

FEASIBILITY OF PEANUT RESIDUAL CAKE EXTRACT AS
THE COAGULANT FOR WATER TURBIDITY REMOVAL

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**FEASIBILITY OF PEANUT RESIDUAL CAKE EXTRACT
AS THE COAGULANT FOR WATER TURBIDITY
REMOVAL**

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FEASIBILITY OF PEANUT RESIDUAL CAKE EXTRACT AS THE COAGULANT FOR WATER TURBIDITY REMOVAL

ABSTRACT

In this study, the potential use of the peanut residual cake extract (PRCE) as the coagulant for water turbidity removal during water treatment has been investigated. PRCE was prepared by grinding it to powder using the ordinary household blender. PRCE was extracted using a solution made of 3 molar of sodium chloride (NaCl) to extract the active ingredient. The feasibility of PRCE coagulant was investigated using kaolin synthetic turbid and further tested with river water via the jar test. The study included the variables of coagulant extraction time and types of mixing during coagulation and flocculation; which were rapid and slow mixing with different initial level and concentration of pH and turbidity values. Rapid mixing time ranged from 1 to 4 minutes, while slow mixing time varied between 15 to 30 minutes. Finally, the performance of PRCE was compared with aluminum sulfate (alum) for the variable of extraction time, found that the most efficient coagulant extraction time occurred after ten minutes onward ($n = 7$, Anova Test at $p = 0.05$). Meanwhile, for the operational mixing time variables of rapid and slow, the latter has given a better result. Simple optimization study also included both variables of initial pH and turbidity values. It was found that pH from 6 to 8 was found to be effective in removing 96-98% of the turbidity. Under optimum conditions with the PRCE dosages from 5 to 10 mg/l, it was that had able to remove more than 90% of turbidity for the initial concentration of 200 to 500 NTU. Validation of PRCE as an effective coagulant was done by comparing it with alum; Both had shown that their results were comparable for turbidity removal efficiency, which were found to be at 90 % and 95.2 %, respectively.

Keywords: PRCE, extraction time, turbidity, rapid and slow mixing time

KAJIAN KEBOLEHSANAAN EKSTRAK KEK SISA KACANG TANAH SEBAGAI PEMBEKU UNTUK PENYINGKIRAN KEKERUHAN AIR

ABSTRAK

Dalam kajian ini, potensi penggunaan ekstrak sisa kek kacang tanah (PRCE) sebagai pembeku untuk penyingkiran kekeruhan air semasa rawatan air telah dikaji. Sisa PRCE telah disediakan dengan mengisar menggunakan pengisar domestik bersaiz sederhana hingga menjadi serbuk. Ekstrak PRCE dikeluarkan menggunakan larutan dengan kepekatan natrium klorida (NaCl) 3 molar. Kajian PRCE sebagai pembeku dikaji dengan menggunakan larutan keruh sintetik berasaskan dan air sungai melalui ujian balang. Kajian menggunakan pembolehubah masa pengekstrakan pembeku dan jenis penyebatian semasa penggumpalan dan pengelompokan; penyebatian pesat dan lambat dengan permulaan berbeza pH dan nilai-nilai kekeruhan. Masa penyebatian yang pesat berjarak dari 1 hingga 4 minit, manakala masa penyebatian yang lambat mengubah antara 15 hingga 30 minit. akhirnya, prestasi PRCE dibandingkan dengan sulfat aluminium. untuk ujian PRCE untuk pembolehubah tempoh masa untuk pengekstrakan pembeku yang paling efisien berlaku selepas sepuluh minit ($n = 7$, Ujian Anova di $p = 0.05$). sementara itu, bagi pembolehubah tempoh masa pencampuran pantas dan perlahan yang kemudian telah menunjukkan keputusan yang lebih baik Manakala bagi kajian pengoptimuman untuk pembolehubah pH dan unit kekeruhan awalan, ia telah didapati bahawa pH dari 6 hingga 8 didapati berkesan untuk menyingkirkan 96-98% daripada kekeruhan. Semasa dalam keadaan optimum (), ia telah mendapati bahawa 5 hingga 10 mg/l PRCE menunjukkan kemampuan yang lebih baik apabila 90% daripada kekeruhan bagi kepekatan kekeruhan awal setinggi daripada 200 sehingga 500 ntu. Perbandingan kecekapan penyingkiran kekeruhan oleh PRCE dengan dengan alum telah menunjukkan bahawa ianya mempunyai kecekapan penyingkiran yang hampir sama iaitu setinggi 90% dan 95.2%.

Katakunci: masa pengekstrakan, kekeruhan, masa pencampuran yang cepat dan perlahan

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Human population is growing together with the increment of economic activities along with the development in industrialization, thence a rise in the need for freshwater. Consequently, there is a threat to global water resources as regards degrading ecologically and not merely issues of poor management or over exploitation. Thus, a lot of developing nations face critical issues of accessing safe and clean water. Surprisingly, around 2 billion persons across the globe are reportedly lacking safe water to drink, followed by a mortality rate of above 20 million kids in developing nations based on suffering from diarrhea yearly. On the other hand, 80% of the diseases that affect these nations are caused by polluted water and poor sanitation (Ghernaout, 2018).

Turbidity refers to the process of measuring water cloudiness for the purpose of water quality indication, alongside the effectivity of filtration. Thus, on a regular basis, higher levels of pathogens some of which includes bacteria, viruses, and parasites found in water, are linked to high rate of turbidity; of which such organisms could be responsible for diverse kinds of water-borne diseases, some of which comprises, headaches, diarrhea, nausea, and cramps. The residual turbidity guideline level for drinking water is said to be set at 5 nephelometric turbidity unit (NTU), a standard fixed by the World Health Organization (WHO), one of which has become the mandated limit for treatment of raw water (WHO, 2017).

Amongst the major efficient approaches of water turbidity removal is the coagulation/flocculation process, one which depicts a very important process for treating both the industrial waste water as well as surface water. More so, this process involves removing turbidity as well as dissolving organic species from water, which is usually done via adding conventional chemical-based coagulants such as synthetic, alum, and

ferric chloride organic polymers. Adding coagulants to water leads to coagulation of water through charge neutralization whereby flocs are settled by gravity, leaving supernatant with reduced turbidity (Antov et al., 2012).

The rapid progress in science and technology towards the ending period of the 20th century resulted to a substantial rise in the standard of living as well as the development of economy in the developed countries globally. Nevertheless, these developments have led to significant deprivation of environments, caused by numerous issues. This novel situation further gave room to the search for a solution that can help balance conservation of the environment, usage of natural resources, and economic growth. Thus, the awareness with regards to the need for environmental protection has increased as a result of such reflections, therefore, great care is taken for what is referred to as “Green and viable technologies”. Thence, the newly set up laws and regulations are targeted at protecting the ecosystem from harmful chemicals; therefore, a directive was given by the chemical community to ensure a process of green chemistry which is aimed at developing less dangerous processes and compounds to both the environment and human health (Ivanković et al., 2017).

Green chemistry (GC), is the chemistry that deals with the design, development and implementation of harmless chemical processes as well as products to the environment and human health, thence reducing potential pollution chances. Green chemistry for water treatment can be defined briefly as chemical production and usage for water treatment that addresses the principles of GC, such as green coagulants and disinfectants (Ghernaout et al., 2011; Ivanković et al., 2017).

The initial conception of GC was developed in the 1990s, of which served as a response to the 1990 Pollution Protection Act, where it was stated that pollution should be reduced by the US national policy via improving designs rather than treatment and

disposal (Ghernaout et al., 2011). GC has been established on twelve principles, that have been practically explained. These principles are shown in Table 1.1.

Table 1.1: The twelve general principles of green chemistry (GC) (Adapted from Ghernaout, et al., 2011)

12 general principles of GC	Explanation
1. Prevent waste	It is better to prevent waste rather than treat or clean up waste after it is formed
2. Atom economy	Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Less hazardous chemical synthesis	Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to people or the environment.
4. Designing safer chemicals	Chemical products should be designed to affect their desired function while minimizing their toxicity
5. Safer solvents and auxiliaries	The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Design for energy efficiency	Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of renewable feedstocks	raw material or feedstock should be renewable rather than depleting wherever technically and economically practical.
8. Reduce derivatives	Unnecessary derivatization (use of blocking groups, protection/deprotection, and temporary modification of physical/chemical processes) should be avoided whenever possible.
9. Catalysis	Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Design for degradation	Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11. Real-time analysis for pollution prevention	Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Inherently safer chemistry for accident prevention	Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

They represent the framework for the design of new chemical products and processes, which can be applied to all sides of the process life-cycle including the raw materials used to the safety of the transformation, biodegradability of products, the toxicity and reagents used (Ivanković et al., 2017).

To correlate between the green water treatment, which can be defined as water treatment processes that use environmentally friendly and human-health harmless additives; and these principles, the following selected GC principles as discussed by Mohammed et al., (2020) are presented.

- i. **Waste prevention** – Prevention of waste is more appropriate as compare to its treatment or cleansing after formation.
- ii. **Synthesis of less hazardous chemical** – In practicable possibilities, there is a need to design synthetic methods that could assure substance usage and generation which possesses less or clear non-toxicity to either the environment or individuals.
- iii. **Use of renewable feedstocks** – It is more suitable to renew feedstock or raw materials instead of depletion incases where there is a possibility of practicality in a technical and economic manner.
- iv. **Design for degradation** – There is a need to design chemical products in order to ensure their non-persistence in the environment after their functioning period as well as possibilities of breaking down into products that are innocuously degradable.

Many researchers had used plant-based coagulants for raw water treatment, they concluded that plant-based coagulants were found to be efficient, non-toxic, biodegradable, produce less sludge volume compare with conventional coagulants, and they are not affecting the final pH of the treated water (Antov et al., 2012; Betatache et al., 2014; Gandiwa et al., 2020; Taiwo et al., 2020). These findings address the above-mentioned GC principles. Thus, in general one can say that plant-based coagulant are green coagulants (that are environmentally friendly) for water treatment, however, more specification would be needed for each individual coagulant.

Considering the current study, candidate believes peanut residual cake extract could serve as a promising green coagulant for the following reasons:

- i. Availability – it is available in most part of the world, as peanut is considered the fifth oilseed over the world (Fletcher & Shi (2016).
- ii. Some studies proved its efficiency in turbidity removal (Birima et al., 2013; Birima et al., 2015).
- iii. Cost effective – since it is a byproduct of the cooking oil industry.
- iv. Environmentally friendly – it is a biodegradable organic material, moreover, the sludge resulted from the coagulation could be useful as fertilizer since it is rich of protein (Fletcher & Shi (2016).

1.2 Peanut

South America (especially, Bolivia alongside other neighboring countries) is the cultivating home of peanut, which is often referred to as groundnut (Dharsenda, et al., 2015), after which its growth spans across the world's tropical and subtropical regions. Interestingly, this crop was extensively grown by indigenous people of the new world as of the time of the expansion in Europe around the 16th century, which was consequently moved to other global regions, such as the Pacific Islands, Europe, Asia, and Africa respectively (Grichar et al., 2004). Thus, the cultivation of peanut in the United States up till 1870 was mainly as a garden crop as well as a field crop; also, peanut was used purposely hog pasturing up till the year 1930. In terms of production, China, India, Nigeria, and the United states are the leading countries in the world (Negrete, 2015; Fletcher & Shi, 2016).

Peanuts have been used in many ways. Some of these ways include it being an edible food, used for peanut butter, sweets, roasted peanuts, boiled peanut, grilled peanut, peanut donuts, nutrients such as calcium, phosphorus, and essential vitamins, its oil used for cooking and soap manufacturing, peanut-containing snacks, and protein extender (Toomer, 2020; Loko et al., 2020). Loko et al., (2020) also mentioned that peanut leaves and shells have been used in traditional medicine.

