# Synthesis and Application of Plant-based coagulant derived from Longan fruit seeds for Turbidity Removal in Water Treatment

By

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QIUP-202004-003852

A thesis dissertation submitted in partial fulfillment of the requirements for the degree of Bachelor of Environmental Technology (Honours).

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2022

Abstract

Water demand is high in Malaysia, thus, there is a need to ensure the water being supplied is clean and safe to drink. In order to accomplish this, water treatment needs to be conducted, and coagulation is an important step in that treatment. However, the use of conventional chemical coagulants like alum has posed several concerns in recent years. This has led to the research and development of natural, plant-based coagulants. This study focused on the synthesis and morphological characterization of a plant-based coagulant from Longan fruit seeds. It also identified the performance of the newly synthesized coagulant in terms of turbidity removal. On top of that, the optimum performance of the coagulant was investigated to achieve maximum turbidity removal efficiency of the coagulant through the modification of several operational parameters, which were type of coagulant solvent, coagulant dosage, initial turbidity level, rapid mixing time, slow mixing time, settling time and pH. Overall, the coagulant displayed lower levels of coagulation activity, with an average turbidity removal efficiency between 23.6 % and 31.9%. However, with the optimization of the jar testing process through the manipulation of operational parameters, the coagulant was capable of removing 46.7% of turbidity from water. In terms of morphological structure, it was identified that the Longan seed powder displayed an oval-like shape, with a granular appearance to them.

**Keywords**: Plant-based coagulant, water treatment, turbidity removal, morphological characterization, optimization of operational parameters.

Abstrak

Permintaan air di Malaysia adalah tinggi, disebabkan itu, adalah keperluan untuk memastikan air yang dibekal ialah bersih dan selemat. Untuk mencapai ini, rawatan air perlu dilakukan, dan koagulasi amat penting dalam proses ini. Tetapi, penggunaan koagulan kimia konvensional seperti alum telah menimbulkan beberapa kebimbangan. Ini telah membawa kepada penyelidikan dan pembangunan koagulan-koagulan berasas tumbuhan semula jadi. Kajian ini telah tertumpu kepada sintesis dan pencirian morfologi daripada koagulan berasaskan biji buah Longan. Kajian ini juga mengenal pasti prestasi koagulan dari segi penyikiran kekeruhan. Tambahan pula, prestasi optimum telah disiasat untuk mencapai penyikiran kekeruhan maksimum melalui pengubahsuaian daripada beberapa parameter operasi, iaitu jenis pelarut koagulan, dos koagulan, tahap kekeruhan awal, masa pencampuran cepat, masa pencampuran perlahan, masa menetap, dan pH. Keseluruhannya, koagulan telah menunjuk tahap aktiviti koagulasi yang lebih rendah, dengan kecekapan penyinkiran kekeruhan purata antara 23.6% dan 31.9%. Tetapi, bila semua parameter operasi telah dioptimumkan, koagulan dapat megeluarkan sebanyak 46.7% kekuruhan daripada air. Dari segi morfologi, ia dikenal pasti bahawa serbuk biji Longan memaparkan bentuk seperti bujur, dengan penampilan berbutir.

**Kata kunci**: Koagulan berasaskan tumbuhan, rawatan air, penyikiran kekeruhan, pencirian morfologi, pengoptimumkan parameter operasi.

TABLE OF CONTENT

## LIST OF TABLES



## LIST OF FIGURES

## LIST OF ABRREVIATIONS

| | |
|---|---|
| SEM | Scanning Electron Microscope |

CHAPTER I

Introduction

## 1.1 Research Background

Water can be said as the most basic and essential need for all living things, especially humans. Water is needed not only for consumption, but for conducting daily activities like cooking, washing items, in machinery, and so on. In Malaysia, for the 2020, it was calculated that 7.7 billion liters of water were consumed per day (Muller, 2021). Thus, it is important to ensure that the water being supplied throughout Malaysia and the world is clean and safe. Water treatment has been around for a long period of time, it is the process that involves applying physical, chemical, and biological operations to completely remove or reduce the amount of contaminants, or undesirable characteristics present in water (Acciona, 2020). Coagulation and flocculation play the most important part of water treatment, these processes involve the removal of unwanted contaminants and materials by adding in a chemical (coagulant), that will chemically be reacting to the unwanted particles, causing them to agglomerate and settle to the bottom of a settling tank, making it easier to be extracted. Coagulation is often conducted in two stages, the first stage involves rapid mixing, where mixing paddles rapidly disperse the coagulant throughout the water, and slow mixing, where a slow mixing movement increases the ability of the coagulant to interact and collide with the unwanted particles in water, eventually causing them to clump together. The most commonly used coagulant in modern water treatment is aluminium sulfate, also known as alum (Nathanson, 2022). It has been showed that alum's highest turbidity removal was within 82% to 99%, depending on the turbidity of the water (Baghvand, 2010). Now, there have also been studies done to test the potential use of plant materials, mainly seeds and peels to produce coagulants. This more natural approach has gained attention as it is seen as a cheaper, more sustainable source of coagulants. In Malaysia, there is a high demand and production of tropical fruits for local consumption, or to be exported. Thus, a large production of fruits ultimately leads to a large generation of fruit waste, mainly consisting of peels and seeds (Praveena & Shamsudin, 2020). This study will focus on synthesizing a natural coagulant from the seeds of the Longan fruit, which is a commonly found tropical fruit in Malaysia. This fruit is among the popular tropical fruits in Malaysia that generates a large quantity of leftover seeds, which usually are thrown away, thus it could be useful to examine if these seeds possess a high amount of protein that could provide it with coagulation properties. There have been very few studies conducted to determine the potential coagulation ability of this fruit or ones similar to it, thus this is a good opportunity to learn more about the characteristics of this fruit as a natural coagulant.

### 1.2 Problem Statement

In water treatment, coagulation and flocculation using chemical coagulants should run smoothly, with no negative effects occurring to the water being treated. However, this is not the case, the use of chemical coagulants has led to several negative effects, especially the use of aluminium sulfate as natural coagulant. These negative effects can be divided into two parts, negative effects to human health, and to the environment.

Firstly, aluminium sulfate residue is carcinogenic, with the ability to affect human health through intellectual and cognitive deterioration. It can also increase the risk of suffering from Alzheimer's and other neurological diseases. (Sulaiman et al, 2017, Kurniawan et al., 2020).

Moving on, chemical coagulants are far behind in terms of green chemistry, with high amounts of residual aluminium sulfate still found present in treated water (Freitas et al., 2018). On top of that, excessive use of chemical coagulants like alum have the tendency to accumulate in the food chain (Kurniawan et al., 2020). Thus, overtime, its presence in the natural environment can be passed around through the food chains where it can affect both the biotic and abiotic factors (Sulaiman et al, 2017).

Thus, a need for a safer, more affordable alternative has arisen, and that alternative could be natural coagulants. Natural coagulants, mainly those being derived from plant sources like *Moringa Oleifera* have shown promising results, and can offer a lot of benefits.

These benefits include an increased effectiveness if applied with a small amount of alum, and they are an inexpensive additive for increasing settling velocity, and reducing the coagulant dosage required (Hamawand et al, 2017).

## 1.3 Objectives of study

1) To synthesize a plant-based coagulant from Longan fruit seeds.
2) To study the performance of plant-based coagulant in the application of turbidity removal from water.
3) To optimize the operational parameters for turbidity removal efficiency
4) To observe the morphology of the Longan seed powder

## 1.4 Scope of Research Study

This study involved the synthesis of coagulant from a plant-based material, and the coagulant was tested using a jar test apparatus to determine its ability to remove colloidal particles present in a synthesized water sample.

Besides that, under the coagulant optimization of operational parameters, the newly synthesized coagulant will undergo several jar tests to determine the optimum conditions required for the maximum possible turbidity removal. The performance of the coagulant will be monitored based on several parameters, which are the type of plant-based coagulant, coagulant dosage, pH of water, initial water turbidity, rapid mixing time, slow mixing time, and settling time.

Primary focus will be placed towards the amount of coagulant needed to achieve maximum turbidity removal; this will help the study determine if the plant materials used to develop the coagulant can be applied into coagulant synthesis even if only a small amount is available.

Besides that, operational parameter optimization would provide insight into whether the newly synthesized coagulant could react rapidly and effectively when introduced into the water sample, and how well the coagulant could stimulate floc formation.

CHAPTER II

Literature Review

## 2.1 Concept of Coagulation

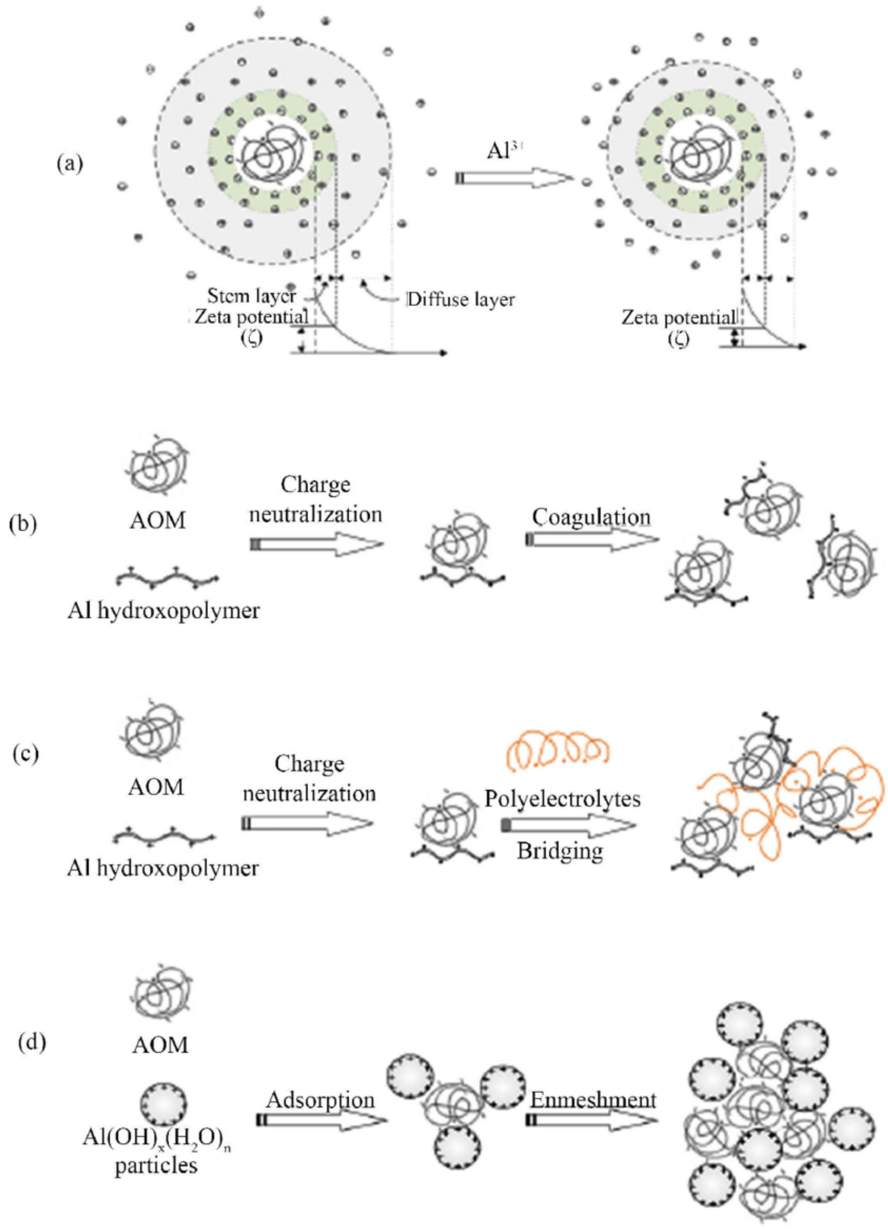



**Figure 2.1**: Mechanisms of coagulation and flocculation

(Ghernaout et al,. 2020)

Coagulation can be defined as one of the chemical treatment processes for water. It is applied to remove solids from water that are too small to be removed from filtration, mainly colloidal solids. This process involves the manipulation of charged particles in the water. Based on figure 2.1, the aggregation of particulates in a particular solution can occur from four different coagulation mechanisms. Firstly, Figure 2.1 (a) illustrates double layer compression. It involves the presence of a suitable coagulant or salt in the solution that compresses the double layer of a particulate and destabilizing it (Ghernaout et al,. 2020). A double layer is formed when negatively charged colloidal particles attract ions of opposing charges to generate a dense adjacent layer to the particle, known as a Stern layer. Then, the diffuse layer is produced as a result of dynamic equilibrium among excess positive ions attracted by the negatively charged particles and the repulsive force of the Stern layer (Ghernaout et al., 2020).

Moving on, Figure 2.1 (b) illustrates adsorption and charge neutralization. These mechanisms are quite simple, they involve the adsorption of two particulates which possess opposite charges, neutralizing their charge and generating floc.

Then, Figure 2.1 (c) illustrates inter-particle bridging, which is the coagulant or coagulant aid providing a polymeric chain that sorbs suspended particulates. The polymer adsorbs on colloidal particles, and then extends its linear or branched-chain, attaching to other particles, consequently, forming an inter-particle bridge (Ghernaout et al., 2020).

Finally, Figure 2.1 (d) illustrates sweep flocculation or emmeshment. It usually occurs the addition of high coagulant dosages to form hydroxide precipitate. The insoluble, amorphous precipitate acts like as a flocculant, encapsulating the suspended and colloidal particles in a soft colloidal floc (Ghernaout et al., 2020).

It has been stated that adsorption and charge neutralization, along with inter-particle bridging could be the two mechanisms that are most involved with plant-based coagulants (Vijayaraghavan et al., 2011).

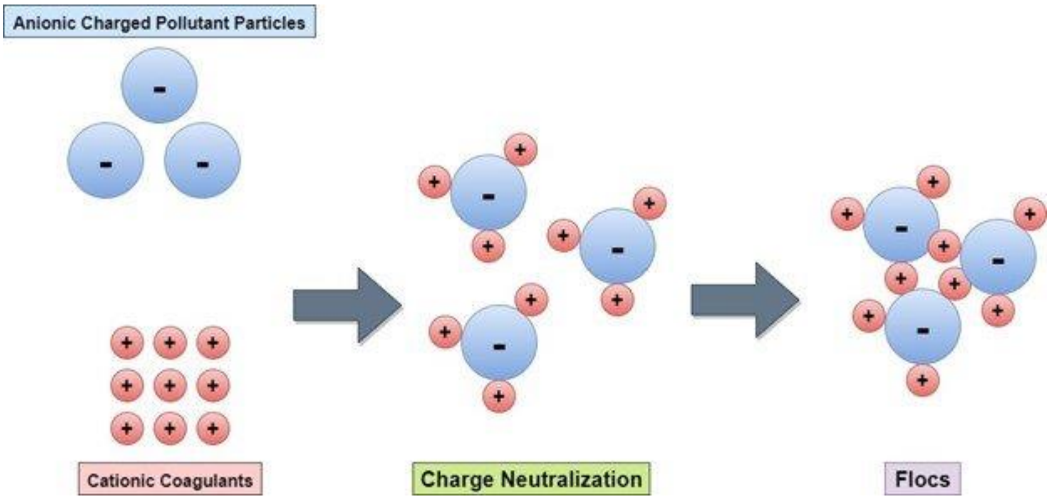



**Figure 2.2**: Mechanism of Charge Neutralization

(Akhter et al., 2021)

Since it is theorized that plant-based coagulants remove pollutants through charge neutralization, it is important to better understand the full mechanism of the reaction. Based on figure 2.2, there are clearly charged colloidal particles that need to be removed from water. Coagulation occurs when the particles in water are destabilized due to the introduction of a coagulant (Nihon Kasetsu Europe, 2018). The particles needed to be removed typically possess negative surface charges which prevent them from settling out, while active components of coagulants possess positive surface charges. When these charges interact, they result in charge neutralization, causing the destabilizing mentioned earlier. Now, the particles begin to adhere to one another, forming microfloc. Microfloc is invisible to the naked eye and is still too light to settle.

