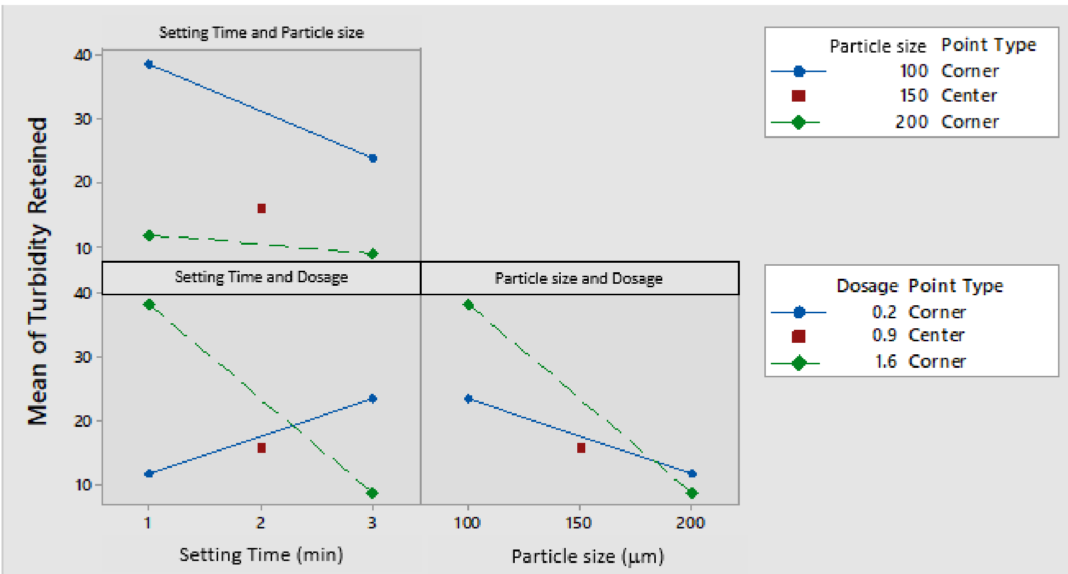

Figure 7: Interaction Effect

The interaction between settling time and particle size is weak because the lines do not cross to each other. However, it was observed that the turbidity is low when the particle size of the coagulant is 200 µm compared to 100 µm. The association between settling time (hours) and dosage (g/L) was observed. Low turbidity was achieved by using 1.6 g/L for a settling period of 3 hours.

ii. Effect of Watermelon seed Dosage at Constant Settling Time

The raw data was analyzed to determine the performance of coagulants, which was calculated using Equation 2, and the results were presented in Table 5.

The coagulant performance diminishes as particle size decreases. The lowest efficiency was obtained when the particle size was 100 µm at a dosage 0.2 g/L. When increasing the coagulants dosage there were improvements in performance. Additionally, increasing the particle size enhanced coagulant performance at lower dosages.

The highest performance of 94.18% was obtained when the particle size was 200 µm at a dosage of 0.8 g/L. The results from Table 5 are further elaborated in Figure 8.

Table 5: Performance of watermelon seed coagulants

Amount of dosage (g/L)	Turbidity removal %		
	200 µm	150 µm	100 µm
0.2	62.43	43.8	33.7
0.4	75.68	63.37	45.98
0.6	83.6	74.67	60.3
0.8	94.18	83.64	77.9
1	93.9	82.76	78.88
1.2	91.9	81.78	83.5
1.4	90.69	81.56	83.4
1.6	89.86	80.97	83.6

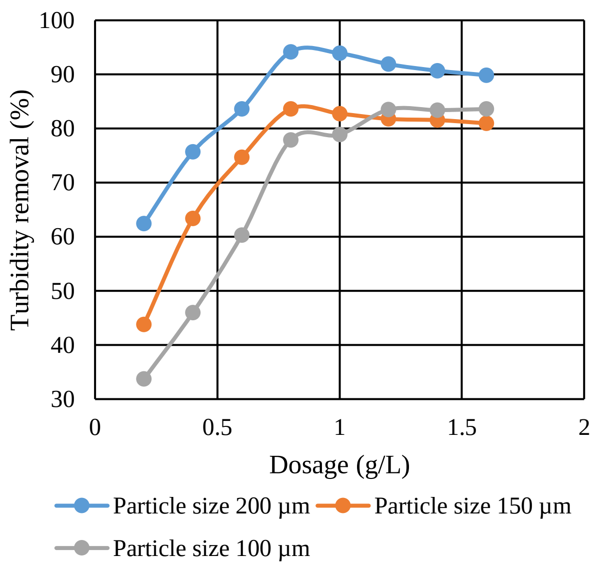

Figure 8: Effect of watermelon seeds at different particle sizes

Figure 8 demonstrates that as particle size increases, turbidity removal also increases. This is because small particles are able to adhere to large particles due to their large surface areas. When the dosage was increased from 0.2 g/L to 0.8 g/L, the turbidity removal increased, but when the dosage increased above 0.8 g/L, the turbidity removal remained constant. This saturation of the coagulants is due to their decreased ability to thoroughly mix with suspended particles.

iii. Quality of pond water after treatment with watermelon seeds

The quality parameters of the pond water were improved after treatment, as shown in Table 6. For instance, the pH changed from 7.85 to 7.80, TDS decreased from 193 to 155 mg/L, and Conductivity decreased from 450 to 430 s/cm.