As mentioned by Fletcher & Shi, (2016), Peanut is also a source of oil as it is considered the fifth most prominent oilseed globally, subsequent to soybean, cotton, sunflower, and rapeseed. Fletcher & Shi also informed that the protein seeds are known as oilseeds meal- a residue from previous oil processing can be used in the form of both soil fertilizers and food for animals.

Literature reveals some studies that focused on the application of peanut seed in water and wastewater treatment. Nand et al. (2012) studied the ability of peanut seeds together with other local seeds to remove the heavy metals from water in Fiji. It was found that peanut could remove around 30% zinc, 40% chromium, 50% lead, and 10% of cadmium respectively. Other studies showed a high potential of peanut seeds in removing turbidity from surface water (Birima et al., 2013; Birima et al., 2015a). Processed peanut seeds were also used as a primary coagulant for the “pretreatment of palm oil mill effluent (POME)”. It was concluded that peanut seeds could remove total suspended solids (TSS) and chemical oxygen demand (COD) of around 94.7% and 73.5% respectively (Birima et al., 2015b).

1.3 Problem Statement

The commonest conventional water-used coagulants and wastewater treatment comprises alum, synthetic organic polymers, as well as ferric chloride (Antov et al., 2012). Although there is a proper recognition regarding the chemicals’ effectivity as coagulants (Kang et al., 2003), yet serious drawbacks exist with relation to their usage, one of which includes, relatively-high purchasing costs (Yarahmadi et al, 2009), ineffectiveness in low-temperature water (Yin, 2010), negative impact on the health of humans, large sludge volume production, and significant impact on treated water pH (Antov et al., 2012). Also, strong evidences abound as regards the link between Alzheimer’s disease development and aluminum-based coagulants in humans (Flaten,

2001; Jodi et al., 2012; Bondy, 2010; Betatache et al., 2014). Thus, extensive investigation of natural coagulants usually occurs due to their biodegradability, efficiency, and plentiful source (Antov et al., 2012; Betatache et al., 2014). Consequently, a number of scholarly works has been conducted for the purpose of investigating peanut seeds effectivity as a water coagulant as well as a treatment for wastewater (Nand et al., 2012; Birima et al., 2013; Birima et al., 2015a; Birima et al., 2015b). However, the effectiveness of PRCE as a coagulant, the optimum time to extract the coagulant component, and the effect of the physical and chemical operation variables, such as, rapid mixing time, slow mixing time, and initial pH are not investigated yet. Studying these parameters is important, as obtaining the optimum extraction time reduces the cost of this process since it reduces energy consumption. Meanwhile, optimizing the physical and chemical variables will reduce the overall time of the coagulation process, reducing the amount of the required coagulant, thus reducing the overall cost of the treatment process.

1.4 Aim and Objectives

This study aims to address some of the missing aspects of presenting PRCE as a natural coagulant for turbidity removal. This is done by optimizing the operational variables of the coagulation process, to reduce its time and overall cost; as well as to compare the PRCE with a well-defined standard coagulant.

The purpose of this study is to conduct a feasibility study on using PRCE as a natural coagulant that has a minimal adverse impact on human health, is environmentally friendly, and is cost-effective.

The specific objectives of the study are:

- i. To obtain the effective time of extracting the coagulant from PRC.
- ii. To optimize the physical and chemical operation variables during coagulation, by examining the effects of rapid mixing time, slow mixing time, and initial

pH. In addition to validating the effectiveness of PRCE as a coagulant under various turbidities.

- iii. To compare the performance of PRCE coagulant to that of aluminum sulfate, the standard coagulant.

1.5 Expected Research Outcomes

The present study will introduce a new alternative natural coagulant for water treatment process. If it's a success, this coagulant could replace or supplement the conventional chemical coagulants. Results of this study could also be used as guidelines for some work which use similar material in traditional ways for water purification.

1.6 Scope of the Study

The scope of this research mainly focuses on the potential of the natural coagulants, namely peanut residual cake extract (PRCE) to function like any other conventional coagulants such as alum and iron derivatives that are available. Consequently, and specifically to this study, Jar Test analysis was carried out to investigate the ability of PRCE as coagulant under varying dosage, initial turbidity, extraction time and pH conditions. Furthermore, Sodium chloride solution was used for the extraction of the active compound as the coagulant. The tested water used in this study was synthetic water prepared by adding kaolin into the clean tap water. Meanwhile, for the river water, it was collected from the stream Sungai Pantai Universiti Malaya, Kuala Lumpur, Malaysia. More so, the initial turbidity of raw water was different, depending on the time of sampling, normal weather, after rain, right after rain, and during rain.

Fourth, the variation of the raw water initial turbidity was dependent on the time of sampling - normal weather, after rain, right after rain, and during rain.

CHAPTER 2: LITERATURE REVIEW

2.1 Turbidity

2.1.1 Definition and Measurement

Turbidity is an optical property whereby the water scatters the light rather than being transmitted in straight lines. The reason for this is the suspension as well as dissolving of certain materials, some of which are: plankton, inorganic and organic matter that are finely divided, clay, silt, chemicals, alongside several other microorganisms (WHO, 2017).

Previously, the measurement of turbidity was done via the Jackson candle turbidimeter alongside units of turbidity which were recorded as Jackson turbidity units (JTUs). However, there are some challenges with the Jackson candle turbidimeter such as its inability to measure lower turbidities- those less than 25 JTU, as well as its dependence on the judgment of humans in determining points of extinction (Borok, 2014). Finally, scientists developed the nephelometric detectors which later became a method recognized for the measurement of turbidity. These nephelometric devices have the ability of measuring the scattering of light via limited angle ranges to the mean light incident in relativity to a standard suspension, which is commonly of formazin. Thus, to measure the suspended sediment, there is a need to make use of nephelometric turbidity units (NTUs) represented as rough indexes (Borok, 2014). Hence, the turbidimeter was used for this study, which measured turbidity in NTU.

2.1.2 Negative Impact of Turbidity in Waterbody and its Indication on Water

Safety

Turbidity has a negative effect on various fields. Among these includes turbidity effect on primary productiveness- which includes the growth of macrophytes, periphyton, as well as phytoplankton, those of which makes provision for the food chain base in aquatic

systems, thus causing an influence of the availability of food for fishes as well as the aquatic invertebrates (Borok, 2014). Borok, (2014) also reported that availability of light in the water body plays an essential role in primary productivity as it fuels the photosynthesis, moreover, high turbidity levels have the ability causing a reduction of light availability for the water column, thus possibly reducing the effect of production.

More so, in the course of inducing the aqueous system with turbidity, there is a provision of adsorption sites by the system for both unwanted species of chemicals alongside microorganisms. Further, it serves as a site of protection for the microbes against the process of disinfection (Oladoja et al., 2017).

The safety of drinking water can be indicated by turbidity; thus, low turbidity is an indication of pathogen removal and therefore, a safe drinking-water. Events of high turbidity have been linked with numerous outbreaks of disease (WHO, 2017). Thus, turbidity is therefore associated with the incidence of gastrointestinal diseases related to tap water consumption (Muoio et al., 2020).

Turbidity is also used for monitoring the quality of water sources; hence a rapid turbidity change could imply signs of significant measures of pollution from the catchments of surface water as well as groundwater (some of which includes, being caused due to spills, storms, thaws, or fire), which might be joined alongside anthropogenic activities. Thence, the investigation of turbidity variations ought to undergo some experiments in order to find out the causes as well as for the purpose of recognizing corrective actions of maximal suitability (WHO, 2017).

Furthermore, during water treatment processes, turbidity serves as a major indicator of flocculation as well as coagulation in a practical manner, alongside the performance of filter. Also, among the strengths of turbidity is its ability to be measured in a continuous manner, followed by connective results with automatic alarm systems, which give room

for rapid responses, and in necessary occasions ensure corrective actions are taken from deviances in noticing specific performances. Normally, the targets of specified turbidity cuts across filtration plants that are well designed, those that have undergone optimization for the essence of achieving removal of particles, are thereby nominated accordingly. Thence, the achievement of these targets seems to be a crucial component which serves as an indication of reductions in pathogens (WHO, 2017).

Moreover, another use of turbidity can be as an operating parameter for the evaluation of disinfection effectivity, as well as a base in determination of disinfectant doses alongside the adjusting of contact times (in cases where necessary). The efficacy of chlorination is thence reduced at turbidity above 1-2 NTU via the increase of the demand for chlorine as well as by protecting inactivity of microorganisms (Keegan, et al., 2012). Though, it is possible to achieve disinfection at higher turbidity levels, the increase of contact times or chlorine doses, is a necessity for achieving the required disinfection (Keegan, et al., 2012). In a similar manner, the disinfectant ultraviolet (UV) light effectivity could be affected via the turbidity, since it reduces UV light transmission or it shields microorganisms from inactivation (WHO, 2017).

2.2 Coagulation and Flocculation in Water Treatment

2.2.1 Coagulation and Flocculation

The process of coagulation and flocculation is a global procedure that is used in treating both urban as well as industrial wastewaters (Pav n-Silva et al., 2009). For instance, in Egypt, aluminum sulfate (alum) was used in the settlement of suspended water particles as far back as 1500 BC (Teh et al., 2016).

The purpose of coagulation flocculation in water treatment is the agglomeration of colloids as well as fine particles into larger ones for the purpose of reducing organic matter alongside turbidity in wastewater as well as other pollutants that are inorganically or organically soluble.

There are two stages in this process: (1) Spread coagulant rapid mixing into possibly treatable wastewater or water via violent stirring; and (2) Agglomeration of small particles via flocculation into larger flocs through slow mixing. Thence, as allowance is given to the flocs for settlement, they undergo removal as a sludge, whereas there is a convey of the treated water also known as supernatant, into the next process or discharged into the waterbody (Teh et al., 2016). This process is accomplished by adding the coagulant traditional chemical-based coagulants, specifically aluminum chloride (AlCl_3), ferric chloride (FeCl_3), and polyaluminium chloride (PAC) (Gandiwa et al.). However, these coagulants encountered some drawbacks as listed in section 1.3. This fact led to searching for alternatives that included plant-based coagulants (Yin, 2010).

2.2.2 Mechanism of Stability

Colloidal particles on the basis of their electro-kinetic charges, tend to behave differently in water. Consequently, there is a similar charge for each particle, alongside the occurrence of a negative charge of almost the entire colloidal particles. Due to their small size (of around 0.01 to 1 μm), there is a lesser force of attraction between the particles as compare to that of the electrical charges (Teh et al., 2016). Because of this, there is a tendency for the particles to remain suspended in disperse as well as being discrete. The particle stability for natural waters is dependent on balancing the strike between the charged particle's electrostatic force as well as that of van der Waals forces, which act as attractive forces. In the latter case, when two particles approach each other, they experience magnetic and electronic resonance (Davis, 2019). Electrostatic repulsion controls stabilization due to the presence of a net negative charge among the particles.

The primary charges of colloids in solution attract ions with opposite charges, known as counterions. Thus, these ions are held in place by both the Electrostatic and van der Waals forces, thus, resulting in a primary charge which is surrounded by a compact layer (also known as a Stern layer).

This is indicated by Figure 2.1. As a result of the enclosed counterions, their counterions - that is “the primary charge’s co-ions”, are attracted to each other, resulting into the diffuse layer being created. Contrasting to the Stern layer charges, movement only occurs via the colloid attached to the diffused layer part sheared at the shear plane. More so, the shear surface defines the potential of Zeta and also this measurement can be used for estimating a particle’s surface charge. Invariably, on a normal ground, Zeta potential is measured via the zeta-potential meter (Teh et al., 2016).