Now, flocculation begins. Flocculation involves the agglomeration of these microflocs into larger, more visible floc, that eventually become heavy enough for the forces to gravity to act upon them, allowing them to settle at the bottom as sludge and be removed.

### 2.2 Plant-based Coagulant materials

Previously studies have indicated that plants could serve as the best material to be used to produce coagulants for water treatment. Plant materials have been brought to the attention of many researchers due to its favorable characteristics, which includes its easy available, and its ability to biodegrade. Common plant materials that have been tested to determine their coagulation properties include durian seeds (Praveena & Shamsudin, 2020). , banana leaves (Premkumar et al., 2021). , orange peels (Shaharom & Quraisyah, 2019), dragon fruit skin

(Muda et al., 2020), and one of the most successful materials is seeds from *Moringa oleifera*, with turbidity removal efficiencies possible of reaching 99% (Desta & Bote, 2021). Other plant materials that have also been heavily researched include Nirmali seeds (S.potatorum) (Maruthi et al., 2013), tannin (Ibrahim et al., 2021), and cactus (Karanja et al., 2017) . In tropical fruits, like the Longan suggested for this study, is said to have the presence of an abundant amount of proteins that possess the capability of providing assistance in the water treatment process. These proteins are mainly involved in the charge neutralization and adsorption of colloidal particles (Bodlund, 2013). These proteins potentially could display good performance when it comes to turbidity removal. Overall, plant-based coagulants are environmentally sustainable, environmentally friendly, and only a simple set of processes are needed in order to produce them, thus it is very sensible to continue doing more research on plant-based coagulants.

## 2.3 Synthesis of Coagulant

The raw materials collected from plant sources have to be treated in order to become the coagulant needed for the coagulation process. There are several methods, such as fine powder production through grinding and active component extraction through mixing powder in solvent under medium heat, which can be applied in order to obtain the coagulant needed.

### 2.3.1 Fine powder production

Before the seeds can undergo active component extraction, they must first be broken down into smaller pieces in order to increase the total surface area of extraction, with any unwanted material being removed. When dealing with fruit seeds, the seeds are often oven dried for a period of 24-36 hours, at temperatures exceeding 100°C (Muda et al., 2020). Once this has been completed, the dried seeds are then grounded up into a fine powder, and filtered to remove any ungrounded material. Besides that, when dealing with plant leaves, they are usually dried in an oven at very high temperatures, around 500°C, for a period of a few days to ensure all moisture is extracted, and later be ground up and sieved (Premkumar et al., 2021). Plants such as cacti, they are usually cut into strips, and then drying them in an oven for a period of 24 hours at 50-60°C. Similarly, plant materials containing a high amount of oil like Jatropha curcas seeds are oven dried at 60°C for a period of 48 hours (Premkumar et al., 2021).

### 2.3.2 Active component extraction

Next, the prepared powder is ready to be treated in order to extract the active components that provide the coagulant action, these active components mainly consist of proteins. Several extraction methods can be applied, these include adding the grounded powder samples into different solvents and mixing them well under medium heat. Example, in another study using L. *Perpusilla*, 50 g of the plant powder was soaked in 1 L of NaCl solution, the suspension was then stirred well using a magnetic stirrer for a period of 10 minutes to accomplish extraction (Prihatinningtyas, 2019). Besides that, active components can be extracted through soaking the powder in 70% methanol and drying after (Praveena & Shamsudin, 2020). Also, more complex methods of active component extraction can be applied. Example, one study using *Descurainia Sophia* seeds applied ultrasound assistance to efficiently extract the active components from the seeds after they has been soaked for a period of 48 hours in the solvent solution (Yarahmadi et al., 2016).

## 2.4 Jar Test

Jar testing is the method of mixing the coagulants and water sample together. It involves a large mechanical apparatus that has mixing paddles, and according to the RPM set by the regulator, these paddles will begin rotating. When it comes to a jar test, it is a three-step process involving rapid mixing, slow mixing, and settling.

### 2.4.1 Rapid mixing

This step involves the rapid movement of the mixing paddles in the mixture of coagulant and water. This is done to disperse the coagulant throughout the water sample, ensuring that all parts of that water sample contain the coagulant necessary for the coagulation process. Rapid mixing is usually done at high speed, a small amount of coagulant is introduced into the water sample, a speed of around 200-300 RPM is set, and it is allowed to mix for around 1 minute (Muda et al., 2020).

### 2.4.2 Slow mixing

This step involves the slow movement of the mixing paddles, promoting the collisions between coagulants and the particles in water. Slow mixing is where coagulation mainly takes place, as the coagulant constant comes in contact with the particles, it will neutralize the charges surrounding the particles and form clumps. Slow mixing can be done for a period of 15-20 minutes, at a speed of 60 RPM (Muda et al., 2020).

### 2.4.3 Settling

This step involves providing a sufficient amount of time for the clumps formed in coagulation to undergo flocculation, which is the formation of larger clumps from smaller ones, and allowing these large clumps to fall to the bottom of the beaker or tank. This makes it easier to collect the clumps at the end of the jar test, either through filtration or other methods. Typically, a mixture is allow a period of 30 minutes for all the floc to settle (Muda et al., 2020).

## 2.5 Operational Parameter Optimizations for turbidity removal performance

In order to determine the optimum performance level of a newly synthesized coagulant, there is a need to test the coagulant under different conditions, based on several operational procedures. The procedures that contribute to the best coagulant performance can later be maintained in order to ensure there is constant effective coagulation. Below are the several parameters that have been taken into consideration when optimizing a coagulant.

### 2.5.1 pH

pH can be described as the indicator used to determine if a solution is neutral, acidic, or alkaline. A pH scale usually ranges from 1-14, 1-6 indicate acidity, and 8-14 indicate alkaline, while neutral is usually 7-7.5. This is important to remember as water sample needed for tests might not always be the same pH, which is usually neutral. Understanding how coagulants perform in different pH conditions will indicate the most appropriate field of use for that coagulant. In some studies, it is indicated that coagulants perform best at neutral levels, and continuously decreased as the pH was raised into alkaline levels. However, other studies have indicated that having a more basic pH of 6, can provide a removal efficiency of 99% (Premkumar et al., 2021). When the pH is increased passed the optimum pH levels, it could be seen that most of the flocs formed at the bottom of the beakers began to defloc, which is the breaking of flocs into smaller pieces. Besides that, it could be seen that as the pH of the water sample was in the alkaline range, the turbidity removal efficiency of *Moringa Oleifera* coagulant decreased, with the optimum pH range being between 4-7, as it was discovered that the presence of hydrogen ions in the water sample helped boost the adsorption ability of the coagulant (Shabaa et al., 2021). According to Praveena & Shamsudin, 2020, it could be seen that the optimum pH at which tropical fruit extract coagulants performed at was in the range of 7.6 to 7.9, sitting in the more neutral zone. In addition, one study suggested that a plant based coagulant made from pine cone extract performed best in either extremely acidic or extremely basic conditions. In that study, the coagulation efficiency obtained under conditions of pH 2 were 77%, and 76% at pH 12 (Hussain et al., 2019). It was theorized that the pine cone extract coagulant had the presence of both cationic and anionic components, thus under low pH conditions, the anionic components became more activated, and under high pH conditions, the cationic components become activated, resulting in better removal (Hussain et al., 2019). The coagulant however did not perform well under neutral pH conditions.

### 2.5.2 Type of plant-based coagulant

During active component extraction, the fine powder generated from grinding the dried plant materials can be added into different solvents. The solvent commonly used for active component extraction is distilled water. However, acidic and alkaline solvents can also be used. Testing the active component extraction with different solvents is good, as it will demonstrate which solvent helps extract the most active components from the plant material, leading to higher concentration of coagulant, which in turn will contribute to maximum turbidity removal. For example, a small amount of fine powder Carica papaya seeds were added to distilled water, NaOH solution, and NaCl solution. Based on the jar testing, it could be seen that Carica papaya seeds showed the best turbidity removal efficiency of 94.5%, and coagulation activity of 92.6% while in NaOH solution (Muda et al., 2020). Besides that, a combination of several solvents can also be used. In one study, the *Descurainia Sophia* seed powder was combined in distilled water containing 1.0 g $L^{-1}$ sodium chloride, and 0.03 g $L^{-1}$ sodium hydroxide, with a highest removal efficiency of 43.3% observed (Yarahmadi et al., 2016).

### 2.5.3 Coagulant Dosage

Coagulant dosage represents the amount of coagulant present in the water sample during the jar test. It is important to know how much coagulant is needed for efficiency turbidity removal as different coagulants have different optimum concentrations. It is important to use the advised dosage of a known coagulant, this is because adding to little coagulant will result in ineffective coagulation and flocculation, while adding too much coagulant can lead to the inhibition of high removal performance, *Carica papaya* seeds, *Cymbopogon citratus* leaves, *Euphoria malainese* seeds, *Nephelium mutabile* seeds, *Pandanus* leaves and *Centella asiatica* leaves displayed optimum performance at a concentration of 130 mg/L, but with a slight increment in the coagulant dosage, adverse performance effects could be seen, *Euphoria malainese* seeds removal performance decreased from 91.7% to 90.4% (Muda et al., 2020). However, it was also seen that by increasing the dosage of *Moringa Oleifera* coagulant, the removal efficiency to treat 250 NTU turbid water of 1000 ml in 30 minutes did increase until 8 g/L, and remained constant after that (Shabaa et al., 2021).

In another study, when 500 mL of 500 NTU turbid synthetic water was tested with different coagulant dosages of banana leaf origin, it could be seen that the optimum dosage was 4 g/500 ml, if the coagulant dosage was increased beyond that, settled flock began deflocculating (Premkumar et al., 2021).

### 2.5.4 Initial water sample turbidity

Water turbidity can be scientifically defined as the cloudiness or haziness of water caused by individual suspended and colloidal particles, that are generally invisible to the naked eye. Water turbidity is caused by natural and man-made activities. Natural sources and activities include the presence of any clay, slit, and algae in the water, these sediments are usually present in higher concentration when move rainfall occurs, which stirs the water and sediments together (Greenspan, 2020). While human sources and activities include anything which could result in the generation of sediments, like mining and agricultural activities, that eventually enter the natural water system. In water treatment, it is important to identify the initial turbidity level of the water, this provides the operators a clue on which coagulant is the best to effectively remove the turbidity from that water. For example, a water sample of 500 mL, with a turbidity level of 500 NTU, was introduced to a banana leaf-based coagulant of optimum dosage 4 g/500 mL, which resulted in the highest removal efficiency of 96% (Premkumar et al., 2021). However, the same coagulant dosage could not reach the same level of turbidity removal for several water samples with different turbidity. Besides that, another study could identify a trend in relation to coagulation and initial turbidity, stating that the higher initial turbidity of the water sample would lead to higher coagulation activity (Prihatinningtyas, 2019). This was because the presence of more colloidal particles in the water would lead to the formation of more bonds between the particles and the coagulant, resulting in larger floc formation (Prihatinningtyas, 2019).

### 2.5.5 Rapid Mixing Time

The purpose of rapid mixing is to allow the coagulant to disperse evenly throughout the water sample, increasing the likelihood of removing most of the particles in the sample. Thus, determining the optimum rapid mixing time is a very important contributor towards efficient turbidity removal. For example, while maintaining all other variables at a constant level, it could be seen that the manipulation of the rapid mixing times would result in different removal efficiencies (Premkumar et al., 2021). This could be seen with banana leaf-based coagulant, the efficiency of turbidity removal increased as the rapid mixing time increased, however after the period of 60 seconds, it could be seen that the flocs formed began to deflocculate (Premkumar et al., 2021).

### 2.5.6 Slow Mixing Time

Slow mixing helps promote more collisions between the coagulant particles and the unwanted particles present in the water sample. Similar to the rapid mixing, the optimum slow mixing speeds needs to be identified in order to obtain the highest removal efficiency results. For example, with other variables kept constant, it could be seen that banana leaf-based coagulant could remove turbidity with a slow mixing time of 25 minutes. However, if the slow mixing time was less than that, they was a noticeable decrease in the amount of flocs formed, and if the mixing time was longer than 25 minutes, deflocculation occurred (Premkumar et al., 2021). However, another study explained that by increasing the contact time between the coagulant and solution, this would result in the increase of removal efficiency. The study displayed that by mixing the water for 50 minutes instead of 30, the Moringa Oleifera coagulant displayed a removal efficiency of 90% from its initial 75%, and 92% for a mixing time of 90 minutes (Shabaa et al., 2021).

### 2.5.7 Settling Time

It is important to allow for the mixture time to settle, as it will make it easier to remove the suspended solids from the mixture. It is important to identify the optimum setting time required for a specific coagulant, as this will heavily affect the overall coagulant efficiency. For example, banana leaf-based coagulant displayed a turbidity removal efficiency up to 99% when the settling time was continuously increased, however after 22 minutes, the removal efficiency became constant. (Premkumar et al., 2021).

## 2.6 Performance comparison between several plant-based coagulants

Based on Table 1 below, it can be seen that research has been done and is on-going regarding plant based coagulants. Plants like *Moringa Oleifera* have been identified in recent years as one plant with among the highest coagulant potential, at it can be seen that as a coagulant it has a maximum removal efficiency of 99%. The figure also indicates that when plant-based coagulants are optimized, they do have a considerably high removal efficiency, with most of the coagulants above displaying removal efficiencies over 90%, with the highest removal efficiency coming from dragon fruit foliage at 99.2%.

**Table 2.1**

Represents the performance comparison in terms of turbidity removal efficiency between different plant-based coagulants.