The average turbidity achieved after pond water purification was 5.2 NTU when watermelon coagulants with a particle size of 200 µm were used for 3 hours, which is in compliance with the drinking water standard of TBS.

Table 6: The quality of the pond water after treatment with watermelon seeds

Parameters	Value	Standard value (TBS)
Turbidity (NTU)	5.2	<25
pH	7.80	6.5-8.1
TDS (mg/L)	155	<500
Conductivity (µs/cm)	430	1335

d. Pond water purification by Cactus coagulants

i. Effect of Cactus Coagulants on Pond Water Purifications

Table 7 presents the ANOVA results of the effects of cactus pads dosage, particle size, and settling time on pond water purification. The p-values for particle size (p = 0.037) are smaller than the critical p-value (p = 0.05). The use of cactus coagulants in pond water purifications results in a significant increase in particle size, while other factors are not significant. Figure 9 illustrates how treatment performance is influenced by settling time, particle size, and dosage.

Table 7: ANOVA Table for Cactus Coagulants

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	1295.65	323.91	88.86	0.079
Linear	3	1295.18	431.73	118.44	0.67
Dosage	1	130.07	130.07	35.69	0.106
Particle size	1	1068.96	1068.96	293.27	0.037
Settling Time	1	96.14	96.14	26.38	0.122
Curvature	1	0.48	0.48	0.13	0.779
Error	1	3.64	3.64		
Total	5	1299.30			

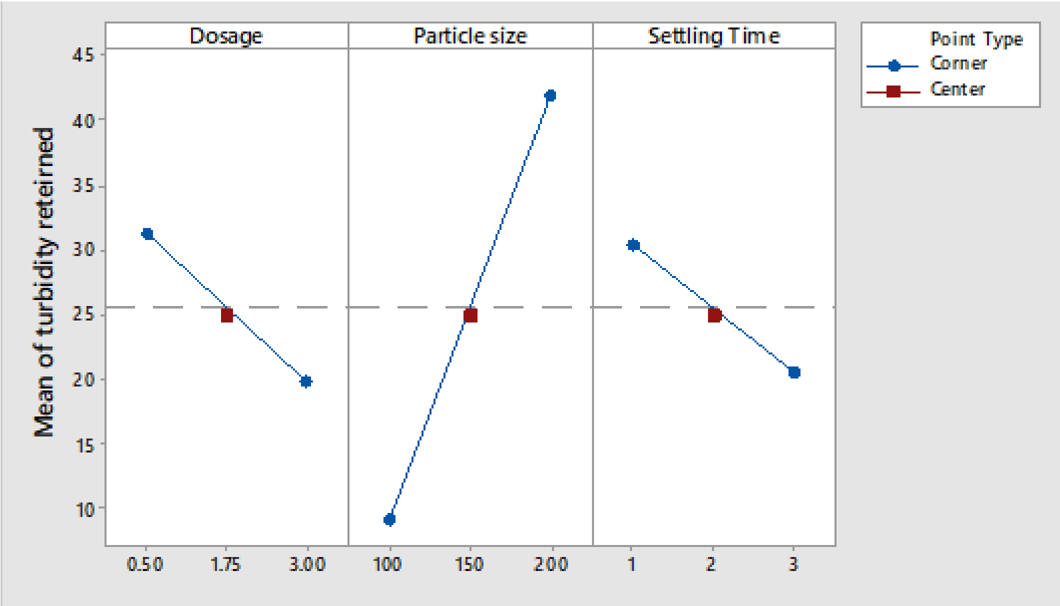

Figure 9: Effect of cactus coagulants

The turbidity in the pond water was reduced when the settling time, particle size, and dosage were all increased.

The interaction plot for these three variables can be seen in Figure 10. Because the lines are slightly parallel, the relationship between dosage and particle size is weak. Turbidity in pond water was lower when particles sizes of 100 µm were used compared to 200 µm particles. There is a significant interaction between settling time and dosage. Low turbidity was achieved when 0.5 g/L cactus coagulant was used for a period of 3 hours. Also, low turbidity was achieved when 3 g/L cactus coagulant was used for a short settling time.