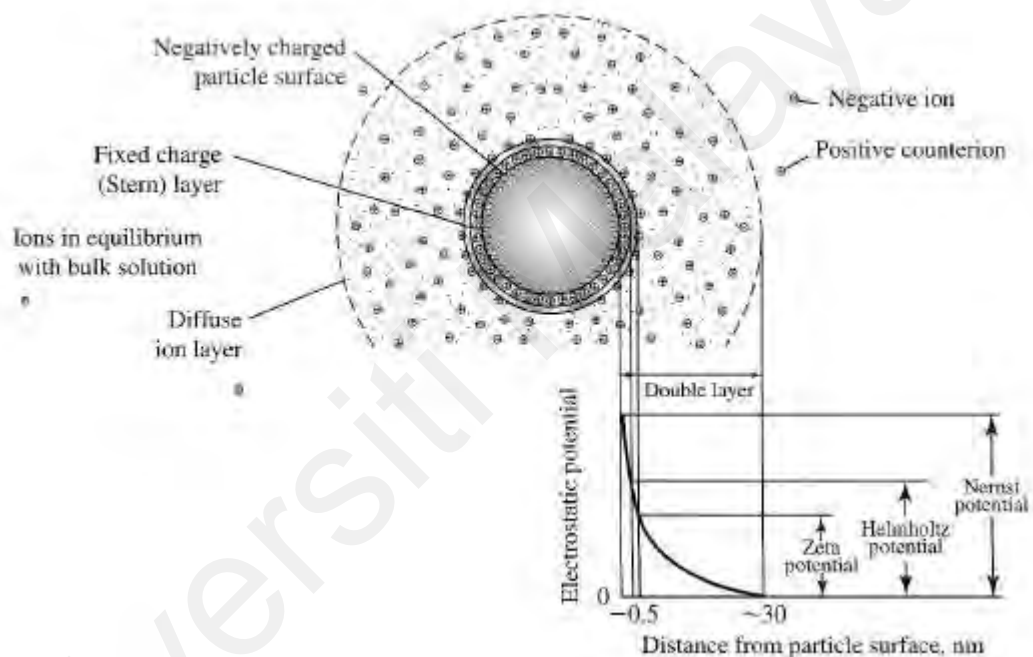


Figure 2.1: Surface charge on a particle in water (Davis, 2019)

Moreover, the DLVO Theory- which is named after Derjaguin, Landau, Verwery, and Overbeek, can be used to describe the stabilization of colloidal particles quantitatively. As illustrated in Figure 2.2, this theory explains the manner by which the repulsion energy- which overlaps the double layers electrically, and the attraction energy- by van der Waals forces, are dependent on the particles distance. Thus, the difference existing between forces of repulsion and attraction defines an energy barrier, which is considered the net interaction energy. To make contact with one another, particles must overcome this huge barrier of energy.

Apparently in normal situations, the height of the barrier is normally far greater as compare to the particle's average thermal energy. Thus, colloidal particles are almost unable to cross this barrier. This will result in a stable suspension. As long as the particle's kinetic energy exceeds the energy barrier, they will coalesce (Teh et al., 2016).

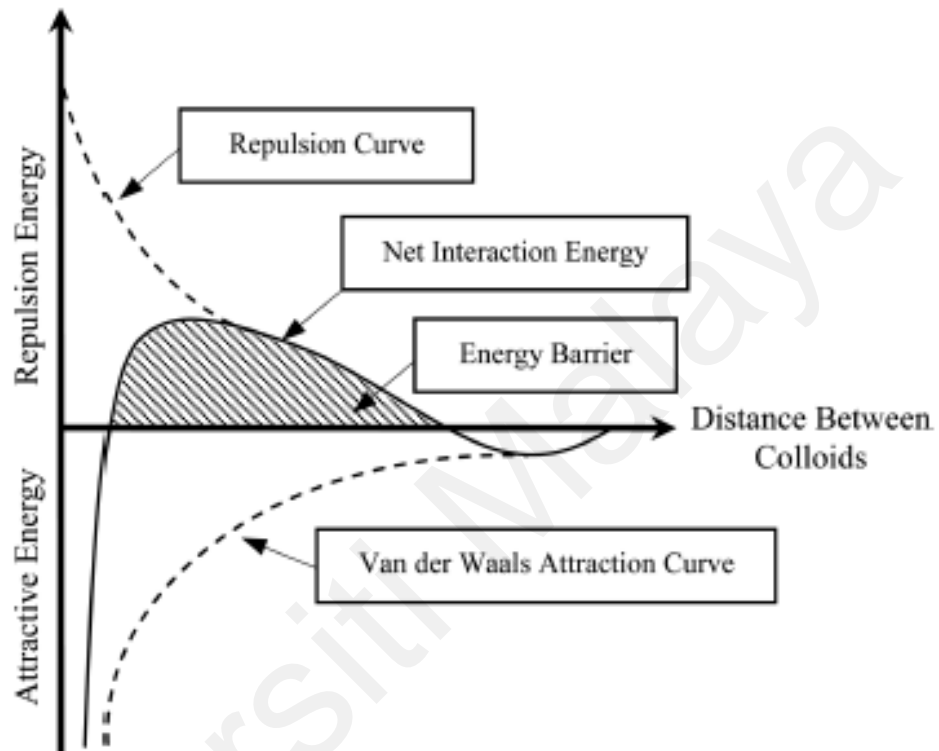


Figure 2.2: Forces between particles as a function of distance between particles (Teh et al., 2016)

2.2.3 Mechanism of Destabilization

The mechanisms employed for destabilizing natural water suspensions are (1) Double layer compression; (2) Charge neutralization; (3) Colloid entrapment; and (4) Intraparticle bridging. Several factors determine the coagulation mechanism, including coagulant formulation, dosage, water and waste characteristics, and mixing devices designed for treatment. (Davis, 2019; Teh et al., 2016). Yin, (2020) reported that polymeric coagulants are categorized into cationic, anionic, and non-ionic and the preceding two are known as polyelectrolytes; moreover, polymeric coagulants in general are linked with mechanisms 2 and 4. Yin also presented the mechanism of destabilization

for some of plant-based coagulants, for instance, *Moringa oleifera* undergoes adsorption and charge neutralization mechanism, while Nirmali seed extracts destabilize particles in water via interparticle bridging. However, based on the studies reviewed on the application of PRCE as a coagulant, none of them determined its mechanism of destabilization.

a. Double-layer Compression

The electric double-layer compression, leads to the reduction of repulsive forces, which in turn allows the particles to come together as well as are left attached due to the Brownian motion alongside the van der Waals attraction forces. Consequently, both the counterions charge as well as strength of the ionic are essential for the double layer compression to take place (Davis, 2019). The reduction in the double layer nearby the colloidal particle takes place via changing the ionic strength when an indifferent electrolyte is added, which in return leads to the colloids being destabilized (Nharingo et al., 2015). More so, in the course whereby conditions are stabilized and there is a low concentration of the counterions, there is an incapability of the colloid particles in getting nearer to themselves as a result of the thick double electric layers attached to them (Teh et al., 2016). Thence, when a rise occurs in how the counterions are being concentrated via salt addition, the layer of diffusion gets thinner, thereby giving room for a nearer gathering of particles prior to the repulsion experience.

The experienced effect can be explained by Figure 2.2, also, the addition of counterions can cause van der Waals attraction to go beyond repulsiveness of the double layer as there is a compression of the repulsive curve towards the left, leading to the achievement of particle coagulation (Bennett & Gary, 2006; Teh et al., 2016).

b. Charge Neutralization

The neutralization of charges is attained frequently via the adsorbing of polynuclear as well as mononuclear metal hydrolysis species or polyelectrolytes on the particles' surface. Various kinds of particles, such as clay and bacteria, can be neutralized by hydrolyzing coagulants. Among the most common destabilization coagulants, aluminum salts (sodium aluminate; alum; and aluminum chloride) as well as iron salts (ferric chloride sulfate; ferric chloride; and ferrous sulfate). Furthermore, continual research has also led to enhancement of prepolymerized coagulants that boasts of high efficiency, some of which includes the polyaluminum chloride (Teh et al., 2016). In the same study, Teh et al., (2016) also reported that occurrence of charge reversal, resulting to re-stabilization, will take place at high dosages; and the reason for this is as a result of charge neutralizing species specificity in nature. Thus, in order to ensure that particles are of a near zero charge in net, it is important to quantify the zeta potential for the purpose of monitoring the charge neutrality degree as well as ensure the best dosage is being determined.

c. Colloid Entrapment

When does exceeded saturation takes place for metals hydroxide, which is a common practice in water treatment, alongside the formation of insoluble precipitates from iron salts, as well as the entrapped matter particulate in this precipitate. During settling, the hydrous precipitates are usually enmeshed alongside additional water colloidal particles and helps with their removal. This type of destabilization is also known as sweep coagulation (Davis, 2019). The resulting larger and more robust flocs often leads to the production of a faster rate of aggregation as compare to that of neutralizing a charge. Importantly, among the major benefit of this approach is its ability to minimally depend

on the type of particle to be removed, not minding whether it is a bacteria, clay, oxide(s), among others (Bennett & Gary, 2006).

d. Intraparticle Bridging

Interparticle bridging is attained via the addition of polymers that can be soluble in water (either the anionic or cationic). Such method entails an adsorption of the polymer chain in the surface particle, which could be via attaching physically or undergoing a chemical bonding. More so, some parts of the polymer chain are attached, with the other parts being extended into the contact solution alongside the other particles' adsorption. Afterwards, the other connected particles are interlocked with the bridged particles all through the creating and mixing of flocs. These flocs get settled quickly and can withstand high shear. However, after breaking, they might not be as easily reformed (Teh et al., 2016).

2.3 Application of Natural Coagulant in Water Treatment

2.3.1 Natural Plant-based Coagulants

Plant-based natural coagulants usage in removing turbidity in water, has been known by several civilizations and communities at least 4000 years far preceding utilization of contemporary treatments of water (Saleem & Bachmann, 2019), several researchers have carried out scholarly works tailored at diverse extracts of plants with the aim of verifying their capability in removing water turbidities (Gandiwa et al., 2020). These researches have been increased potentially in the last fifty years, thus indicating the growing concern of the subject-area (Saleem & Bachmann, 2019). With regards to performance, plant-based coagulants have proven as workable alternates to the present chemicals as coagulants and flocculant aids (Kristianto, 2017).

Polymeric coagulants could be categorized as “cationic, anionic, or nonionic”, wherein the first two are referred to as polyelectrolytes (Bolto & Gregory, 2007). Majority of

studies pertaining to natural coagulants, have addressed them to be “polyelectrolytes”, notwithstanding, most of these scholarly works did not in actual sense carry out deep characterization of chemicals for the determination of their ionic activity (Muthuraman & Sasikala, 2014). Based on the aforementioned, it is important to make use of the term carefully, and as such should be applied after the determination of the ionic activity which is to be visible in the coagulant. More so, from a general perspective, natural coagulants are known as proteins or polysaccharides. Most of the plant-based polymers as well as polyelectrolytes have undergone investigation with regards to their coagulation characteristics far back as the latter periods of 1970s. Basically, a lot of these tested coagulants are in the family of the Fabaceae, of which the coagulation component is extracted from their seeds (Saleem & Bachmann, 2019). Though there have been reports of a lot of plant based coagulants in literature (Yin, 2010; Camacho et al., 2017). However, the majorly and generally recognized in the scientific community are four, namely: “nirmali seeds, *Moringa oleifera*, tannin and cactus”. These are presented in the following paragraphs. In addition to that, information about peanut, which is used as plant-based coagulant in the recent researches as well as in the present study, is also presented.

a. Nirmali Seeds

Strychnos potatorum (nirmali), refers to a moderate sized tree that is spread in the central and southern parts of India, Burma, and Sri Lanka, they are known among the local people as a traditional medicine. More so, Indian reports of Sanskrit writings have revealed the use of these seeds in purifying surface of turbid water for as far back as 4000 years, thus indicating them as the initial reported coagulants that are plant based, employed for the purification of water. Further, the extracts of the nirmali seed are anionic polyelectrolytes, such of which the mechanism of destabilizing water particles, is done via a process called “interparticle bridging”. Furthermore, from previous investigation, it

has been revealed that there is a presence of lipids in the seed extracts, as well as -COOH contained alkaloids, free surface groups included with -OH, as well as carbohydrates, all these which ensure the improvement of the capableness of the coagulation extract. Additionally, the extract of Nirmali seeds' have the ability of an 80% mitigation of kaolin solution turbidity. Although, adequate mechanism of the coagulation which are related to extracts of nirmali seed, are not yet investigated extensively, it is arguably probable to state that a copious amount of -OH groups presence across galactan as well as galactomannan chains, provides adsorption sites that are weak but plentiful, which eventually results to the bridging effect of the coagulant's interparticle as mentioned earlier (Yin, 2010; Vijayaraghavan, et al., 2011).

b. *Moringa oleifera*

M. oleifera is a tropical plant that grows around the regions of Latin America, India, Asia, and sub-Saharan Africa, it is a non-toxic (at low concentrations) whose seeds comprises of water soluble as well as edible oil matter, and is recognized as the most studied coagulant that is plant based, by several researchers. More so, it is referred to as a plant that has multiple usage, with almost all parts of its plant system being useful with maximal benefits. However, it is mostly used as a source of food as well as medicine in developing communities. Further, there are reports existing which states that rural persons from African nations make use of the seed extracts of this plant for purification of turbid river water as far back as the 1980s; thence, numerous scholarly works has been conducted for optimizing its utilization as a low-cost coagulant for the technology of water treatment (Yin, 2010).