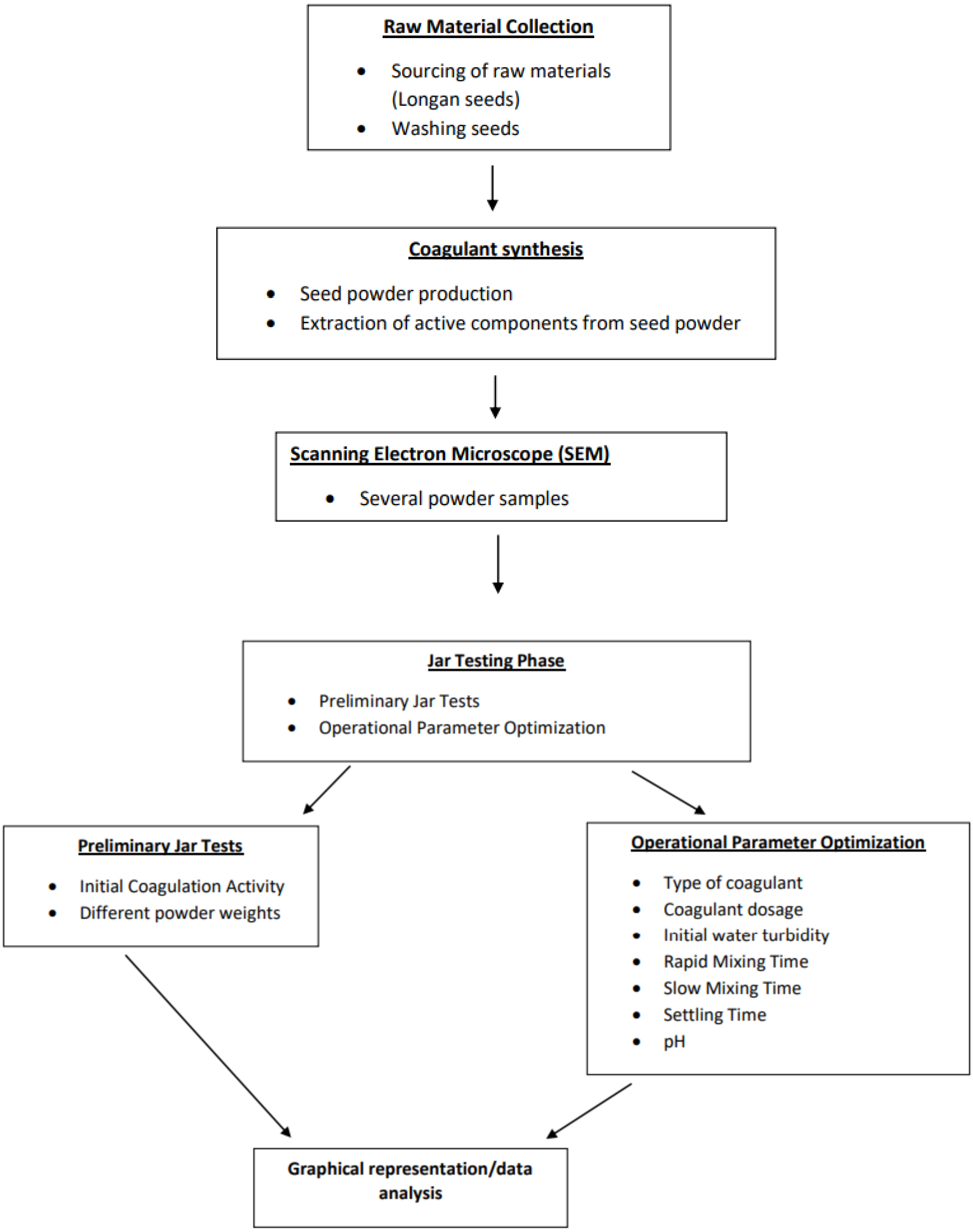
| **Coagulant Material** | **Removal Efficiency** | **Source** |
|---|---|---|
| ***Jatropha curcas* seeds** | 99%* | (Muda et al., 2020) |
| **Dragon fruit foliage** | 99.2 %* | |
| ***Sterculia foetida* seeds** | 97%* | |
| **Chickpea *(Cicer Arietinum)*** | 86%* | |
| **Orange peels** | 96%* | |
| ***Carica papaya* seeds** | 95.6%* | |
| ***Moringa oleifera* seeds** | 99% | (Desta & Bote, 2021) |
| **Jackfruit (*Artocarpus Heterophyllus)*** | 95.8% | (Natumanya & Okot-Okumu, 2016) |

*At optimum conditions

# CHAPTER III

## Methodology

### 3.1 Research flowchart



## 3.2 Synthetic waste water

The water used for this study was synthesized using kaolin clay. A measured amount of kaolin, ranging from 1 to 2 g was added into roughly 1 L of water. A glass rod was then used to stir the kaolin until it became homogenous with the water. This mixture would now become the stock solution for testing. Certain levels of water from this stock solution, ranging from 5-20 mL were taken out and mixed with 800 ml of water in order to get a desired turbidity level. The use of this synthetic water allowed for the proper adjustment of the turbidity levels without the worry of reading fluctuations. The turbidity levels of the synthetic waste water were maintained between 5-30 NTU throughout the study.

## 3.3 Collection and Synthesis of Plant-based Coagulant

The seeds planned for this study were sourced locally, collected from areas where bats have been known to consume the fruit flesh and discard the seeds. The seeds were collected and properly stored in containers. The seeds were properly washed before any lab work was done to them.

### 3.3.1 Producing a fine powder

Roughly 500 g of seeds were dried at 100°C for a 24-hour period. This drying process removed all moisture and made the seeds easy to breakdown. The outer shell of the seeds were peel away in order to extract the seed core, which was the useful part of the seed. The seed cores were broken down into smaller pieces using a pounder and motar. Once all the seed cores had been broken down, the cores were grinded down into a fine powder using the electric grinder. This grind was then collected and put through several sieves, starting with sieve size 20, then 40, and finally 60. The end result was a very finely textured powder that was ready to be used for active component extraction. The yield powder content was around 85 g, with the larger, sieved out grind materials being kept in case of later use.

3.3.2 Extraction of active components

In order to extract the active components, various amounts of seed powder, ranging from 1 to 5 g were weighted and introduced into 250 mL of distilled water. The powder was then slightly mixed using a glass rod. Then, the mixture was allowed to mix properly for 20 minutes on a magnetic stirrer, mixing at roughly 350 rpm for a period of 20 minutes, with light heat applied to it. After the 20 minute period, the powder had combined quite well with the distilled water, turning a yellowish-brown color. Most of the large, suspended particles were then removed from the mixture using a 60-sized sieve, this was done to ensure the mixture was as homogenous as possible. The mixture was stored in the refrigerator at temperatures below 20°C in order to preserve its contents. The mixture was now ready to be tested as a coagulant.

### 3.4 Coagulation and Flocculation

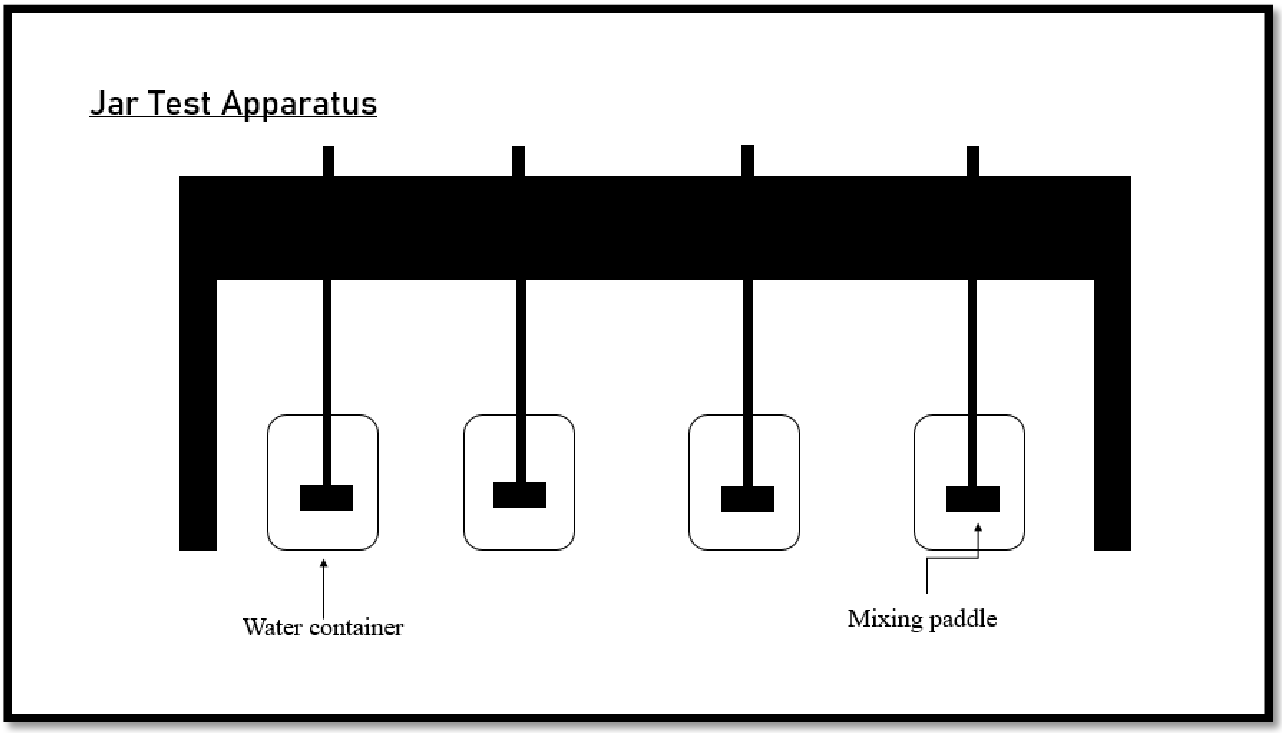



**Figure 3.1:** Simple drawing of a Jar test apparatus

The diagram above displays a jar test apparatus, a mechanical device that acts as a mixer, combining the coagulants with the water sample at different RPMs.

To determine the coagulation properties of the newly synthetize coagulant, jar testing with the jar test apparatus was conducted. The operation procedures of the jar testing were standardized, with rapid mixing being conducted at 200 RPM for 1 minutes, slow mixing at 80 RPM for 20 minutes, and settling time for 20 minutes. For primary testing, a lower seed powder concentration coagulant was tested in high dosage to determine if any coagulation would occur. The operating procedures and seed powder concentration would later be modified depending on the research objectives.

## 3.5 Operation Parameter Optimization of Newly Synthesized Coagulant

Once determining the basic coagulation properties of the newly synthesized coagulant, several operational parameters were modified to determine the optimum performance level of the coagulant. Below represents the different operational parameters tested.

### 3.5.1 Type of coagulant

The active components from the seeds used to synthesize the coagulant were extracted using three different solvents, NaOH, NaCl, and distilled water. The coagulants extracted from each of these solvents were tested and compared to each other, this was to determine which solvent provided the best solution for active component extraction.

### 3.5.2 Coagulant Dosage

The dosage of coagulant varied from low to high dose to determine the optimum amount of coagulant needed for maximum turbidity removal. The initial dosage used for primary testing was 5 mL. The dosages later varied from 1 mL, 2 mL, 3 mL, 4 mL, 6 mL, and 7 mL respectively. The optimum solvent identified was maintained for the rest of the testing.

### 3.5.3 Initial water turbidity

Based on the synthetic water samples made, with varying turbidity, each of the samples were tested using the previously determined optimum factors. This would indicate if the newly synthesized coagulant is more efficient in treating high, medium or low turbidity water. The initial turbidity range to be will be 20-30 NTU. The turbidity ranges of the water sample would later be varied in the ranges of 5-10 NTU, 11-15 NTU, 16-20 NTU, 31-35 NTU, and 36-40 NTU.

### 3.5.4 Rapid mixing time

Rapid mixing is applied to evenly distribute the coagulant throughout the water sample. The rapid mixing time was manipulated to determine if the coagulant being tested needed a longer or shorter time to disperse. The initial rapid mixing time was set at 1 minute. The times would later be varied from 30 s, 90s, 120 s, 150 s, and 180 s respectively. The previously determined optimum parameters were maintained.

### 3.5.5 Slow mixing time

Slow mixing is applied to promote collision between the particles in the wastewater and the coagulant. The slow mixing time was manipulated to determine how much excitation is needed for the coagulant to perform best. The initial slow mixing time applied was 20 minutes. The times were varied from 10 minutes, 15 minutes, 25 minutes, 30 minutes, and 35 minutes. Other optimum parameters would be maintained, as determined from previous testing.

### 3.5.6 Settling time

Settling time is a period for the coagulated particles to form floc and sink to the bottom of the jars. The initial settling time applied was 20 minutes. The times were varied from 15 minutes, 25 minutes, 30 minutes, 35 minutes, and 40 minutes. All other optimum parameters were maintained.

### 3.5.7 pH

The initial pH level of the water samples being treated are in the neutral range. To examine if the pH does affect the removal efficiency of the coagulant, the two more water samples of similar turbidity will be set up, but one will be manipulated to have a slightly acidic pH, and the other will be manipulated to have a slight alkaline pH level.

### 3.6 Scanning Electron Microscope (SEM)


**Figure 3.2**: Example of Scanning Electron Microscope (SEM)

Based on Figure 3.2, a scanning electron microscope applies a focused beam of high-energy electrons to collide with the surface of a solid specimen sample, releasing a variety of signals as they collide (Nanoscience Instruments, 2022). The signals received will reveal information regarding the sample, mainly the external morphology, crystalline structure, orientation, and chemical composition (Nanoscience Intrustments, 2022).

To examine the external morphology and identify the differences between soaked and un-soaked samples of the plant powder used to develop coagulant, four samples were prepared and sent for viewing under SEM. The four samples were:

1) Raw seed powder
2) Seed powder soaked in distilled water
3) Seed powder soaked in 0.1 NaCl solution
4) Seed powder soaked in 0.1 NaOH solution

# CHAPTER IV

## Results and Discussion

All turbidity readings taken and analyzed were done using a turbidity meter. Multiple readings were also taken to increase accuracy.

Removal efficiency was calculated using formula $(T_0 - T_1)/T_0 \times 100$

$T_0$ = Initial water turbidity

$T_1$ = Final water turbidity

### 4.1 Jar Testing

4.1.1 Initial Coagulation Test

The test was conducted to determine if the methods applied were successful in synthesizing a plant-based coagulant from Longan seeds. The coagulant A used in this test was made by combining 1 g of Longan seed powder with 250 ml of water, and allowing it to mix under medium heat for a period of 20 minutes. The initial turbidity level of the water was set to 26 NTU, and 5 ml of coagulant was used in the test. Based on Figure 4.1, it could be seen that the newly synthesized coagulant did display coagulation activity. At the beginning of the test, after the coagulant was added, a small increase in the water turbidity could be see, going from 26 NTU to 27 NTU, this is mostly likely due to the introduction of the coagulant. However, over the course of the jar test, the coagulant displayed a steady decrease in the water turbidity, with the final turbidity reading being 18.73 NTU. Based on Figure 4.2, it could be seen that the removal efficiency of the coagulant was 28%, which can be considered as good for a newly synthesized coagulant. The coagulant will be later optimized to try and achieve a higher removal efficiency.

In another study, when Longan seed powder was initially tested as the main coagulant, it could be observed that the maximum removal efficiency for color was 28.3% (Aziz et al., 2018). Almost exactly similar to the results obtained in this study.