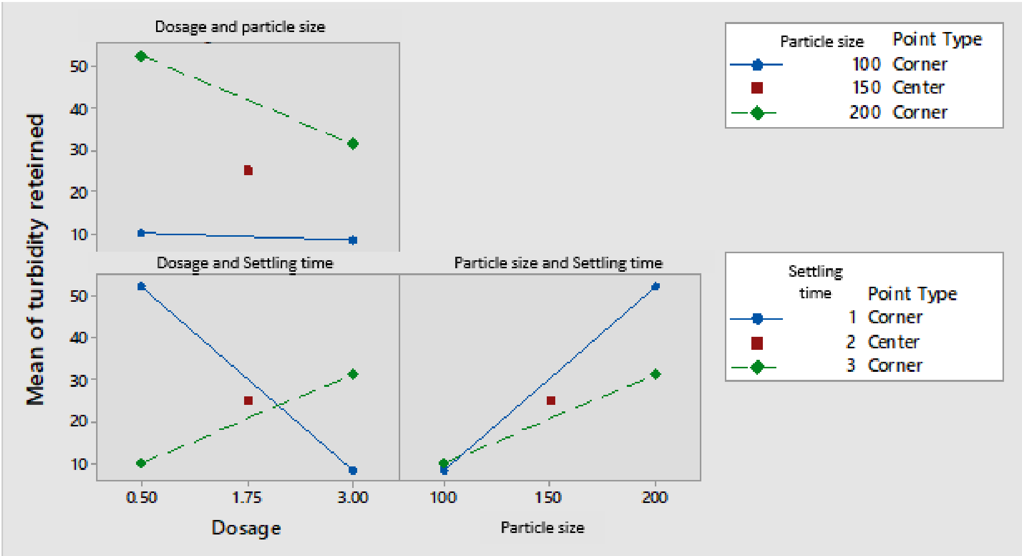

Figure 10: Interaction effect plot for turbidity retained

The significant interaction between particle size and dosage was also found, however, minimal turbidity was reached at particle sizes of 100 µm for both low and high settling times.

***ii. Effect of Cactus coagulant at Constant Settling Time*.**

The effect of cactus coagulant dosage on pond water purification was calculated using Equation 2, and the findings are displayed in Figure 11. Increased dosage improved the performance of cactus coagulants, but decreased with increasing particle size.

The interaction between suspended particles in the water and polygalacturonic acid is slow when large particle sizes are used during treatment, resulting in poor water chemisorption. Larger particles require more ethanol during preparation if the active sites are not fully activated.

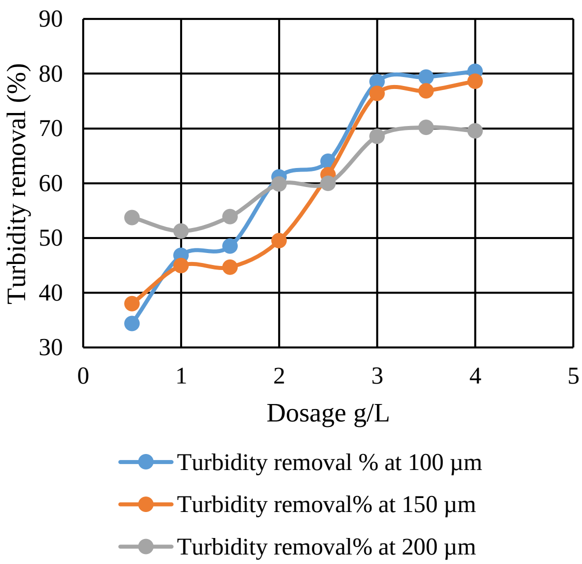

Figure 11: Effect of cactus seeds at different particle sizes.

Poor chemisorption may occur due to inadequate interactions between the active surfaces of polygalacturonic acid in the cactus coagulants, leading to limited turbidity removal.

iii. Quality of pond water after treatment with cactus

Table 8 shows that the other quality parameters of pond water improved after treatment. The pH changed from 7.85 to 7.63, TDS decreased from 193 to 179 mg/L, and Conductivity decreased from 450 to 400 s/cm.

The average turbidity achieved after pond water purification was 19.1 NTU when cactus coagulants with a particle size of 100 μm were used for 3 hours. This turbidity level is in compliance with the drinking water standard.

Table 8: The quality of the pond water after treatment with cactus pads

Parameters	Value	Standard value (TBS)
Turbidity (NTU)	19.1	<25
pH	7.63	6.5-8.1
TDS (g/L)	179	<500
Conductivity (μs/cm)	400	1335

Conclusion

The jar apparatus was utilized to evaluate the efficacy of two natural coagulants, namely watermelon seeds and cactus pads, in treating pond water. A 2^3 factorial design was employed to analyze the effects of three factors: particle size, settling time, and coagulant dosage on turbidity removal from pond water. Statistical analyses by ANOVA tables were used to determine the significance of the results. The average low turbidity attained after pond water purification was 19.1 NTU for cactus pads and 5.2 NTU for watermelon seed, with an initial turbidity of 99.63 NTU. The results indicate that the cactus and watermelon seed coagulants were able to remove 78.58% and 94.18% of the turbidity in pond water, respectively. Both coagulants exhibited a positive correlation between settling time and turbidity removal, indicating that longer settling times resulted in more turbidity removal. With a significance level of p=0.05 all main factors had significant effect on the turbidity removal process. In addition to that other parameters such as TDS, pH and conductivity were also altered during coagulation. For instance, TDS reduced from 193 to 155 mg/L, the pH shifted from 7.85 to 7.80, and Conductivity decreased from 450 to 430 s/cm when watermelon seeds were utilized.

Recommendations

Watermelon seeds and cactus coagulants have been proven to be effective as a potential replacement for chemicals like alum and ferric salts commonly used in coagulation-flocculation water treatment, according to these findings.

Acknowledgement

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