In addition, *M. oleifera* seeds contain rich cationic proteins which are stated as designated lower molecular weight cationic proteins represented as MO_{2X} or MOCP. Such Protein-based coagulants are normally extracted from the defatted or raw seeds by aqueous extraction. Hence, coagulant proteins of *M. oleifera* are represented by MO_{2X}

proteins, specifically MO_{2.1} and MO_{2.2}, these are recognized as natural variants of the residues of ~6.5 kDa peptide of 60 amino acid (Saleem & Bachmann, 2019).

c. Tannin

Tannin is a common name, which refers to the obtainable natural materials of the extensive compounds of polyphenol, an instance of which is the organic extract from tree bark and wood, such as *Acacia*, *Castanea*, or *Schinopsis*. More so, the weight of the molecule varies within the range of hundreds to tens of thousands. Invariably, it is used generically as an agent for tanning purposes in the leather industry (Vijayaraghavan, et al., 2011). Furthermore, Tannin application in form of natural coagulant, has been limited due to several conflicting reports of how it affects the health of humans. However, there are some studies which reported tannin can be used to adequately replace chemical coagulants (Yin, 2010). Moreover, tannin's efficiency as a coagulant which is plant based for the coagulation of water, is impacted by the tannin's chemical structural composition, which have been extracted from the tannin modification degree as well as that of the plant (Yin, 2010; Vijayaraghavan, et al., 2011).

d. Cactu

Cacti species were recently used in water treatment compared to other plant-based coagulant, examples of which includes, *M. oleifera* or nirmali. The most frequently studies specie in the cactus family, used in treating water is the *Opuntia*- locally referred to in North America as "prickly pear" or in Mexico as "nopal". This type of cactus has been known for a long time to have properties of medicine in it as well as sources of food (Yin, 2010). Consequently, *Opuntia*'s high coagulation potential is attributed mostly to the existence of mucilage, one of which is a stored carbohydrate with viscous and complex attributes, in the inner as well as outward pads of a cactus, and possesses great capacity to retain water (Vijayaraghavan, et al., 2011).

Miller et al. (2008) referred coagulation capability of *Opuntia* to the galacturonic acid that it contains. They suggest that coagulation mechanism of *Opuntia* is mainly its particles bridging.

e. Peanut

Humans have relied on peanuts or groundnuts as a food crop for centuries; it is one of the cheapest sources of protein as they are mainly consumed as raw nuts, salted nuts, roasted nuts, etc. Peanuts also of the most important oilseeds globally is the peanut, and its surprisingly rising to be a valued plant protein source (Dharsenda et al., 2015). More so, Peanut residual cake (PRC) refers to an obtainable residue from industrial production of peanut oil, which is generated after the process of pressing as well as extracting the peanut kernels solvently. There are several steps in the process, namely: a) Lamination, b) Cooking (at 110 °C), c) Pressing, d) Solvent extraction (hexane), and e) Solvent elimination process (Gayol et al., 2013). This by-product is also known as peanut okara (Dharsenda et al., 2015), which is partially defatted (Yu et al., 2007).

The basic peanut okra flour composition per 100g is moisture 7.8g, carbohydrates 34.70g, fiber 14-16g, lipids (Fats) 0.55-5g, proteins 25-28g and ash 1.4g (Dharsenda et al., 2015). PRC is an inexpensive and underutilized by-product although it has been characterized as rich in protein (Yu et al., 2007; Dharsenda et al., 2015). Furthermore, based on the analysis of their results, Birima et al. (2013) referred the peanut seeds coagulating activity to the protein associations that they contain.

2.4 Sedimentation and Sedimentation Theory

Water particles move in accordance to the attraction of gravity. There is a fluid drag backwardness for this motion as it is dependent on the velocity of the particles. Further, at the initial resting state of the particle, it will undergo acceleration till there is an exact balance between the force used to drag it and the exerted gravitational force.

Afterwards, there is a movement of the particles at constant speed referred to as “terminal velocity” (Gregory, 2005).

Four kinds of particles settle in water namely, (1) discrete particle settling; (2) flocculant settling; (3) impeded settling; and (4) compression settling (Davis, 2019).

2.4.1 Discrete Particle Settling

Particles settle separately at a constant settling velocity during the sedimentation, and their settling is separate and all through the settling process, there is no record of flocculation (Davis, 2019). Davis, 2019 also mentioned that among the majorly common examples of such particles include grit and sand (refers to a mix of abrasive particles, which contains substances such as broken glass, sand, among others); more so, in such cases, the settling of the particle velocity can be calculated using Stokes’s law.

2.4.2 Flocculant Settling

This sedimentation type characterizes the flocculation of particles in the course of sedimentation. Some examples of the occurrence of such particles includes the coagulation of an iron or alum in primary sedimentation wastewaters, as well as in the filter trickling settle tanks. Moreover, it is impossible to apply the equation of Stokes due to the continuous size changes of the particles undergoing flocculation alongside their shape. Moreover, based on the floc water entrapping, variation occurs also with the preciseness of the gravity. The behavior of flocculant settling is commonly studied using laboratory test with settling columns (Davis, 2019).

2.4.3 Hindered Settling and Compression Settling

Water with a high particle concentration (greater than 1000 mg/l) undergoes both hindered settling as well as compression and discrete settling. Hinder settling is observed in the lime-softening process, activated sludge settling, and sludge thickening processes. Due to the high particle concentration, there is less free space between particles.

Therefore, the fluid velocity between particles is greater, so the particle settling velocity is reduced in comparison to the individual particle velocity. Thus, as a result of particles being highly concentrated, there is a tendency of the liquids moving in an upward direction over the space amidst the particles. Thence, adjacent particles usually settle in form of zones. Meanwhile, contact particles try in keeping their relative position similar to the former. The result is that settling particles settle to the top of a clear layer. This phenomenon is defined as hinder settling (Davis, 2019).

Amidst the continuation of settling process, there is a formation of the particle's layers in a compressed manner as thus: a nearness between particles and no definite settling of the particles. Therefore, it is called compression settling (Davis, 2019)

2.5 Application of Peanut Seeds as a Coagulant in Water and Wastewater Treatment

Nand et al. (2012) conducted a study for investigating the potentials of local seeds, which is referred to as "*Moringa oleifera*", peanuts, cowpeas, and corn in removing heavy metals from a raw water in Fiji. The heavy metals removed were cadmium, copper, chromium, lead and zinc. In that study, researchers concluded that the adsorption rate of peanut seeds amounted for 8% of copper, 50% of lead, 60% cadmium, 30% of zinc and 40% chromium from the raw water of Fiji.

Birima et al. (2013) have conducted a study that investigated the extraction ability of a peanut seed coagulant. Thus, the peanut seeds were used after the oil was extracted in the laboratory. More so, the component of the coagulant was extracted via the use of distilled water as a solvent; as well as saltwater. The salts used included potassium chloride (KCl); sodium chloride (NaCl), potassium nitrate (KNO₃), and ammonium chloride (NH₄Cl). For initial turbidity of 200 NTU, peanut seeds that were extracted by NaCl as a solvent were able to remove 92% by utilizing just around 20 mg/l of coagulant; whereas the processing of the peanut seeds by distilled water was able only to reduce just

around 31.5% of exact turbidity of similar dose. Furthermore, other salts aforementioned, have been discovered as good solvents that can help in the extraction of the component of coagulant from the peanut seeds, which entails a consequent improvement of the coagulating activity with literally no significant difference from that of NaCl.

Birima et al. (2015a) reported that NaCl solution was used to extract the coagulant ingredient from peanut cake, whereof the authors carried out a study on the investigation of the extracting temperature effect on the process of coagulating via the use of peanut cake as the major coagulating agent. Three levels of extraction temperature, namely 20, 30, and 40 °C, were investigated, and three different initial turbidities, namely, 50, 100, and 150 NTU were studied. Thus, conclusions revealed that the removal of turbidity was improved with a rise in the extractor's temperature. It was also found that the extracted coagulant was very efficient in removing turbidity from surface water.

Birima et al. (2015b) later carried out another study where the authors investigated the potential of peanut seed as a coagulant regarding the pretreatment of the pam oil mill effluent (POME). Thus, coagulant ingredient was extracted from peanut seeds using NaCl solution as a solvent. Further, three NaCl concentrates of different variations, namely distilled water (without NaCl), 1 mol/L, and 2 mol/L, were tested. Also, the POME COD, its initial turbidity as well as the TSS, tested were 11684 NTU, 22784, and 63955 mg/l, respectively. Consequently, the results revealed that there were improvements regarding the efficiency removal of the tested parameters based on the extracting of the peanut seeds active coagulating component via the use of NaCl. It was found that peanut extract was very effective in use as a coagulating agent to remove COD as well as TSS, with a removal efficiency of 94.7% and 73.5% respectively.

A recent study was conducted by Birima, (2021) to investigate the interaction effect of some operational parameters on turbidity removal using a coagulant extracted from peanut cake. NaCl solution was used as a solvent to extract the coagulant.

The parameters studied included the initial turbidity of the raw water, rapid mixing time, and slow mixing time. The fractional factorial design was employed selecting three levels for each parameter. The levels set for the initial turbidity were 50, 100, and 150 NTU, whereas, those set for rapid mixing time and slow mixing time were 1, 2, and 3 minutes; and 15, 20, and 25 minutes respectively. A one-way ANOVA was conducted to test the individual as well as the interaction effect of these parameters. The researcher found that the removal efficiency was significantly affected by each of the individual parameters. They also found a significant effect of the interaction between the initial turbidity and slow mixing time; and that between rapid mixing time and slow mixing time. However, the interaction between the initial turbidity and the rapid mixing time did not affect the turbidity removal.

2.5.1 Analysis of the relevant researches

The following paragraph presents the critical analysis of the literature review for the research that has been conducted on the application of peanut seeds/cake as a coagulant.