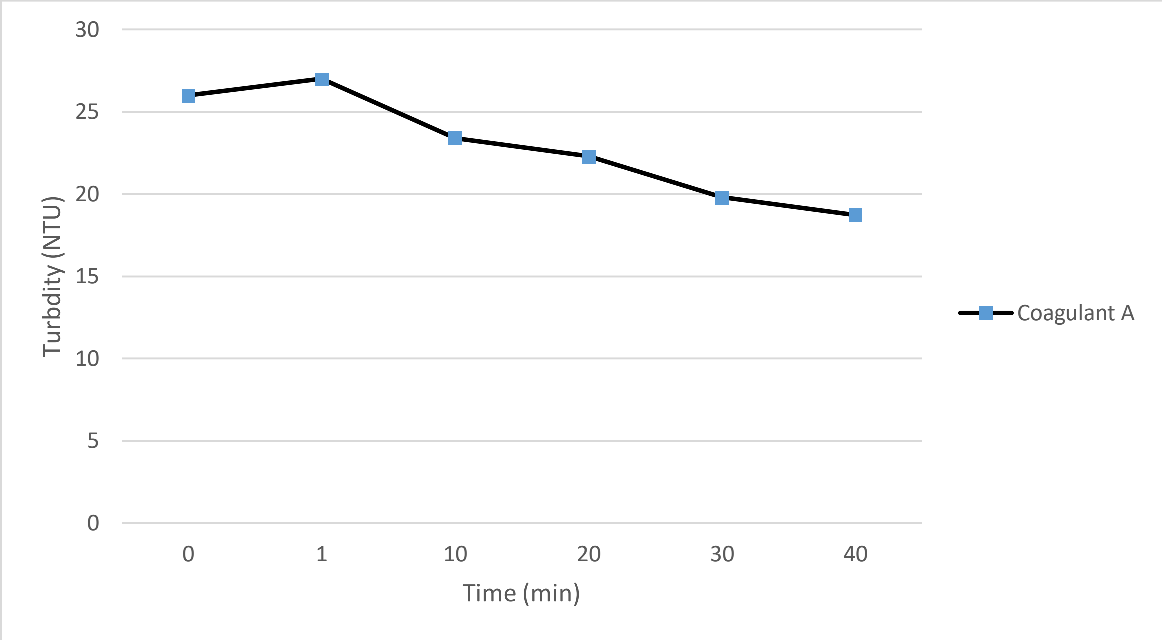



**Figure 4.1**: Represents the turbidity removal with represent to the coagulant

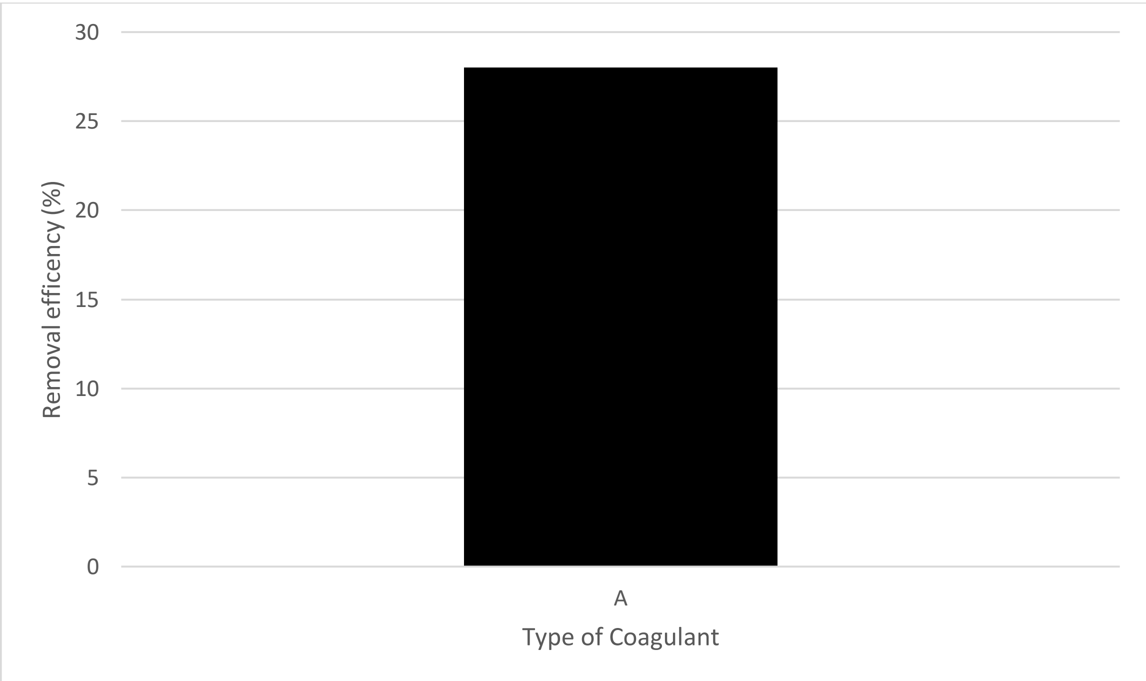



**Figure 4.2**: Represents the turbidity removal efficiency with represent to the coagulant

### 4.1.2 Seed powder weight

The jar test was conducted using the suggested optimum solvent determined from the test, which was distilled water. Seed powder ranging in weights of 1 gram to 5 grams were carefully measured using a weight balance and used to make the plant-based coagulant. 5 ml of coagulant from each batch was applied in the jar testing. Based on Figure 4.3, it could be seen that all coagulant displayed turbidity removal, however it could been seen that not all coagulants performed effectively. On top of that, it became obvious that as the seed powder concentration increased, it resulted in a slight color change in the water sample, however, significant color change only occurred in the 4 g and 5 g seed powder coagulants, which also displayed low removal efficiency. This is most likely due to the very high amount of seed powder being mixed with only 250 ml of water, making it increasingly difficult to extract all active components from the seed powder. This can be explained using the concept of a saturated solution. A saturated solution can be defined in chemistry as a chemical solution which contains the maximum allowable concentration of solute dissolved in the solvent. In this case, the addition of seed powder above 3 g surpassed the saturation point of the solvent (water), resulting in more solid participate forming at the bottom of the beaker (Helmenstine, 2020). Thus, when the coagulants of 4 g and 5 g were homogenously mixed and added to the water samples, the unsaturated solid participates most likely contributed towards an increase in the water turbidity and hindered the turbidity removal ability of the coagulants.

In terms of best performance, Figure 4.4 indicates that the coagulant containing 3 g of seed powder had the highest removal efficiency of 26.4%, and did not display a significant color change when added to the turbid water. On the other hand, it could be seen that the coagulant containing 4 g of seed powder displayed the lowest removal efficiency of only 4%, followed by a significant color change to the water sample. Thus, based on the results, it is suggested that 3g is the optimum weight of Longan seed powder to synthesize the coagulant.

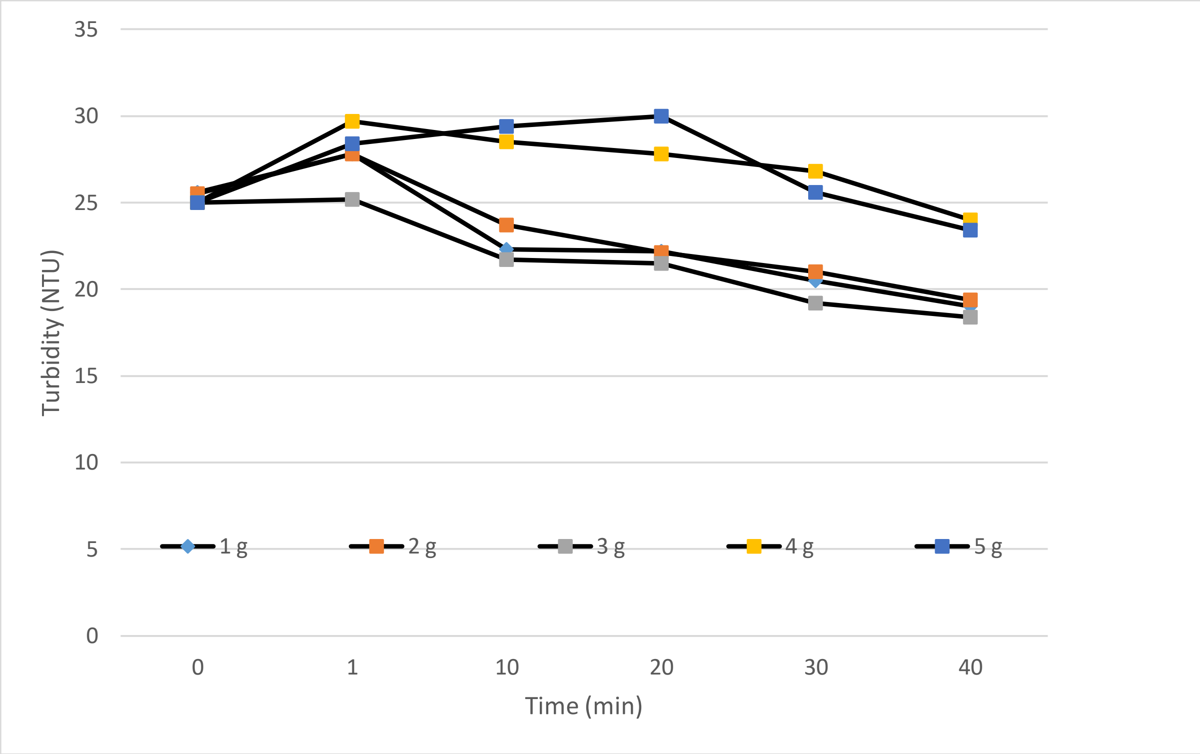



**Figure 4.3**: Represents the turbidity removal with represent to the different powder weights.

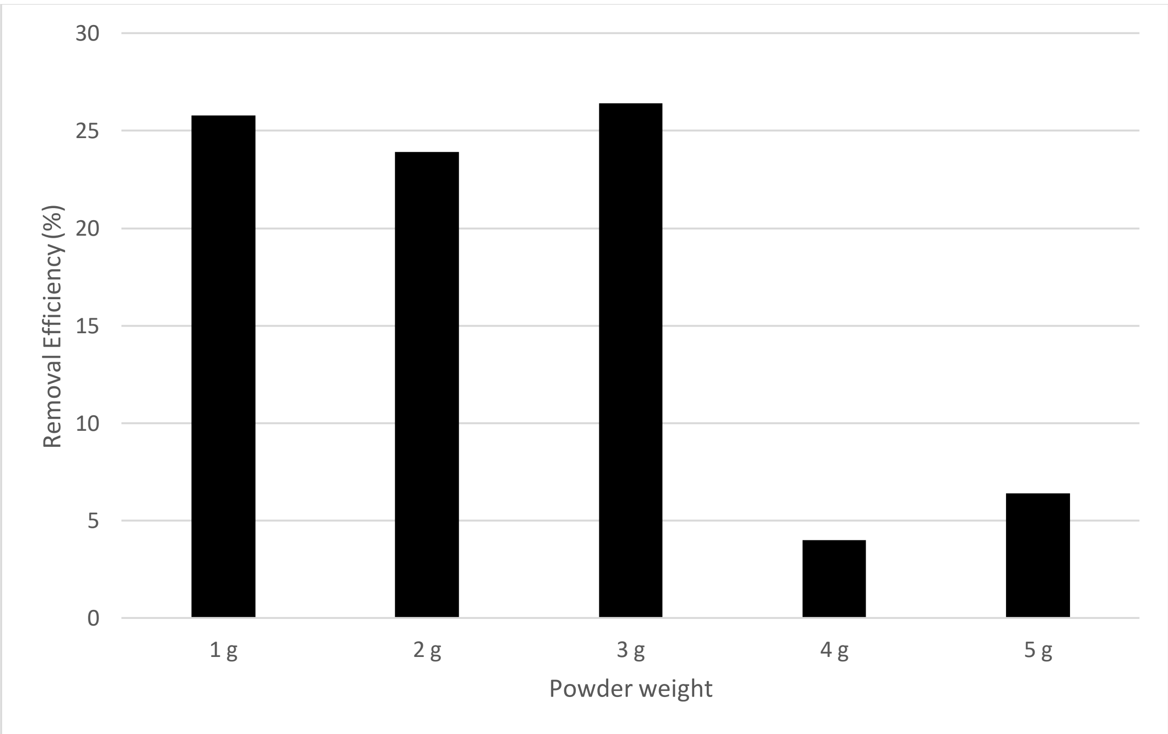



**Figure 4.4**: Represents the removal efficiency with represent to the different powder weights.

## 4.2 Operational Parameter Optimization

### 4.2.1 Type of Coagulant-Different Solvents

The test was conducted to determine which coagulant synthesized from the Longan seed powder would provide the best turbidity removal efficiency using the optimum powder weight of 3 g. The standard jar testing procedures were maintained in this test. Three coagulants were synthesized, coagulant A (3g seed powder + 250 ml distilled water), coagulant B (3 g of seed powder + 250 ml 0.1 NaCl solution), and coagulant C (3 g seed powder + 250 ml 0.1 NaOH solution). Based on Figure 4.5, it suggests that the coagulant made using distilled water, coagulant A, displayed the most coagulation activity and turbidity removal, with coagulant B and C displaying low coagulation activity. On top of that, it could be seen that for coagulant C, the addition of 5 ml of coagulant into the water sample resulted in a noticeable color change, turning the water from cloudy clear to cloudy brown. Figure 4.6 indicates the removal efficiency, coagulant A with the highest removal efficiency of 23.6%, coagulant B with 20%, and coagulant C with the lowest removal efficiency of 11.5%. Thus, it was determined that coagulant A was the best coagulant to conduct further testing on.

Based on other studies, most identified that NaCl and NaOH solutions usually perform better as solvents for active component extraction compared to distilled water. However, this varied according to concentration of the salt solutions and the type of plant-based material being used. Example, in a study conducted to determine the optimum solvent for banana peel coagulant, it was identified that distilled water and NaOH solution provided the best active component extraction compared to NaCl solution (Mokhtar et al., 2019). Besides that, another study, using rambutan seeds identified that NaCl and distilled water solvents performed better compared to NaOH solution (Zurina et al., 2014).