The investigation of peanut seeds/cake as a coagulant is dated back to 2012; when peanut seeds were used to remove some heavy metals. That research (Nand et al. 2012) found that peanut seeds possess the coagulation component, and it was capable of removing some of the heavy metals with the removal percentage varies between low to medium (10 % for the copper to 60 % for the cadmium). Afterward peanut seeds whose oil was extracted were used effectively in removing turbidity (Birima et al. 2013). Turbidity removal was improved by using salted water as a solvent to extract the coagulant component from PRC instead of using distilled water; this led to an improvement in removal efficiency by doubling it almost 3 times (92% for salted water compared to 31.5% for the distilled water). The extracting temperature was found to affect the coagulation via the PRCE, thus turbidity removal was found to be increased by

increasing the extracting temperature (Birima et al. 2015a), however, the studied temperatures were limited to only three levels – 20, 30, and 40 °C. The improvement of the coagulation activity of PRC by using salted water as solvent (NaCl solution) was also confirmed by another study (Birima et al. 2015b) which found that the removal efficiency of COD and TSS from POME was significantly increased by using NaCl solution as solvent. Birima (2021) studied the effect of initial turbidity, rapid mixing time, and slow mixing time on turbidity removal using PRCE, the researcher concluded that there was a significant effect for each of the individual parameters, and also there was a significant effect for the interaction between the initial turbidity and slow mixing time; and the interaction between rapid mixing time and slow mixing time. This recent study although it highlighted an important finding, however, the researcher didn't optimize these parameters.

There is a lack of research about optimizing the coagulant's extracting time, as well as the physical and chemical operation parameters such as rapid mixing time, slow mixing time, and initial pH. In addition to that, a comparison between the performance of PRCE and a standard coagulant such as aluminum sulfate is also needed to be investigated. So, such research could contribute to finding the highest turbidity removal, minimizing the amount of the coagulant used, and reducing the overall cost of the water treatment.

CHAPTER 3: MATERIALS AND METHODS

This chapter presents the materials and methods used for conducting this research. The main laboratory works include preparation of the synthetic turbid water, grinding the PRC into powder, extraction of coagulant component, collection of river water, adjustment of pH, and running the jar test to evaluate the coagulation activity using PRCE. The flow chart of the experimental works is shown in Figure 3.1.

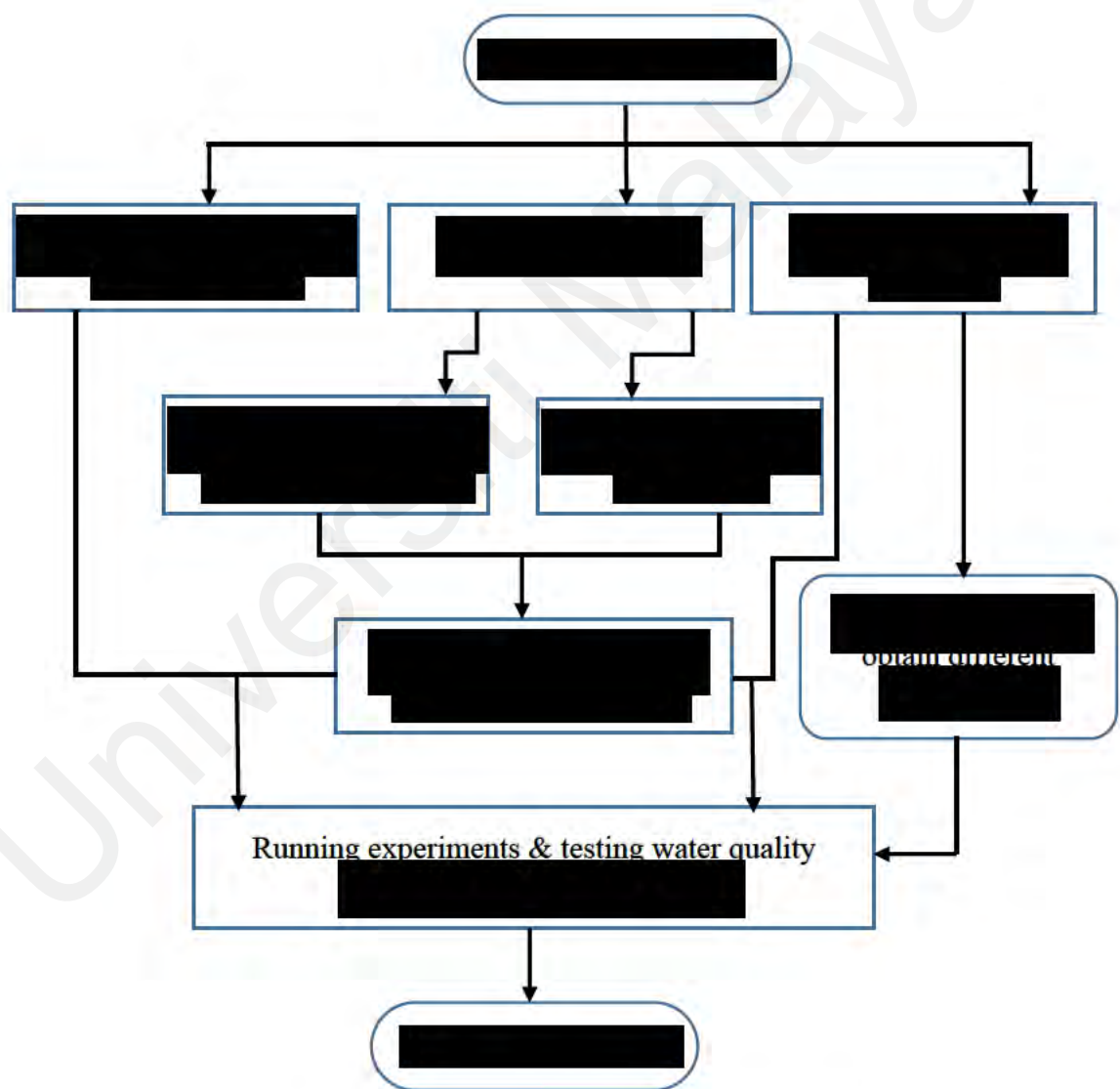


Figure 3.1: Flow chart of the research work

The detailed results of all experiments are shown in appendix A, whereas the statistical analysis and the photos of the experiments' procedures are shown in appendices B and C respectively.

3.1 Preparation of Synthetic Turbid Water

The preparation of the synthetic turbid water used for purpose of coagulation test was done according to some procedures as revealed by some researchers Okuda et al. (2001), Abidin et al. (2013) and Muthuraman et al. (2014) as follows: Ten grams of kaolin were added into liter (1 L) of tap water. Further, stirring of the suspension occurred for about an hour for the purpose of achieving a uniform disperse of the kaolin particles, after which they were kept for about 24 hours to enable the particles complete hydration process, and were then stored in a plastic bottle. This method was utilized as a stock solution in preparing the water samples for various turbidities during the coagulation tests. Thus, this solution ensured the varying of turbidities within the range of 50 NTU up to 500 NTU, which underwent preparation via a series of dilutions. Figure 3.2 shows the stock solution of the turbid synthetic water.



Figure 3.2: Fresh prepared synthetic turbid water

3.2 Preparation of Solutions

3.2.1 Sodium Chloride Solution

Sodium chloride solution was prepared according to Birima et al. (2013). In this method, 3 mol of NaCl (1 mol = 58.443 g) were added into a 1 L volumetric flask, followed by 500 ml distilled water, resulting to a complete dissolving of the salt, after which an addition of more distilled water was put into the flask mark to ensure it completed one liter.

3.2.2 Peanut Cake Stock Solution

Peanut cake was brought in solid form as a by-product of the peanut oil industry. Its stock solution was prepared according to Birima et al. (2015) procedure as follow: Peanut residual cake (PRC) which was produced in solid form (appendix C), was grounded to powder via a domestic food blender (ELBA MODEL: EBM -9182, Malaysia). Further, around 2.5 g of the powder was poured into a high-speed mixer, followed by the addition of a 200 ml NaCl solution, and was blended within the required extraction time, for the purpose of extracting the active ingredient. More so, the filtering of the resulting suspension was done via a normal filter paper (Smith Filter Paper Qualitative High Speed 101, Diameter 90), the filtrate was made up to 500 ml, which was done to give an approximate of 5000 mg/l for the stock solution. Thence, preparation of the stock solution was freshly done for use at appropriate time needed, as shown in Figure 3.3.

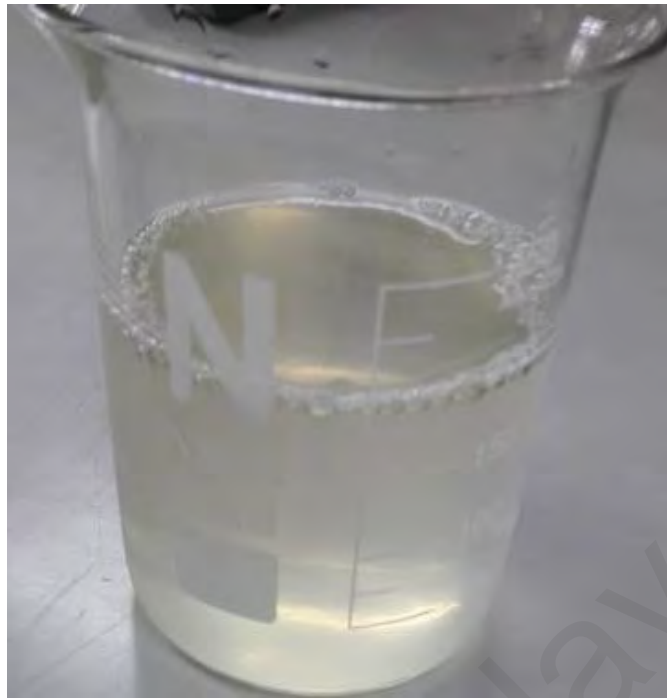


Figure 3.3: Example of the extracted stock solution from PRC

3.2.3 Sodium Hydroxide and Sulfuric Acid Solutions

For the adjustment of the water pH, dilute sodium hydroxide (NaOH) solutions and sulfuric acid solutions were used, with the purpose of studying the effect of the coagulation process initial pH. For preparation of NaOH, 20 g was weighed and dissolved in 500 ml of a volumetric flask in order to prepare 1 N of NaOH, it was left for several minutes to stabilize, then to prepare 0.02 N solution, 20 ml of this solution was poured into a one-liter volumetric flask, of which underwent a dilution up to the distilled water mark (APHA, 2005).

Regarding the preparation of H₂SO₄, 14 ml of concentrated H₂SO₄ was diluted with distilled water in a 500 ml volumetric flask. The solution was left for several minutes to stabilize. Then, 20 ml of this solution was diluted into a 1-Liter volumetric flask to prepare 0.02N H₂SO₄ (APHA, 2005). The solutions of 0.02 NaOH and 0.02 H₂SO₄) were used for pH adjustment.

3.2.4 Aluminum Sulfate Solution

Aluminum sulfate solution was prepared according to Kan et al. (2002) and Al-Husseini et al. (2018) by dissolving 500 mg aluminum sulfate powder in one liter of distilled water. This solution was used as the standard coagulant solution for the purpose of comparing performance of the PRC coagulant. Notably, equivalent of around 0.5 mg/l of aluminum sulfate is resultant to 1 ml of this solution.

3.3 River Water Samples

River water samples were collected from stream Sungai Pantai at the Universiti Malaya, Kuala Lumpur, Malaysia. The location of the sampling point is shown in Figure 3.4 as indicated by the pinpoint and the coordinates. This location was chosen because of some reasons, first, it was easy to access the sampling point within the vicinity of university campus; thus, convenient samples collection when the study required water samples with changes of weather conditions. Turbidity of water samples would be differ during different weather conditions - normal weather, after rain, right after rain, during heavy rain that resulted in a runoff, thus getting high turbidity. Samples were collected using a bucket tied with rope, at about one meter from the edge of the stream and about 30 cm below the surface of the water to avoid the floating dust and other materials.

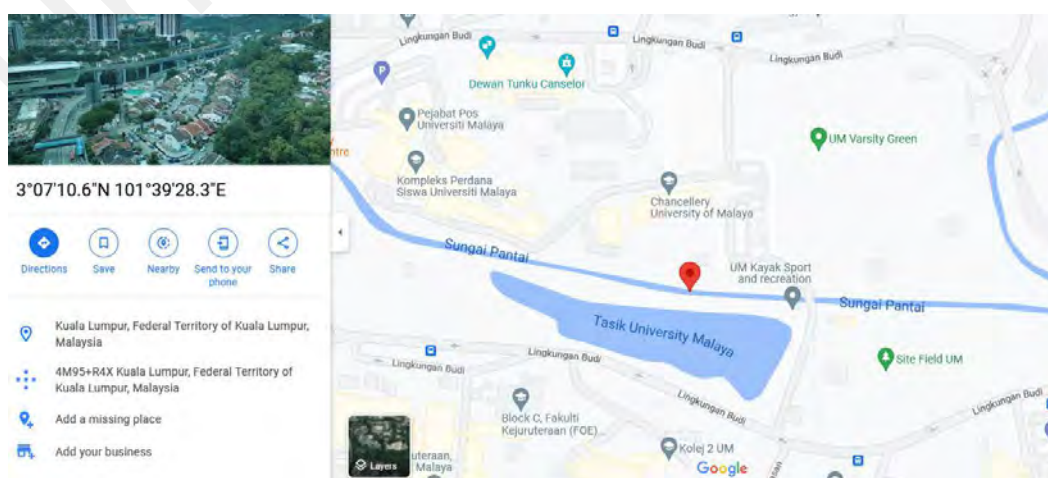


Figure 3.4: Location of the sampling point
(Map was downloaded from Google Map, January 2022)

3.4 Calibration of Jar Tester

Speeds of the stirrers of the Jar Tester were calibrated by using Tachometers (model CT6 OPTICAL/CONTACT HANDHELD TACHOMETERS with led display). This procedure was needed because the existing jar tester was an old model, in which the rotational speed of the stirrers was shown in numbers; therefore, the calibration was conducted so as to ensure determination of the correct speeds in rpm. More so, the speeds were set at 100 rpm as highest speed and 40 rpm as lowest speed.

3.5 Coagulation Test

Jar test was conducted for the purpose of evaluating the coagulating PRCE activity. It consists of six paddles. Five hundred ml of turbid water were added into each 500-ml beaker which were placed on each slot of the jar tester. Moreover, one beaker acted as control (a beaker without coagulant), whereas the remaining five beakers were PRCE fed at various doses.

For the study of optimum extraction time, PRC coagulant was added to each beaker simultaneously and continued agitation for around 1 minute at a speed of 100 rpm. Notably, the speed used in mixing was lowered to around 40 rpm, after which it was kept for a period of 15 minutes (Okuda et al., 2001; Abidin et al., 2013).

Furthermore, in order to study how effective, the rapid mixing time was, an agitation of the apparatus occurred at 100 rpm for the required rapid-mixing time, which varied as 1, 2, 3 and 4 minutes, after which the speed for mixing was lowered to around 40 rpm (Okuda et al., 2001; Abidin et al., 2013) and kept for 15 minutes (slow mixing time). Moreover, the slow mixing time effect was studied via fixing the rapid mixing-time at its optimum value, chosen from the above step, also, the slow mixing time was manipulated between 15 to 30 minutes, using a period of 5- minute intervals. Subsequent to a 1-hour sedimentation period, the water sample was collated from each beaker, using a pipet.

The testing sample was taken from around 1 cm below the water's surface (Birima et al., 2013). The residual turbidity and pH were measured.

The following equation was adapted from literature (Birima et al., 2015). The purpose was to be able to determine the needed stock solution volume that was correspondent to the coagulant desired dose in mg/l.

$$C_1 \times V_1 = C_0 \times V_0 \quad (\text{Eq 3.1})$$

C_1 denotes the stock solution concentration (5000 mg/l)

V_1 denotes the needed stock solution (ml) volume, correspondent to the desired dose.

C_0 denotes each beaker's desired coagulant dose (mg/l).

V_0 denotes the raw water volume for individual beakers (500 ml)

3.6 Analytical Method

Measurement of the turbidity sample was done via a turbidimeter (model HACH, 2100Q); whereas the measurement of the pH was done via a pH meter (model SARTORIUS PB- 10).

Regarding turbidity measurement, for the initial turbidity, the sample was shaken very well to make sure that it was homogenous before it had been inserted into the testing cell. While, for the samples taken from the beakers for the residual turbidity measurement, the water sample was withdrawn from 2 cm below the surface of the water using the pipette. This is to avoid the floating particles, as well the settled ones. Then it was added into the testing tube up to the neck, afterward, the tube was wiped with a piece of cloth and inserted into the testing cell to get the turbidity in NTU. There was no need for selecting the wavelength, as the turbidimeter was automatically adjusted to work in the near-infrared range (NIR 700-1000 nm).

3.7 Statistical Analysis

Two replicates of the coagulation test were conducted to evaluate the PRCE performance on turbidity removal; under the different studied conditions. A one-way analysis of variance (ANOVA) was carried out to determine whether or not there is a statistically significant difference between the means of three or more independent groups, using, the spreadsheet MS Excel 2013. P-Value < 0.05 was used as the criteria for F values. This statistical test was used in comparing variances within the “group means” in a sample, while putting into consideration a single independent variable, i.e., to study the effect of independent variables such as extraction time, slow mixing time, rapid mixing time, and initial pH on the dependent variable which is the turbidity removal.

3.8 Study Limitation

The findings of this study have to be seen in light of some limitations. First, the jar test apparatus used in this study was an old model.

Second, effect of the parameters used (chemical and physical), namely, rapid mixing time, slow mixing time, different initial pH, and turbidity, is studied individually, i.e. the interaction effect between these parameters is not studied.

Third, the conditions whereby the experiments were conducted, such as the ambient temperature, were not controlled. In addition to that, the synthetic water which was used for the experiments was not prepared once at a time. This could make the homogeneity of the water sample not 100% same, so, the effect of these two factors could make small variation in the results.

Fourth, the variation of the raw water initial turbidity was dependent on the time of sampling - normal weather, after rain, right after rain, and during rain.

CHAPTER 4: RESULTS AND DISCUSSION

Literature on using PRCE as coagulant reveals that there is a lack of research about optimizing the coagulant's extracting time, as well as the physical and chemical operation parameters such as rapid mixing time, slow mixing time, and initial pH. In addition to that, a comparison between the performance of PRCE and a standard coagulant such as aluminum sulfate is also not investigated. Thus, such research could contribute to finding the highest turbidity removal, minimizing the amount of the coagulant used, and reducing the overall cost of the water treatment. Therefore, this chapter presents and discusses the results of the aforementioned parameters.

4.1 PRCE Coagulant Extraction Time

The minimal coagulant extraction time was studied using the residual turbidity results obtained at different extraction durations. It was observed that the optimum dosage (which was determined by the jar test as the dosage that achieves the minimum residual turbidity) for all experiments conducted at different extraction times was found to be 20 mg/l, as shown in Figure 4.1.

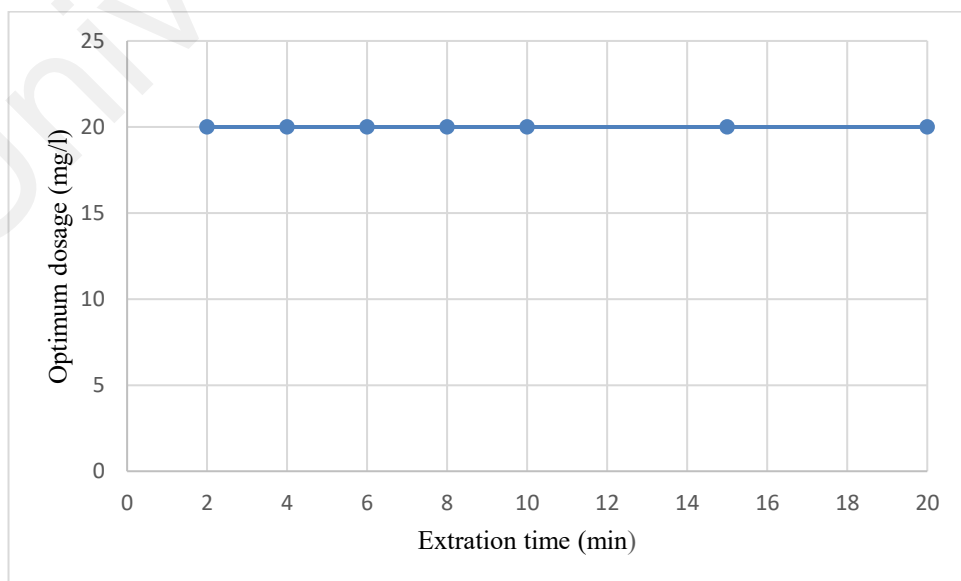


Figure 4.1: Optimum dosage for different extraction time with initial turbidity equal to 200 NTU

This dosage was selected on the basis of the jar test, which was carried out for each experiment at different extraction time. Thus, this result is in agreement with that of a past study carried out by Birima et al. (2013). In that study, it was found that the initial turbidity's optimal dose of around 200 NTU resulted to 20 mg/l.

Range of extraction time in this study was set between 2 to 20 minutes with an increment of 2 minutes. Increment of 5 minutes was used after the tenth minute's duration. Each data point in Figure 4.2 represents the result of the extraction time at the optimum dosage. Initial turbidity for each duration was kept at 196 to 200 NTU. Figure 4.2 shows

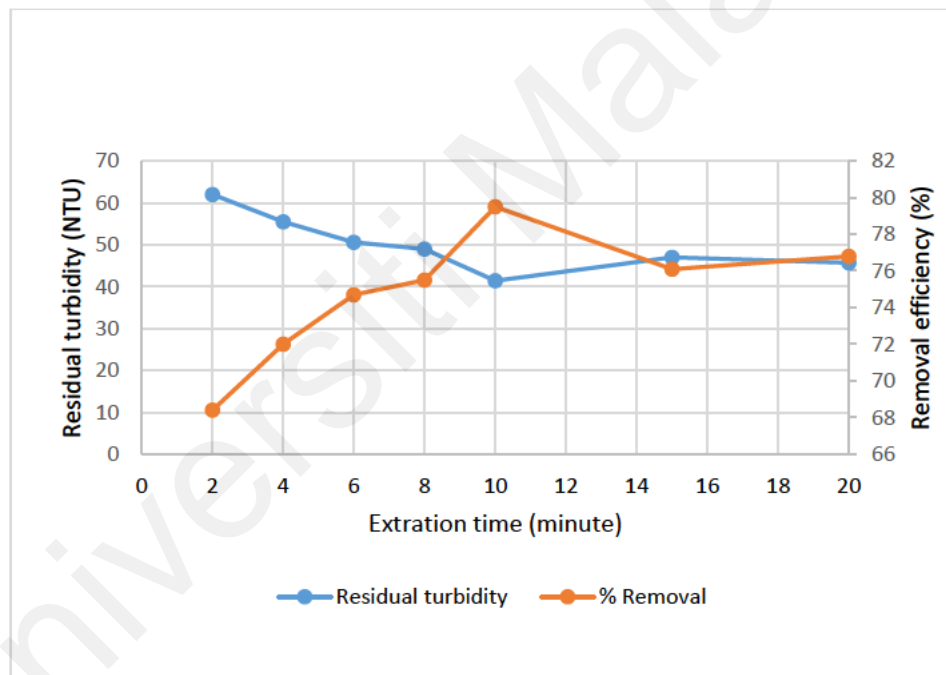


Figure 4.2: Residual turbidity and percentage of removal for different extraction time

that a decrease in the residual turbidity over an increase in the extraction time up to 10 minutes, afterwards it increases gradually with increasing the extraction time. This indicates that within the limitation of the extraction time, the optimum duration is at 10 minutes, when the residual turbidity dropped to 41.4 NTU with the corresponding percentage removal of 79.5%.

A one-way ANOVA showed that the extraction time had a significant effect on the removal of turbidity, $F(1, 12) = 564.59$, $p = 0.000$.

4.2 Effect of Operational Variables on the Coagulation with PRCE

This section discusses the effect of the physical and chemical variables, namely, rapid mixing-time, slow mixing-time and pH; on the turbid water coagulation, via the use of a PRCE coagulant.