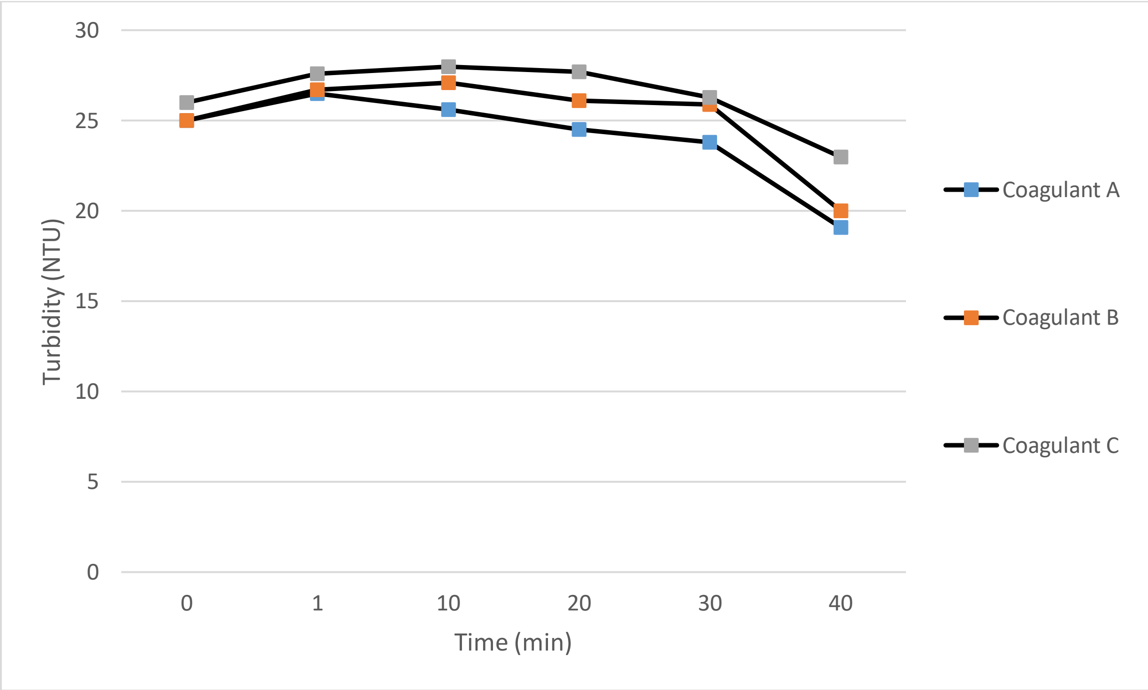



**Figure 4.5**: Represents the turbidity removal with represent to different coagulants synthesized from the Longan seed powder.

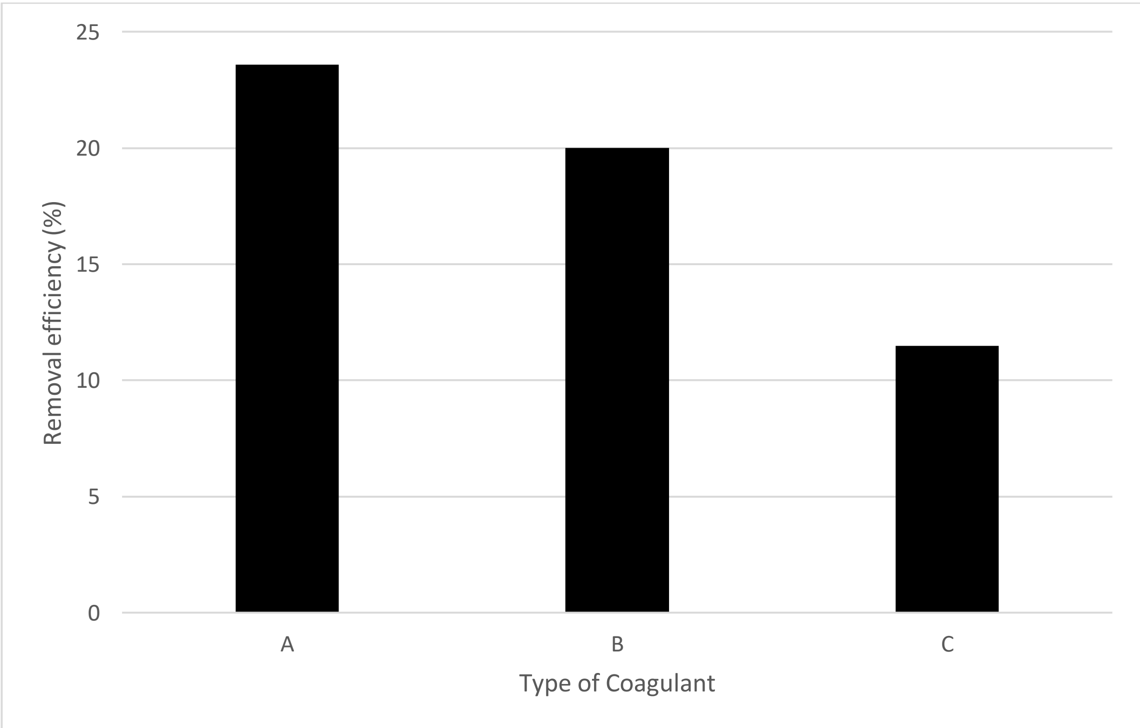



**Figure 4.6**: Represents the turbidity removal efficiency based on the three different coagulants.

### 4.2.2 Coagulant Dosage

The test was conducted to determine if the dosage of the plant based coagulant would affect the turbidity removal efficiency. The optimum coagulant determined from the previous test was maintained for this test. The coagulant dosages were manipulated, using 1 ml, 2 ml, 3 ml, 4 ml, 5 ml, 6 ml, and 7 ml respectfully.

Based on Figure 4.7, it could be seen that at all dosages, coagulant activity was observed. However, for dosages after 5 ml, it could be seen that the water turbidity began to increase over time, before it gradually decreased. This could be due to the high amount of coagulant added into the water, allowing for more seed powder particles to make the water cloudy, resulting in a noticeable color change.

It could be seen that the greatest coagulation activity and turbidity removal was experienced at lower dosages, with 1 ml showing the highest removal efficiency at 27.2%, followed by the second highest removal efficiency 24.5% coming from 2 ml dosage. Figure 4.8 indicates that a possible trend of decreasing removal efficiency as the coagulant dosage is increased. However, it could be seen that 3 ml and 4 ml of coagulant dosage did not perform as expected. The removal efficiencies of the dosages were 18.9% and 16.7% respectfully. In comparison to the 5 ml dosage, which had a removal efficiency of 23.8%, it does not follow the trend mentioned earlier. Several reasons could be given for this. Firstly, the lack of active component proteins. Possibly, the coagulant dosages of 3 ml and 4 ml did not possess enough active components during the jar test, which limited their potential turbidity removal amount as less proteins were available to bind with colloidal particles (Hussain et al., 2019). This is most likely due to not mixing the coagulant until homogenous before measuring the doses to be tested. Also, the 5 ml dosage used could have possessed a larger amount of active components, which allowed for it to be overly successful in reducing turbidity from the water, as more active components were available to bind with the colloidal particles. Finally, it could be due to the natural settleability of the individual water samples which hindered the ability of the coagulant to reduce the turbidity. Based on the overall results, it was adopted that the possible optimum coagulant dosage is 1 ml.

In another study, it was also identified that low coagulant dosage with optimum turbidity performed the best, and provided an indication that if the coagulant dosage was increased beyond optimum, it would contribute towards the generation of turbidity in aqueous solution (Hussain et al., 2019).

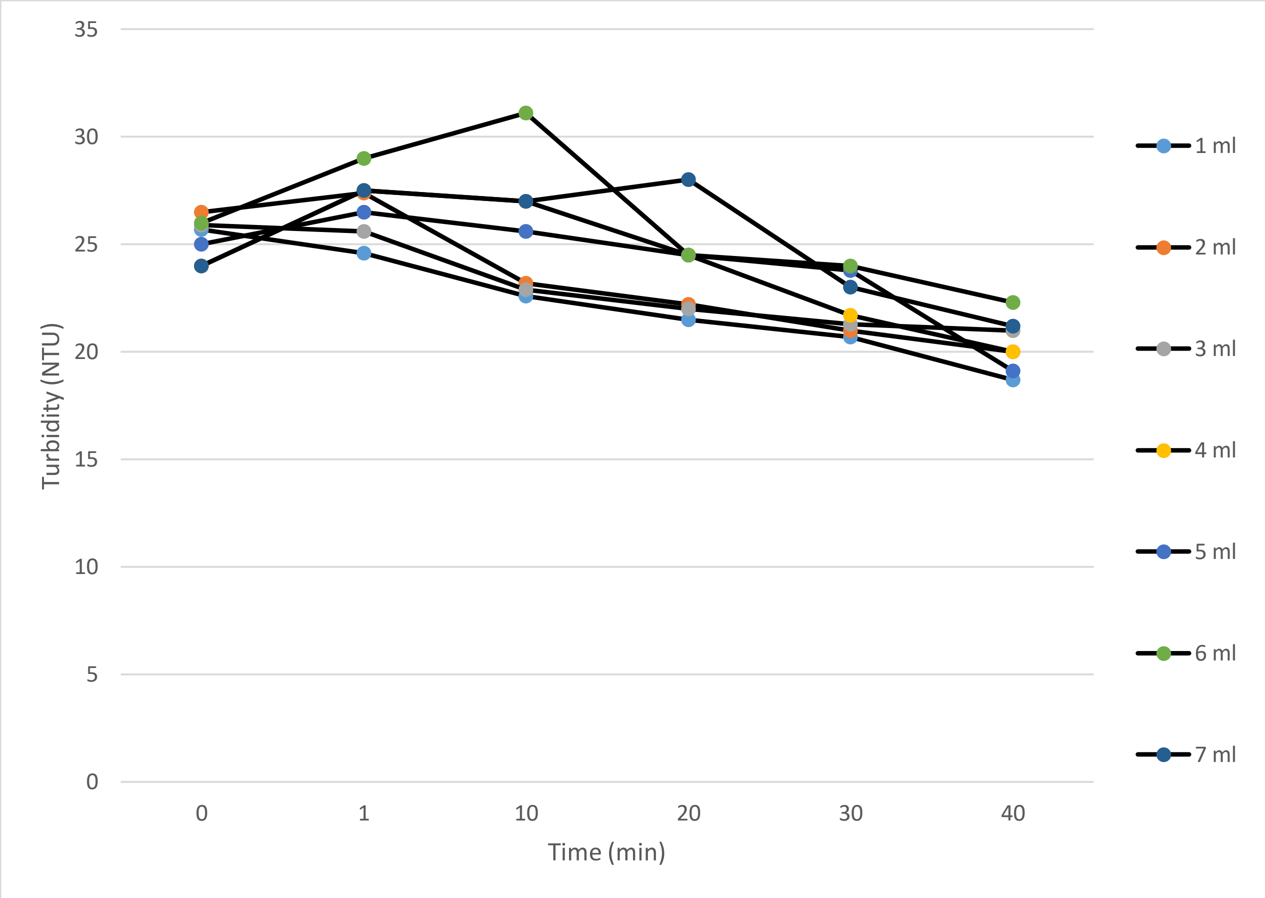



**Figure 4.7**: Represents the turbidity removal over time with represent to the coagulant dosage

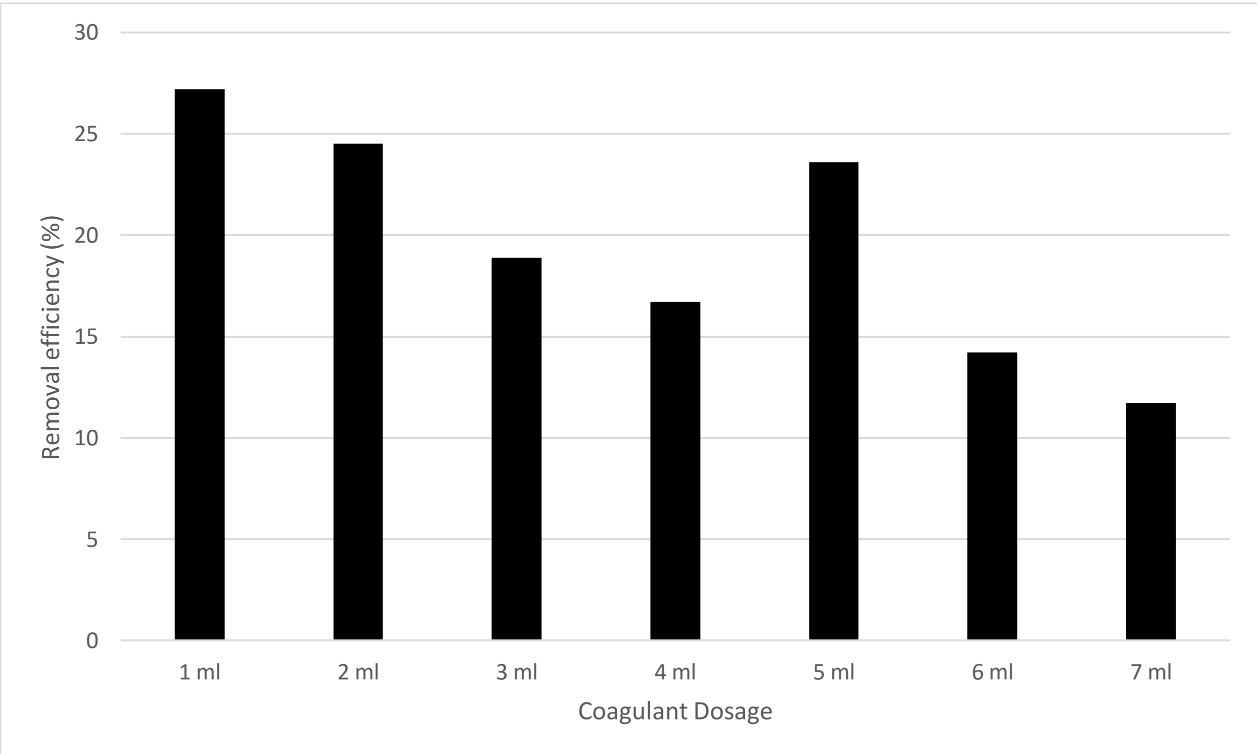



**Figure 4.8**: Represents the turbidity removal efficiency with represent to the coagulant dosage

### 4.2.3 Initial turbidity level of water sample

The test was conducted to determine the effect that the initial water sample turbidity level would have on the removal efficiency of the coagulant, and to establish the optimum range at which coagulation activity occurs. The previous optimum parameters were maintained for this test, using the 3 g seed powder + distilled water coagulant, and an optimum coagulant dose of 1 ml. The turbidity level of the water sample was manipulated into several small ranges, which were 11 to 15 NTU, 16-20 NTU, 21-25 NTU, 26-30 NTU, 31-35 NTU, and 36-40 NTU. All considered as low turbidity ranges (<50 NTU).

Based on Figure 4.9, it could be seen that not all turbidity ranges displayed similar trends in the turbidity removal. Turbidity range 36-40 NTU displayed a steady reduction in the turbidity over the entire jar testing period, however the final removal efficiency was not very high. For the other turbidity ranges, a slight increase in the turbidity could be seen before the turbidity began to decrease, this is most likely due to the coagulant contributing towards a slight color change turbidity increase, however this only lasted for a short period of time. Based on Figure 4.10, the best removal efficiency of 26.3% was in the range of 16-20 NTU, followed by 23.6% for the range of 21-25, and finally 21.1% in the range of 26-30 NTU. This could indicate that the coagulant is capable of removing lower level turbidity, with an optimum turbidity removal range of 16-30 NTU.