4.2.1 Rapid Mixing Time

In Figure 4.3, there is an indication of the residual turbidity versus coagulant dosage of diverse rapid mixing times, namely 1, 2, 3, and 4 minutes.

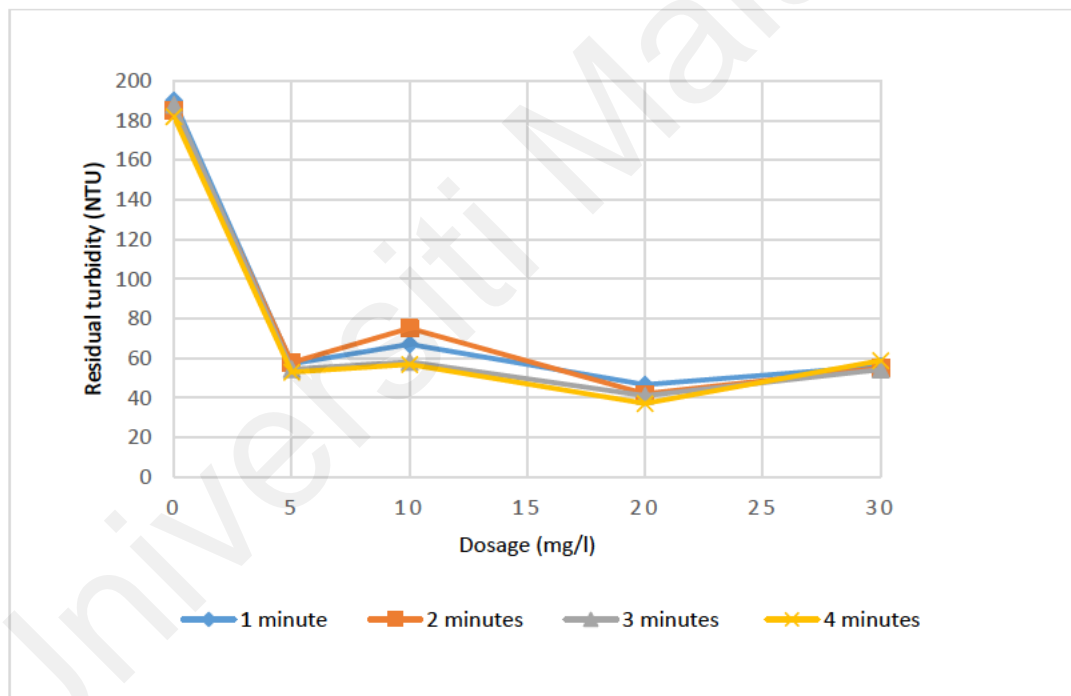


Figure 4.3: Residual turbidity versus coagulant's dosage at different rapid mixing time

The initial turbidity for all experiments was kept at 200 ± 2 NTU. It is observed that the residual turbidity dropped dramatically when the coagulant was added, then it increased slightly at the dosage of 10 mg/l before it decreased gradually by increasing the coagulant's dosage until it reached the lowest value at optimum dosage of 20 mg/l.

Afterward, it increased again by increasing the coagulant's dosage. The respective residual turbidity obtained at the optimum dosage for 1, 2, 3, and 4 minutes was found to be 46.6, 42, 41, and 37.6. These results indicate that changing the rapid mixing time within the studied range did not affect the optimum dosage. However, the removal efficiency was slightly increased by a rise in the rapid mixing time. Based on this result, it could be said that the shortest rapid mixing time required for turbidity removal is one minute; since the difference in turbidity removal between one and four minutes was not large. From the work of Kan et al. (2002), the researchers carried out investigation on rapid mixing time effect on the removal of particles via the use of poly aluminum chloride (PACL), the scholars inferred that the removal of turbidity witnessed a gradual rise alongside the increase in the rapid mixing time from 0 to 5 minutes. They also reported that the characteristic of the formed micro flocs contributed to the variation of residual turbidity reading.

Furthermore, BinAhmed et al. (2015) studied the rapid mixing time effect on the process of flocculating. They reported that rapid mixing time does not affect the rate of floc growth; however, the formation of flocs is affected by it in terms of size and strength. Thus, for the short rapid mixing time, a larger size floc was formed. Another study confirmed this finding carried out by Yukselen & Gregory (2004), they found that extended rapid mixing time resulted to more limitations in the floc growth; they referred this to the formation of the small as well as compact aggregates in the course of the rapid mixing, which resulted to smaller flocs. The study concluded that within short periods of rapid mixing, there are lesser chances of more open and compact aggregates, thus instigating the growth of large flocs. Based on these findings, it can be suggested that for the present study, the rapid mixing time effect on removal of turbidity is as a result of the formed flocs features; also noting that, the slight improvement in turbidity removal might be attributable to forming additional compacted dense flocs that led to better settling.

A one-way ANOVA revealed that there was a statistically significant effect of rapid mixing time on the removal of turbidity, $F(1, 6) = 362.9$, $p = 0.000$.

4.2.2 Slow Mixing Time

In Figure 4.4, the variation of the residual turbidity alongside the coagulating dosage for different slow mixing times, specifically, 15, 20, 25, and 30 minutes, is illustrated.

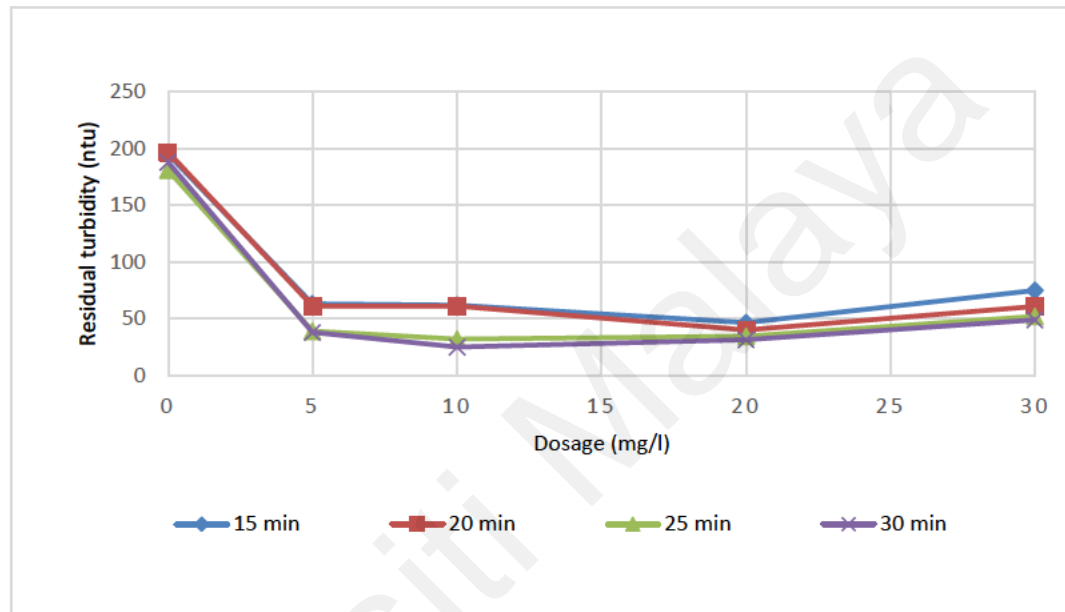


Figure 4.4: Residual turbidity versus coagulant dosage for different slow mixing time

The initial turbidity was kept at 205 NTU. As can be seen from Figure 4.4, for the four lines, the residual turbidity decreases slightly at the control beaker (zero dosage). However, it decreases sharply around the 5 mg/l dosage, where it keeps decreasing slowly until the optimum dosage of 20 mg/l after which, there is a rise in the residual turbidity again. The residual turbidity for the slow mixing times of 15, 20, 25 and 30 minutes was 46.5, 40.0, 32.0 and 25 NTU respectively. Figure 4.4 also shows that the optimum dosages (the dosage which achieved minimum residual turbidity) for the slow mixing time of 15 and 20 minutes were 20 mg/l, whereas, for 25 and 30 minutes they were 10 mg/l. This result indicates that increasing the slow mixing time does not only increase the removal efficiency, but it also reduces the required optimum dosage.

Thus, the aforementioned might be attributable to the formation of more compacted and dense flocs during the long slow mixing time, other than that it may also be due to the ability of PRCE to recover the breaking flocs rapidly. The optimum slow mixing time within the limits of this study was found to be 30 minutes, with the removal efficiency of 88.1%.

A one-way ANOVA showed slow mixing time had a significant effect on the removal of turbidity, $F(1,6) = 42$, $p = 0.001$.

Zhang et al. (2013) carried out a study on the slow mixing time effect as regards the process of coagulation at different operating conditions. The research was focused on finding the slow mixing time effect on both flocculation of sweep as well as coagulation of neutralization via the use of polyaluminum chloride (PACl) and mixing time ranges from 1 to 60 minutes. It was concluded that there was a decrease in residual turbidity over an increase in the slow mixing duration from 15 to 40 minutes; however, the optimal slow mixing duration was also affected by the mixing intensity. For instance, the optimal mixing duration was found to be 15 min at $G = 15 \text{ s}^{-1}$, however, it was 30 min at $G = 4 \text{ s}^{-1}$.

4.2.3 Initial pH

Figure 4.5 shows the residual turbidity and the corresponding removal efficiency versus the initial pH of the raw water; which, varies between pH 5 to pH 9. It is noticed that the turbidity removal efficiency between pH 5 and pH 8 was slightly decreased from 98.5 to 96.3%, however, at pH 9, the removal efficiency dropped to 72.4%. Abidin et al. (2013) carried out an investigation on coagulating pH effect, whereby, a natural coagulant extracted from *Jatropha curcas* seeds was used for turbidity removal. In that study, for the pH varied from 1 to 12, the highest removal of turbidity was found to occur at pH 3, afterward, it decreased slightly up to pH 8, followed by sharper decreasing from pH 9 to

12. In contrast, Cao et al. (2010) carried out an investigation on the effect of pH on the coagulation process. They concluded that turbidity removal increased with a rise in pH from 4 to 5.5, which later decreased from pH 6 to 9. The conflict between this result, the

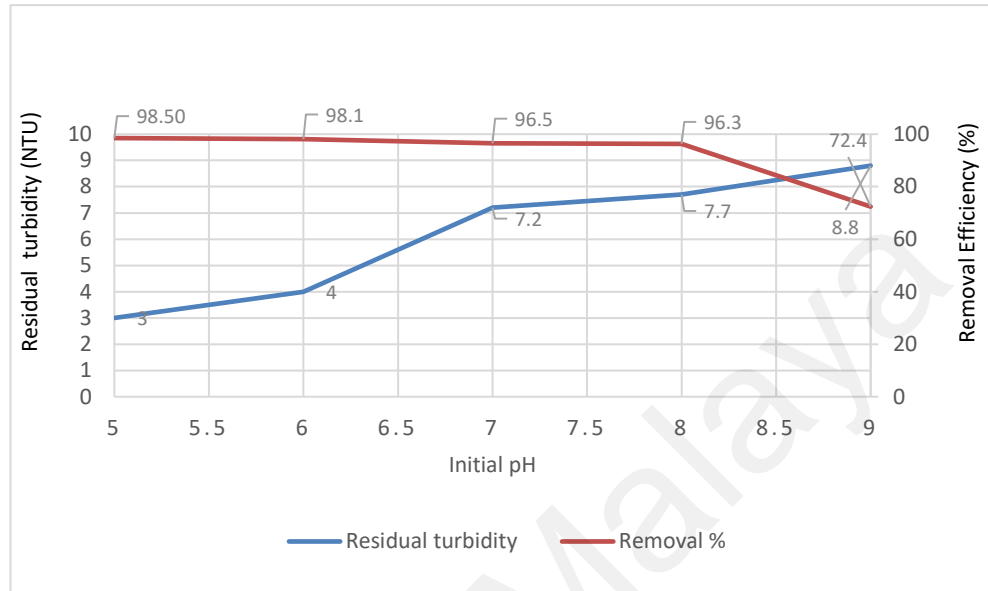


Figure 4.5: Variation of residual turbidity and percentage of removal versus the initial pH

one mentioned above, and the current result, might be due to the type of coagulants used. This is so since the current study and Abidin et al. (2013) used natural coagulants, while Cao et al. (2010) used synthetic ones. These findings concluded to the fact that the optimum pH for coagulation is dependent on the kind of coagulant used.