These results can be supported by another study. In that study, soybean was used as the material to make the natural coagulant. The initial water turbidity was 22 NTU, and at the optimum dosage of 120 mg/L, the turbidity removal efficiency was 23.2%, similar to the highest removal efficiencies obtained in this study (Ghusoon J. Shabaa et al., 2021)

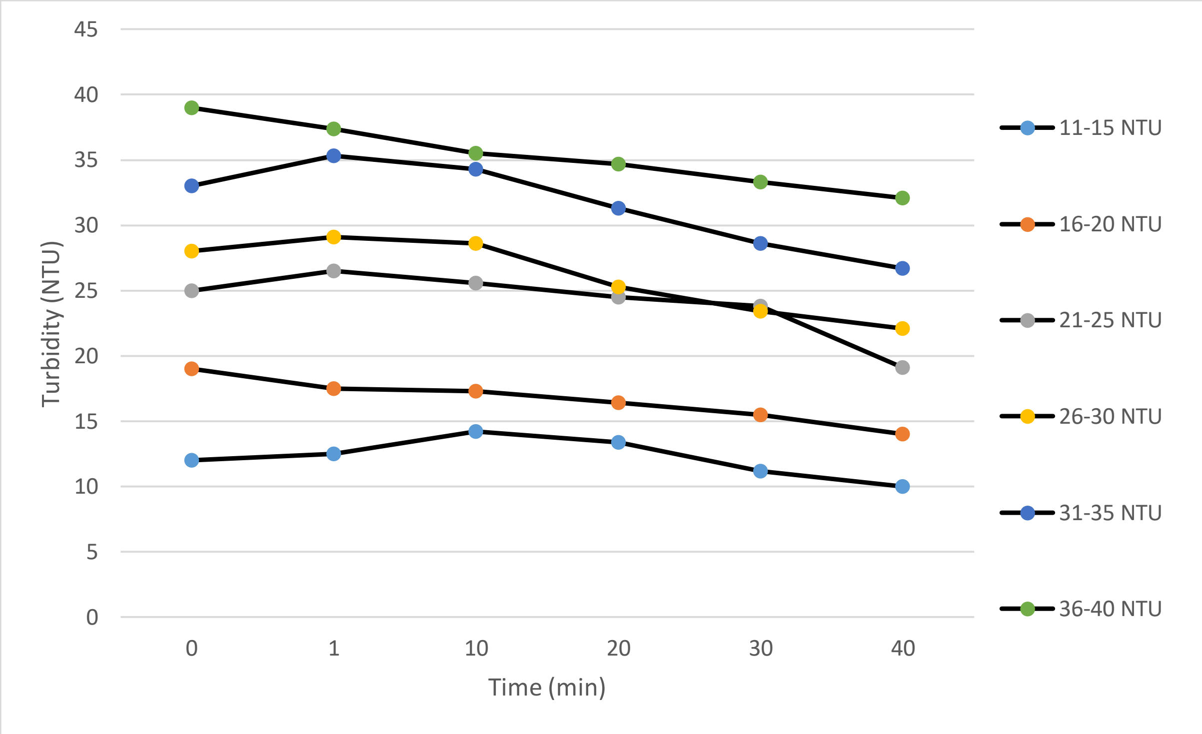



**Figure 4.9**: Represents the turbidity removal with represent to the initial turbidity level of the water sample

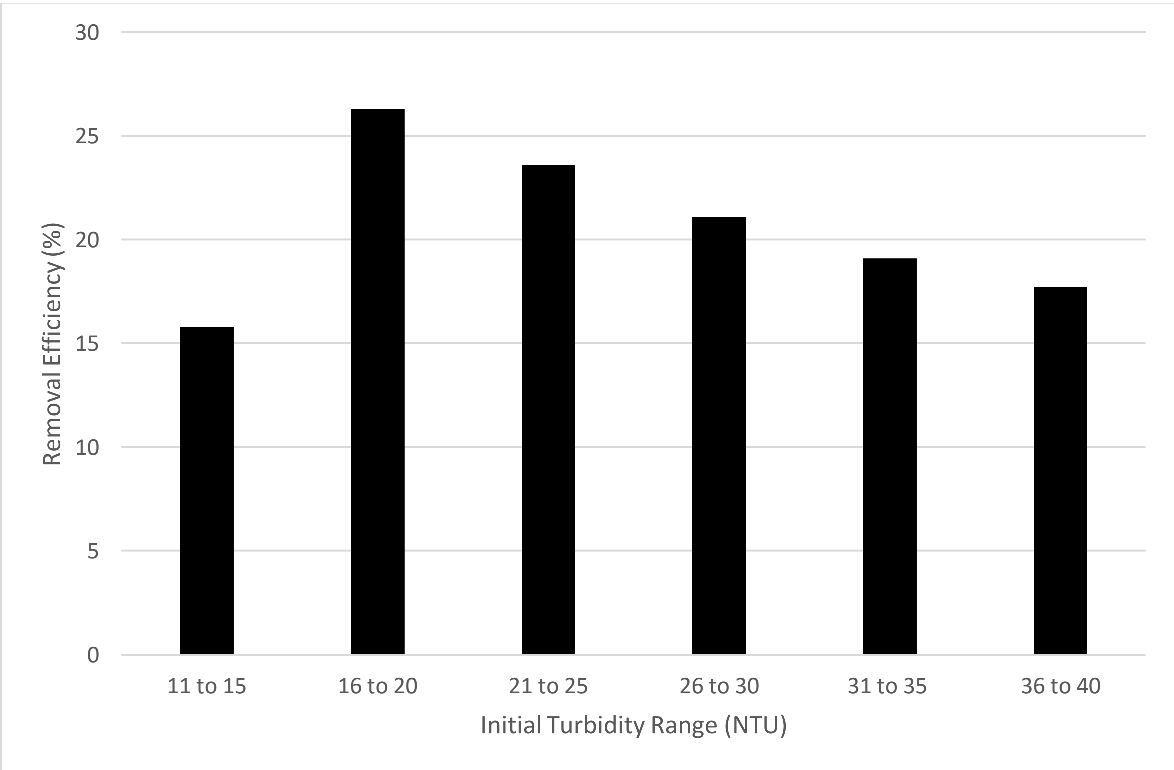



**Figure 4.10**: Represents the removal efficiency with represent to the initial turbidity level of the water sample.

### 4.2.4 Rapid Mixing Time

The test was conducted to determine the effect of rapid mixing time would have on the turbidity removal efficiency of the coagulant. The optimum parameters of 1 ml coagulant dosage, initial turbidity range 15-30 NTU, and 3 g seed powder + distilled water coagulant were maintained in this test. Based on the Figure 4.11, it could be seen that all samples displayed coagulation activity, and the trend identified was a decrease in the removal efficiency as the rapid mixing times were increased. This could be due to the increased rapid mixing not allowing the coagulated particles to settle out, or causing the coagulant to not be properly dispersed throughout the water sample. Based on Figure 4.12, the best removal efficiency of 28.8% was observed at a rapid mixing time of 30 seconds, or 0.5 minutes, while the worst removal efficiency was 21.1% observed at 3 minutes of rapid mixing. This could suggest that the plant-based coagulant only needs a short period of time for it to evenly disperse throughout the water sample. Thus, it was concluded that the possible optimum rapid mixing time is 30 seconds.

These results can be justified by another study. In that study, the lowest rapid mixing time tested was 60 seconds, and the highest mixing time was 300 seconds. When the mixing time was increased after 60 seconds, it was observed that as the rapid mixing time was increased, the turbidity removal and removal efficiency gradually decreased (Premkumar et al., 2021).

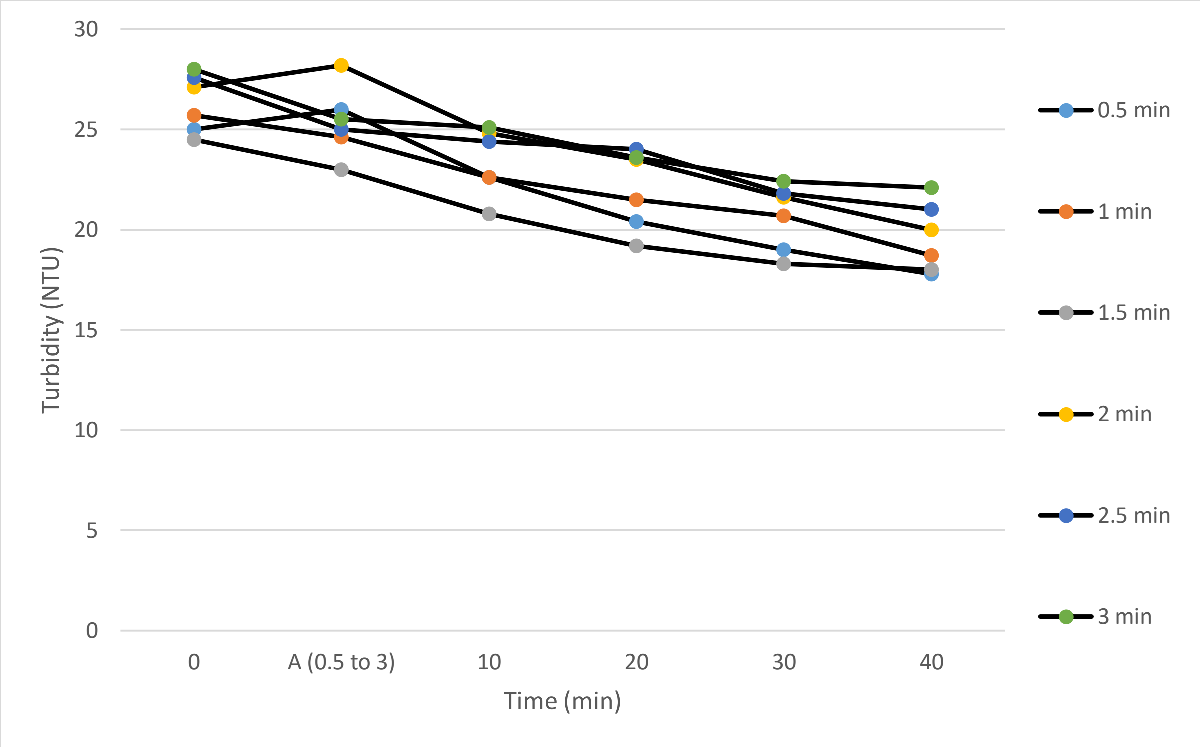



**Figure 4.11**: Represents the turbidity removal over time with represent to the rapid mixing time

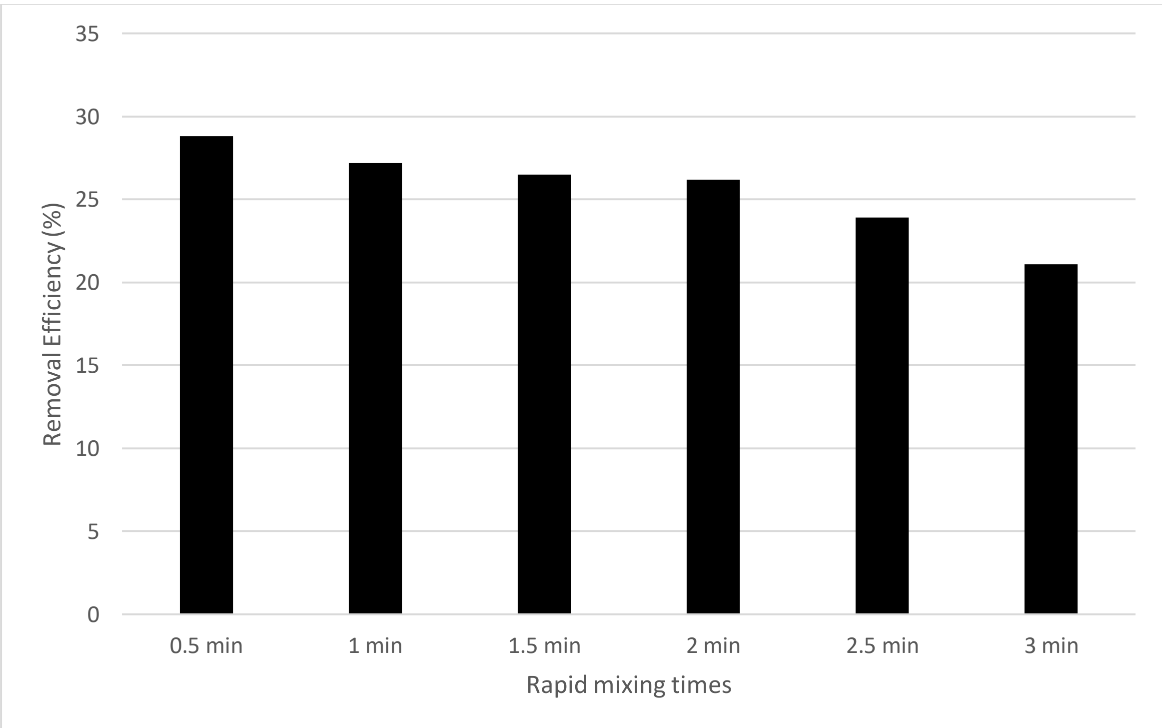



**Figure 4.12**: Represents the removal efficiency with represent to the rapid mixing time.

### 4.2.5 Slow Mixing Time

The jar test was carried out to determine the effect of settling time on the turbidity removal efficiency of the plant based coagulant. The optimum operational parameters obtained previously were maintained in this study, using the coagulant made from distilled water solvent, a coagulant dosage of 1 ml, an optimum initial turbidity in the range of 16-30 NTU, and a rapid mixing time of 30 seconds. Based on Figure 4.13, it could be seen that all samples tested displayed generally low coagulation activity, however, at 20 minutes of slow mixing, the turbidity removal seemed the most significant compared to the rest.

Figure 4.14 better visualizes the trend in the removal efficiencies based on the mixing times, and it can be seen that the removal efficiencies increased as the slow mixing times were increased until a maximum removal efficiency of 28.8% was reached at 20 minutes, when slow mixing times were increased after this point, it could be seen that the removal efficiency began to gradually decrease. This is most likely due to the settled floc breaking up (deflocculating) and mixing back into the water sample.

These results can be justified by another study, the study allowed for the slow mixing time to increase with the removal efficiency, however, after reaching 99% removal at 25 minutes and allowing the slow mixing to continue, it could be seen that percentage of turbidity removal began to decrease as clear deflocculation was occurring (Premkumar et al., 2021).

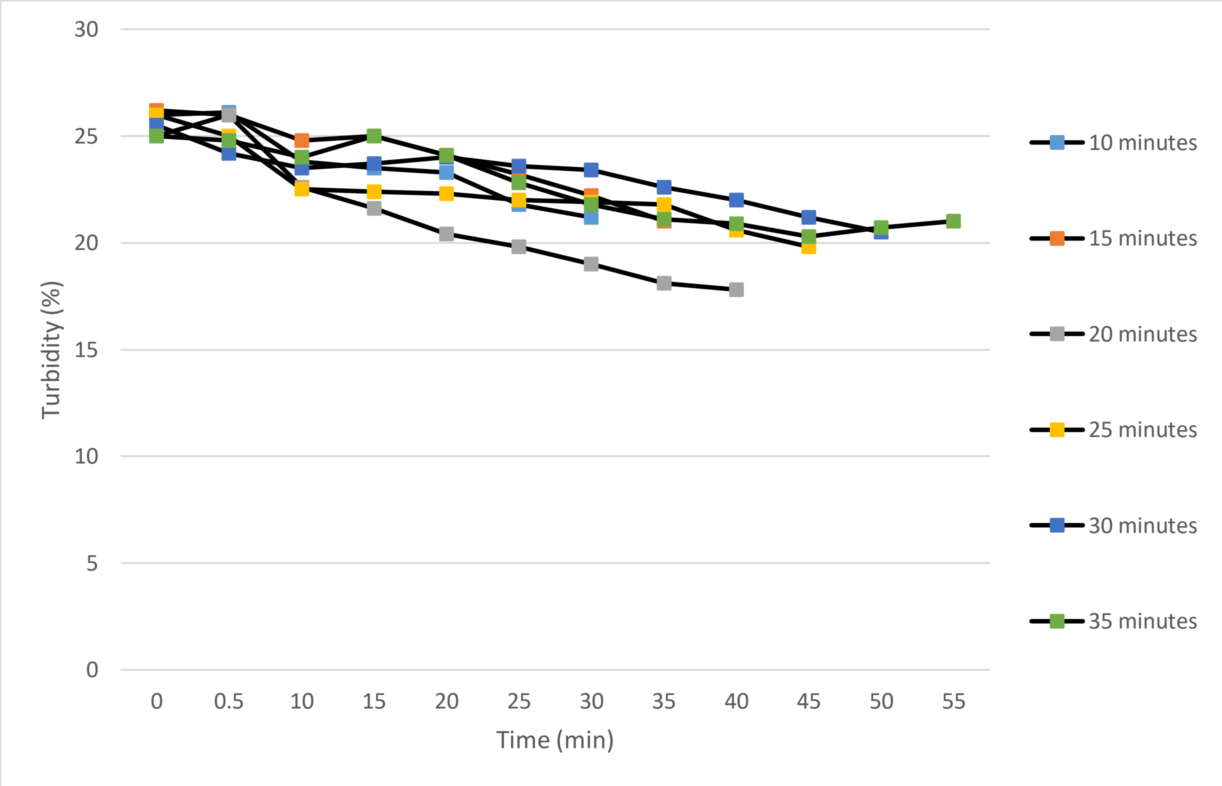



**Figure 4.13**: Represents the turbidity removal over time with respect to the slow mixing time

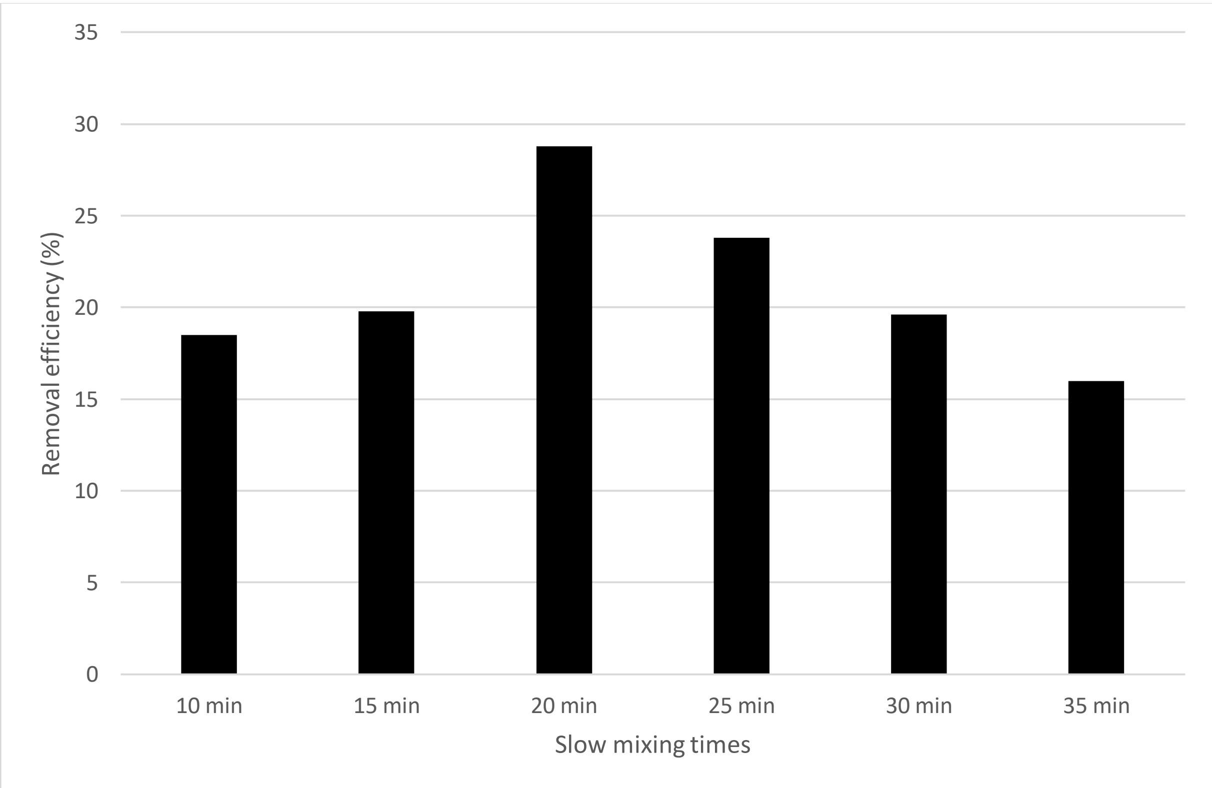



**Figure 4.14**: Represents the turbidity removal efficiency with respect to the slow mixing time

### 4.2.6 Settling Time

The jar test was carried out to determine the effect on settling time on the removal efficiency of the coagulant. The optimum factors obtained from the previous tests were remained, with a coagulant dosage of 3 ml, a turbidity level in the range of 15-30 NTU, a rapid mixing time of 30 seconds, and a slow mixing time of 20 minutes.. The settling times for this round of testing were, 15 minutes, 20 minutes, 25 minutes, 30 minutes, 35 minutes, and 40 minutes. Based on Figure 4.15, it could be seen that all samples displayed coagulation activity. The most noticeable trend identified was as settling time increased.

Based on **Figure 4.16**, this trend is better visualized. The best removal efficiency was observed at 40 minutes of settling time with 31.9%, while the lowest removal efficiency was 23.9% at 15 minutes settling time. Based on these results, it can be concluded that the optimum settling time is 40minutes.

Supporting evidence for these results could be obtained from another study. In that study, settling time was allowed to increase until the removal efficiency of the banana leaf coagulant reached 99%, to which they made the conclusion that as settling time increases, the percentage removal of turbidity increases (Premkumar et al., 2021).

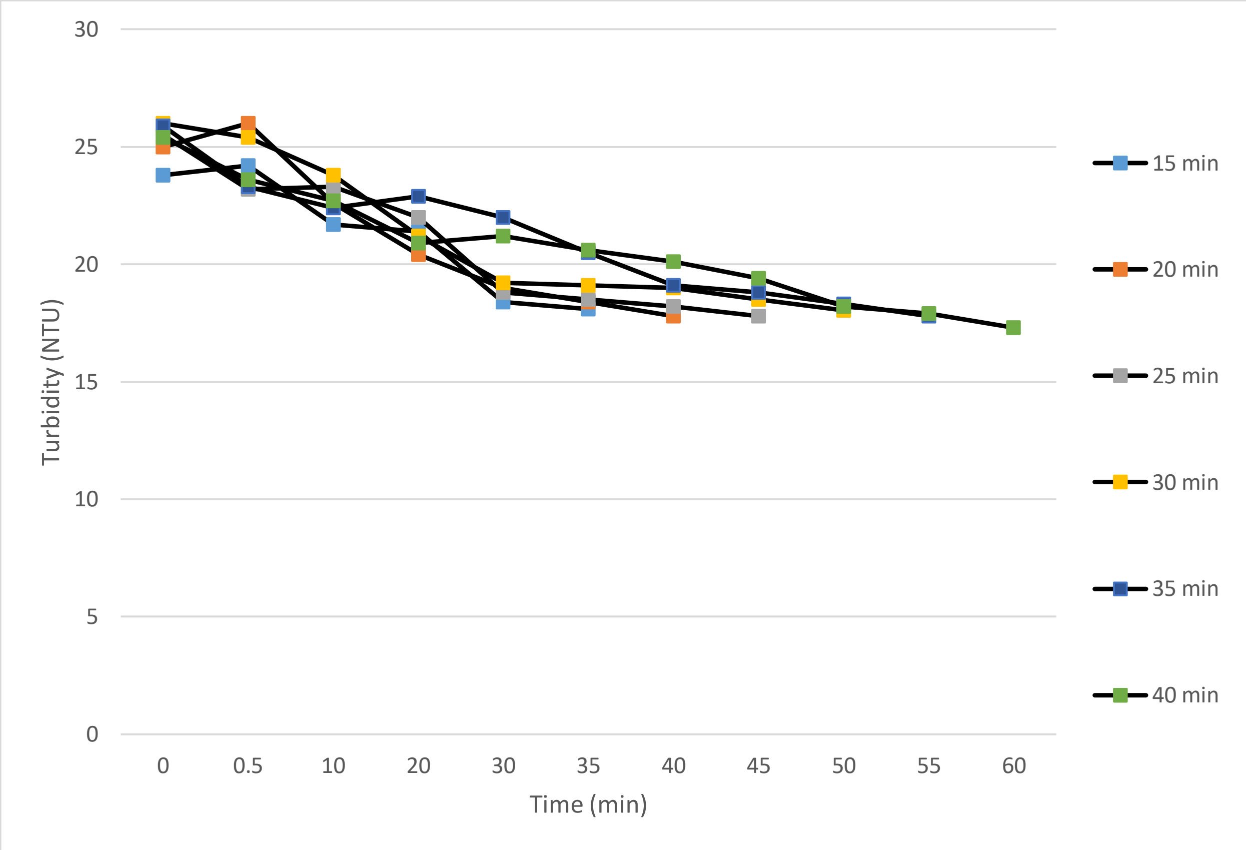



**Figure 4.15**: Represents the turbidity removal with respect to the settling times

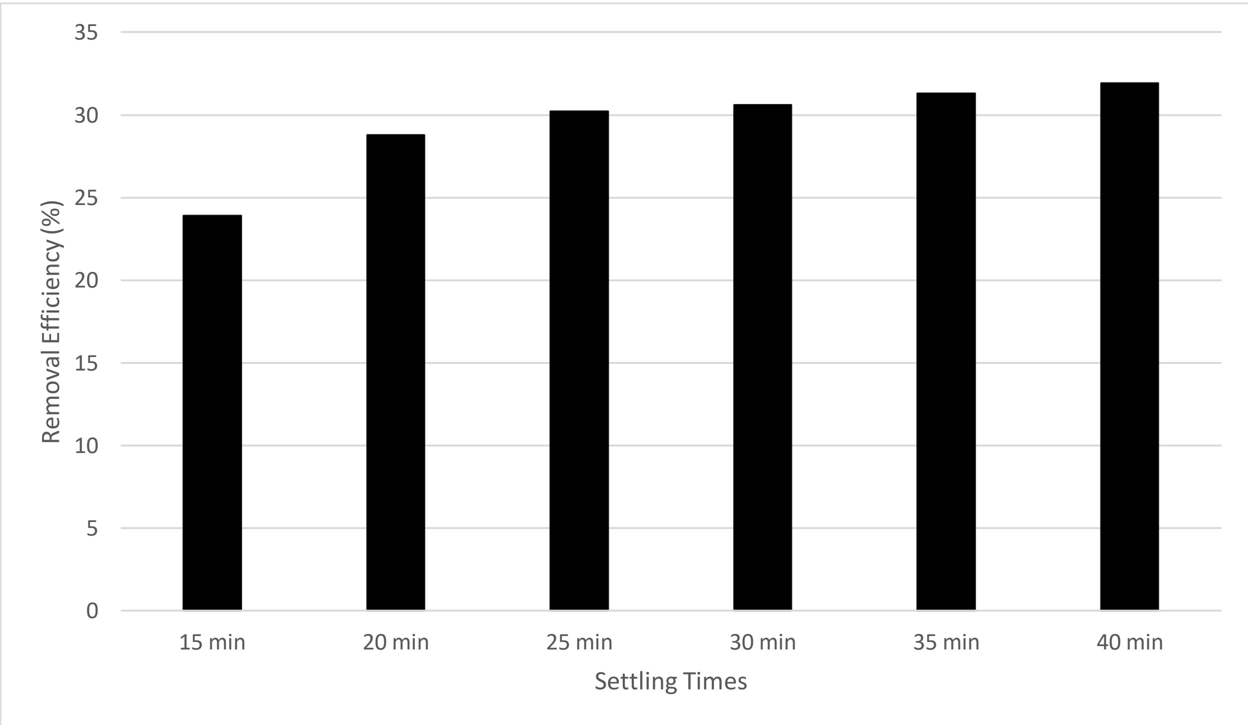



**Figure 4.16**: Represents the removal efficiency with respect to the settling time.

### 4.2.7 pH

The test was conducted while maintaining the optimum operational parameters from the previous test. This test focused on determining which pH of initial water sample would provide the optimum conditions for coagulation to occur. The pH of the three sample were pH 7.5 for neutral, pH 3.6 for acidic, and pH 10.1 for alkaline. The test was run using 1 ml of 3 g distilled water seed powder coagulant, with an initial turbidity in the 16-30 NTU range, with a rapid mixing time of 30 seconds (0.5 min), a slow mixing time of 20 minutes, and a settling time of 40 minutes.

Based on Figures 4.17 and 4.18**,** it could be seen that the pH levels of neutral and alkaline displayed similar turbidity removal, with removal efficiencies of 34.3% and 32.9% respectively. However, under acidic conditions it could be seen that the turbidity removal was rapidly increased, with a removal efficiency of 46.7%. This could indicate that in the presence of acidic water, the coagulant is better activated, allowing for more coagulation and flocculation to occur, which resulted in the larger formation of floc and better removal efficiency.

Several other studies have indicated similar outcomes. A pH test conducted using *Moringa oleifera* as the plant material indicated that the removal efficiency of the coagulant was optimum under acidic pH conditions around pH 4 to 7. It was mentioned that the presence of more hydrogen ions aided in the adhesion of the active components to the colloidal particles, allowing for more charge neutralization to occur, and subsequently more flocculation (Shabaa et al., 2021).

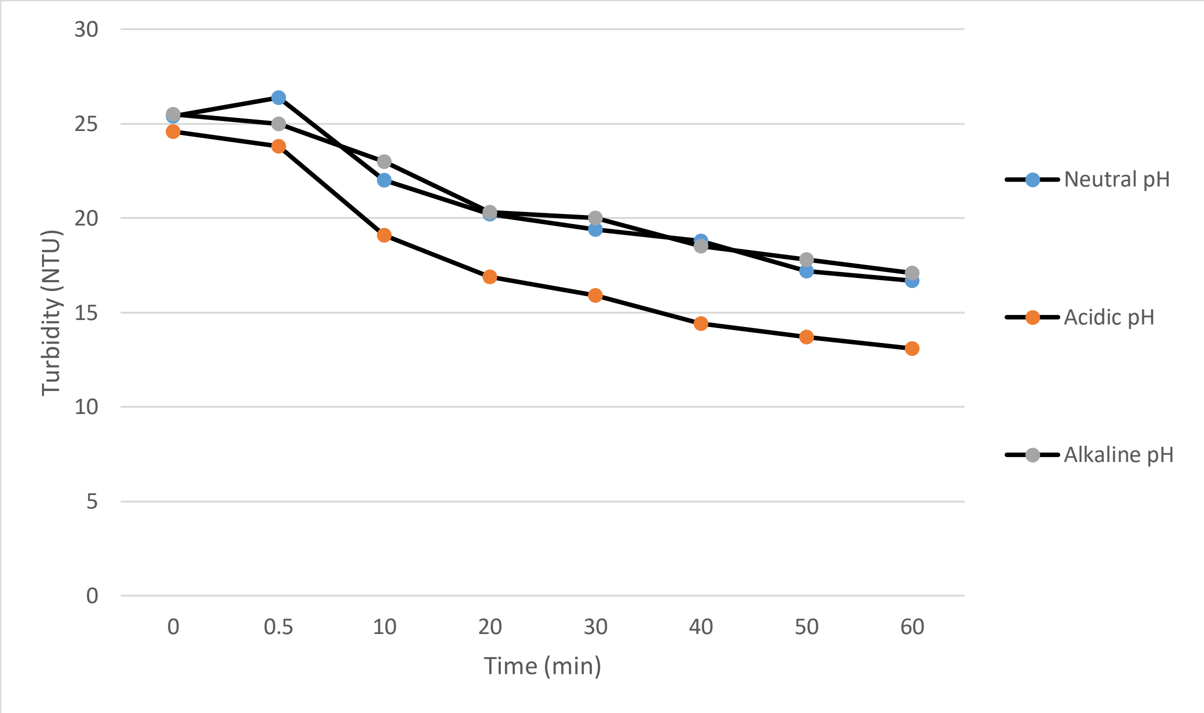



**Figure 4.17**: Effect of pH on turbidity removal with respect to time

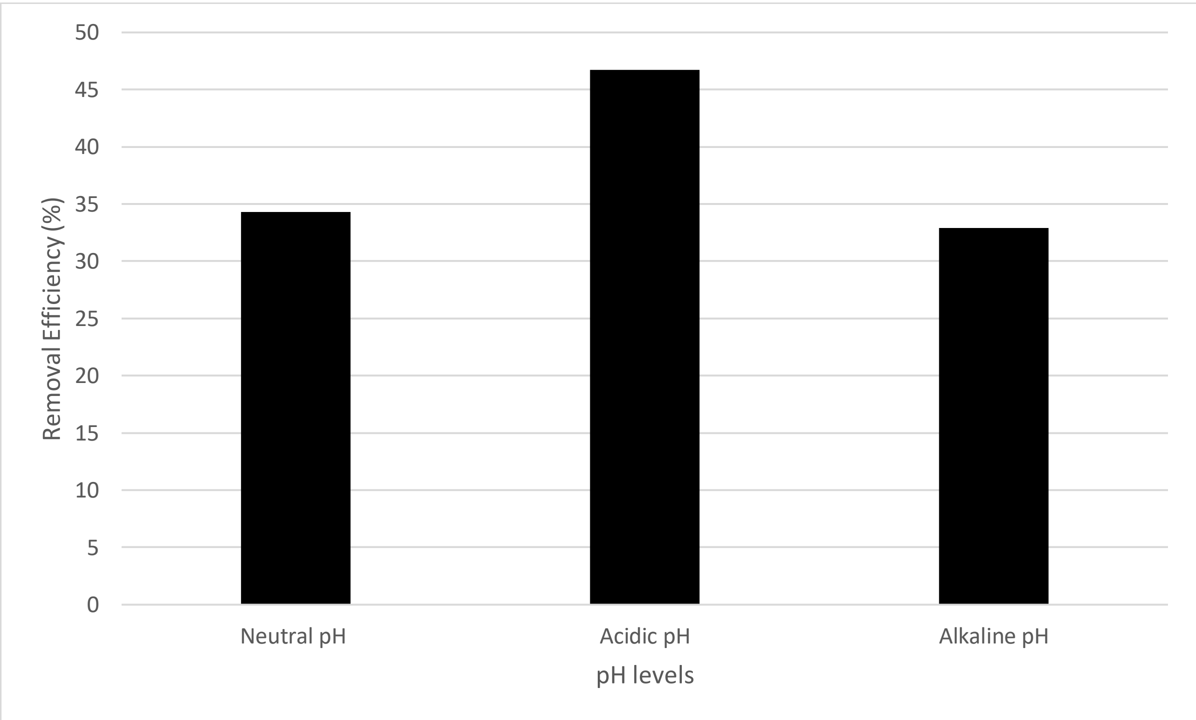
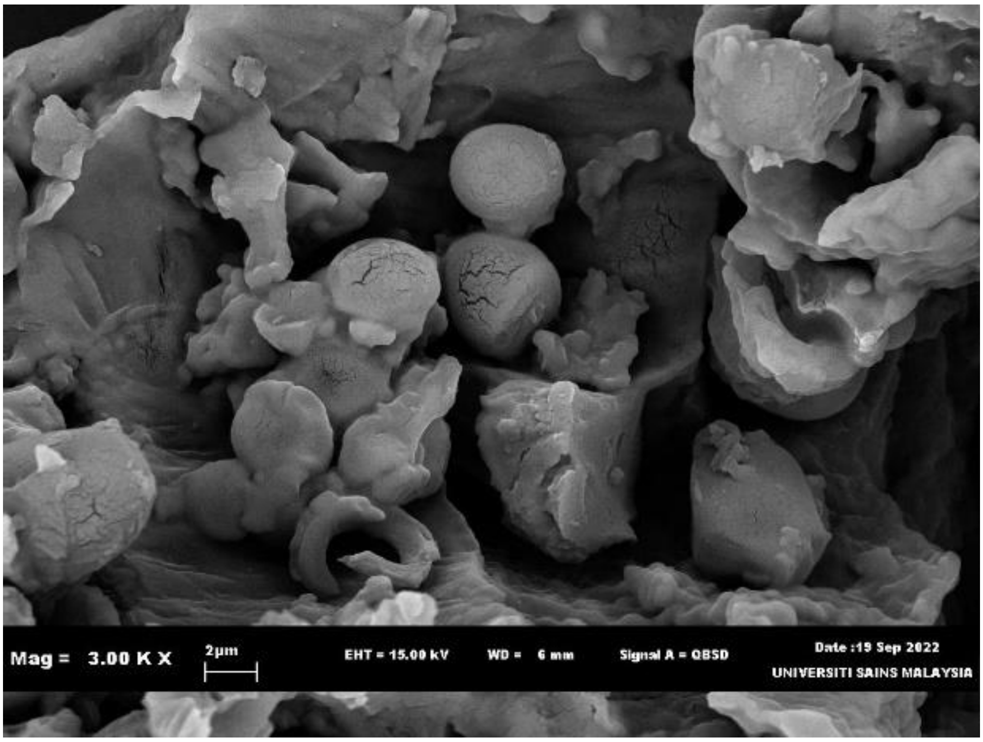


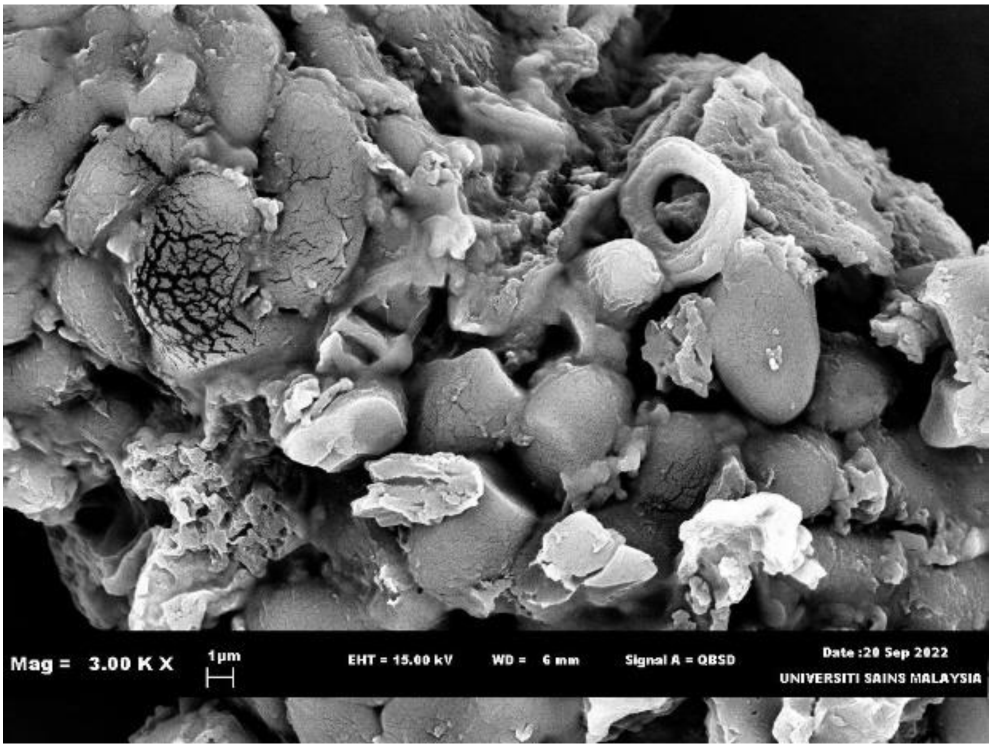

**Figure 4.18**: Turbidity removal efficiency with respect to pH

4.3 Scanning Electron Microscope

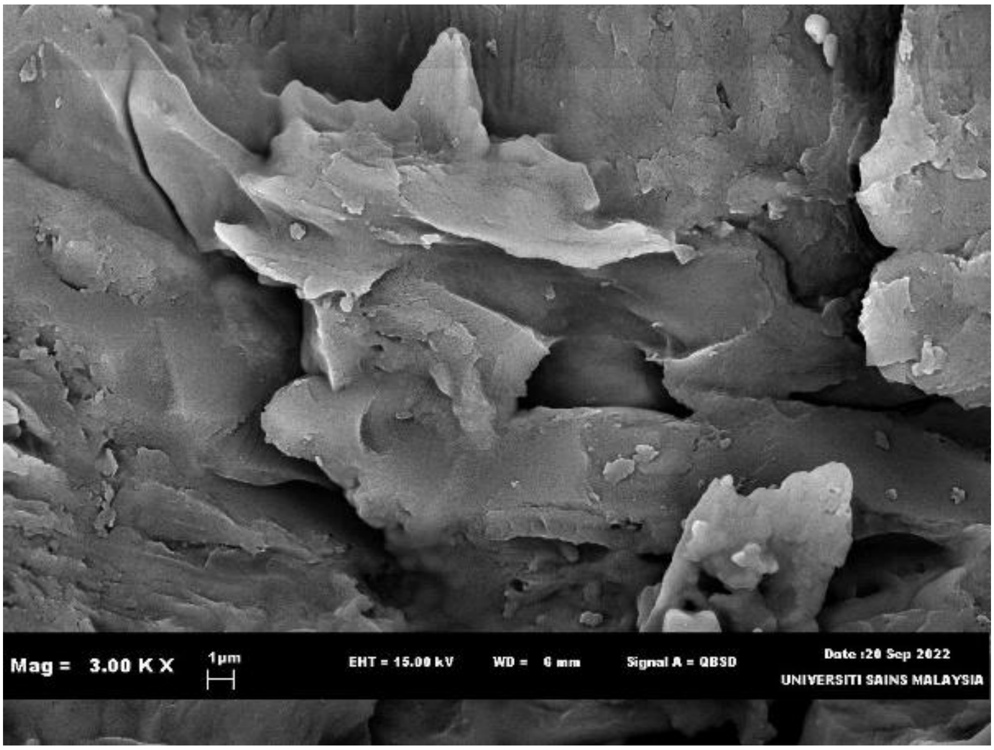
To study the suface morphology of the Longan seed powder, four samples were prepared and examined using a scanning electron microscope (SEM). Based on the images in Figure 4.19, several explanations and comparisons can be made. Firstly, it can be seen that seed powder samples A ,B, and D all display a oval-like shape, and appear to have a certain granular appearance to them. A similar observation was made in another study, which grouped the oval granular structure of longan seed powder forming a clod of epitical, with a rough surface, containing fine particles of irregular shapes (Aziz et al., 2018). that described the However, sample C seemed to have a more flat, sheet like appearance to it. Besides that, the granular structures of samples A and D seemed to have less grooves, with a smoother texture, while sample B's granular structure had more grooves, which also appeared to be deeper. All other samples appeared to have more structure and shape to them, however sample B appeared to be more broken down, with an overall rougher surface. This could suggest that more active components were able to be extracted from within the seed powder's structure, and the seed powder particle itself could possess better adhesive properties due to having more grooves and creveses for small particulates to adhere upon.




A. Raw powder sample




B. Seed powder soaked in Distilled water




C. Seed powder soaked in NaCl solution


D. Seed powder soaked in NaOH solution

**Figure 4.19**: Represents the SEM images obtained at 3000x magnification for four powder samples.

# CHAPTER V

## Conclusion

This study successfully synthesized a plant-based coagulant from Longan fruit seeds. In terms of application, the coagulant was tested to remove turbidity from water. Overall, the coagulant displayed relatively low coagulation activity, however by modifying several operational parameters, the turbidity removal efficiency of the coagulant began to increase. In this study, the operational parameters observed included the type of coagulant solvent, coagulant dosage, initial water turbidity level, initial water pH, rapid mixing time, slow mixing time and settling time. In general, under neutral conditions, the coagulant displayed removal efficiencies between 23.6 % and 31.9%, and the highest turbidity removal efficiency obtained in this study was 46.7%, which occurred once all operational parameters were modified. The optimum operational parameters included a plant-based coagulant using distilled water solvent, 1 ml coagulant dosage, 16-30 NTU turbidity range, acidic pH of water, 30 seconds rapid mixing, 20 minutes slow mixing, and 40 minutes of settling. In terms of characterization, using a scanning electron microscope, this study was able to view the morphological structure of the Longan seed powder. The structure of the seed powder generally displayed an oval granular structure with irregularity on its surface.

In conclusion, this study was able to provide more in-depth information regarding the behavioural patterns and characteristics of a plant-based coagulant synthesized from Longan fruits seeds, and even though the overall coagulation performance can be considered to be low, it could be suggested that Longan fruit seeds can be applied as an environmentally friendly coagulant aid to conventional chemical coagulants. Thus, reducing the concentration of chemical coagulants needed to treat turbidity in water, and reducing the dependency on chemical coagulants in the future.

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