Hu et al. (2017) investigated the effect of the initial pH on the flocs size and flocs growth. Researchers concluded that, higher pH led to a larger size in flocs, but a slower growing rate; this result could interpret the drop of turbidity removal at pH 9 (Figure 4.5), because there are two factors affecting the process – flocs size and flocs growth rate, however, in this case, growth rate could be the dominant factor. i.e., at pH 9, the rate of flocs growth is slow, and this might lead to slow flocs settling.

4.3 Validation the Effectiveness of the PRCE and Aluminum Sulfate as the Coagulants using Kaolin Synthetic and River Water

This section discusses the effectiveness of the PRCE in coagulation for both synthetic and river water with varying initial values of turbidity in the range of 50 to 500 NTU. It also compares PRCE and aluminum sulfate as coagulants.

4.3.1 Effect of Various Initial Turbidity

In Figure 4.6, the residual turbidity variation is presented versus coagulant dosages for water treated by PRCE.

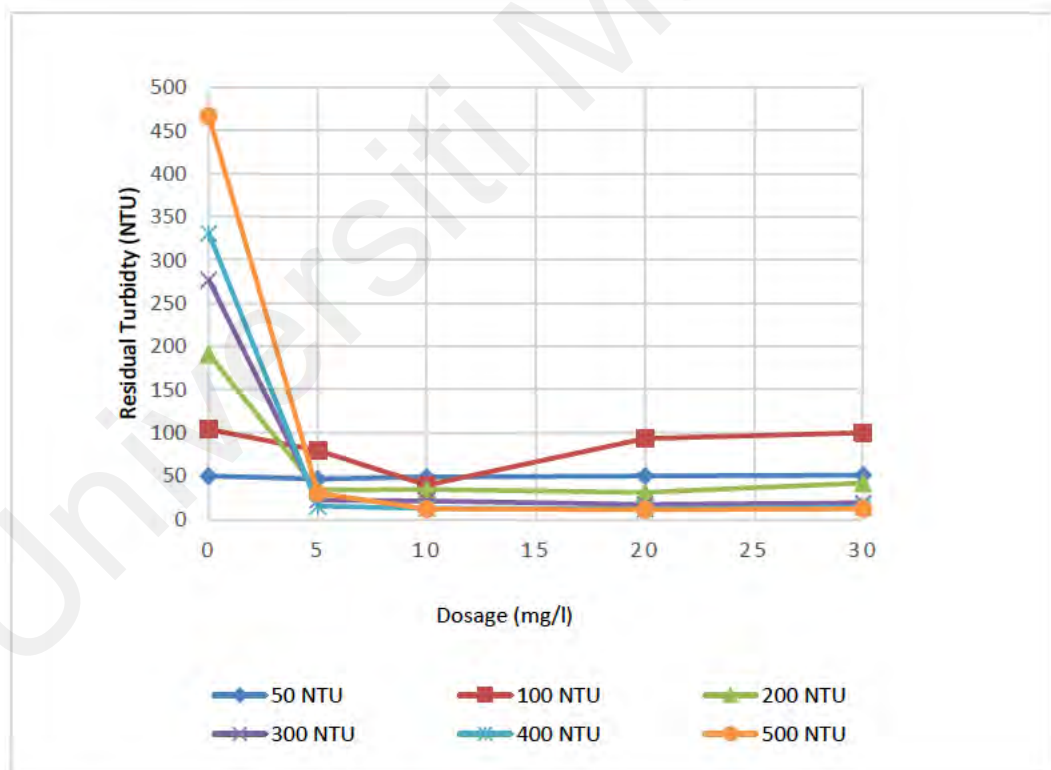


Figure 4.6: Variation of residual turbidity versus coagulant dosage for various levels of initial turbidity

From observation, the optimum dosage of the PRCE for 50 and 100 NTU are 5 mg/l and 10 mg/l respectively; whereas, a 20 mg/l optimum dosage was observed for the initial turbidities of 200 to 500 NTU. More so, the percentage removal for the turbidity initially ranged from 64.2% to 97.8%. Also, noticeably, there was a rise in the removal efficiency with an increase in the the initial turbidity. These results are comparable to the previous study carried out by Birima et al. (2013) whereby, for synthetic water with an initial turbidity of 200 NTU, the removal efficiency of a coagulant extracted from peanut seeds was found to be 92%. These researchers informed that the removal of the turbidity was significantly improved via the use of the NaCl solution serving as a solvent rather than using distilled water, since the removal efficiency of the former attained around 4.4 times more effective as compare to the latter. Regarding the low removal efficiency at an initial turbidity 50 NTU, generally natural coagulants were found to be ineffective in removing low turbid water. This fact was reported by Asrafuzzaman et al. (2011), who used three natural coagulants, specifically, *Moringa oleifer*, *Cicer arietinum* and *Dolichos lablab*, for the removal of turbidity from the water which was prepared in three diverse turbidity ranges, including high (90 – 120) NTU, medium (40 – 50) NTU and low (25 – 35) NTU. It was found that three of the coagulants worked much better in high turbidly compare with low and medium ones. The reason of this phenomenon was interpreted by Gaikwad and Munavalli (2019) who referred it to the mechanism of coagulation by *Moringa oleifer*, which is predominately an adsorption between the active component of coagulation in *Moringa oleifer*, alongside suspension particles that gives room to the bridging of inter particles. Therefore, for high turbidity, the suspended particles as well as the colloidal concentration is more than the low turbidity; a situation which provides adequate particles to ensure the charged sites are bridged with the coagulant.

4.3.2 Coagulation of River Water with Varied Initial Turbidity Levels

Figure 4.7 shows the residual turbidity versus PRCE dosages for river raw water collected from Sungai Pantai.

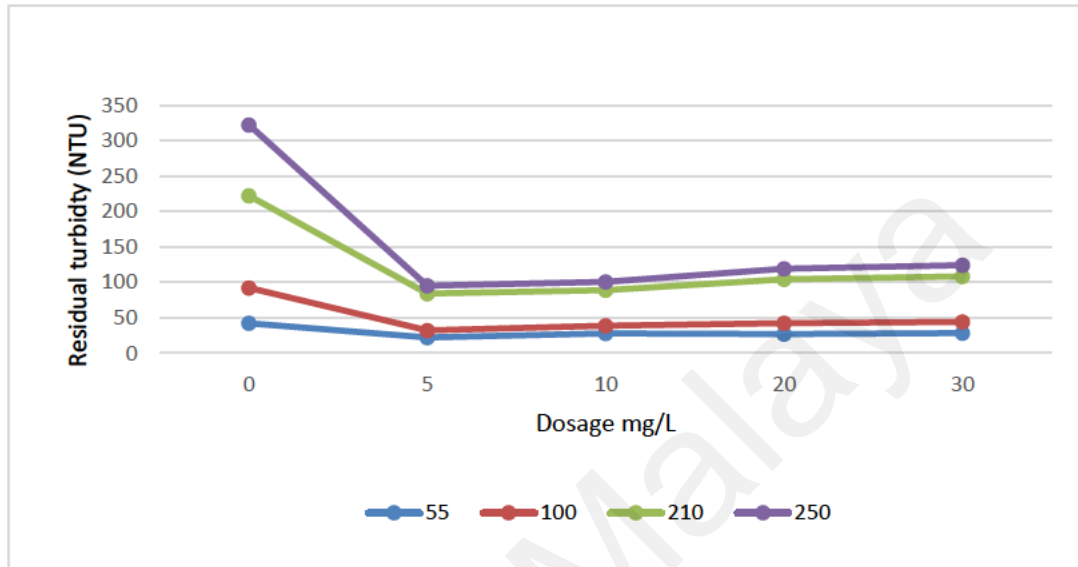


Figure 4.7: Residual turbidity versus coagulant dosage for river water

In general, the initial turbidity of raw water was 55, 100, 210, and 250 NTU. This variation of the initial turbidity was obtained by collecting the water samples at different weather conditions (normal weather, after rain, right after rain, and during rain). Results show that residual turbidity and the consequent percentage of removal are 22 NTU (60%), 50 NTU (76.2%), 10 NTU (90%), 11 NTU (95.6%) respectively. The respective optimum dosages are 5 mg/l and 10 mg/l. Conclusively, the results reveals that PRCE works effectively as a coagulant with the river water. Moreover, its performance is better in high turbid waters rather than low turbid ones.

Pritchard et al. (2010) compared the performance of *Moringa oleifera* in turbidity removal for low turbid natural and a 45 NTU turbidity synthetic water. It was found that *Moringa oleifera* worked better in natural water than in synthetic one.

Similarly, in the present study for low turbidity of 50 NTU, PRCE gave better removal in raw water than in synthetic water.

4.3.3 Comparative Efficiency for Validation of the PRCE and Aluminum Sulfate

This section discusses the performance of the PRCE and aluminum sulfate as coagulants. The comparison has been performed based on the turbidity removal and optimum dosage of each coagulant, to compare the effectiveness as well as the amount of coagulant required for both coagulants. Figure 4.8 shows the percentage of removal versus coagulants dosages for PRCE and aluminum sulfate for the initial turbidity of 200 NTU.

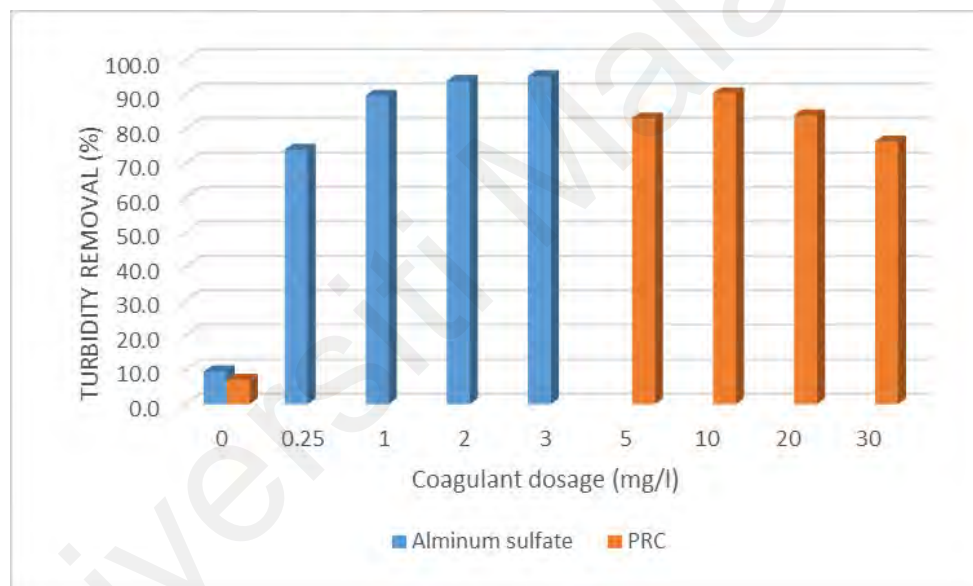


Figure 4.8: Percentage of turbidity removal versus coagulant dosage for PRCE and aluminum sulfate in mg/l

It is observed that, at zero concentration of the substrate, natural sedimentation took place. This could be attributable to the settlement of suspended solids in the water sample that contribute to the turbidity. Also at zero substrate, theoretically both experiments (with alum and with PRCE) should give same result. However, practically there was small difference in results (removal for alum experiment was 9% and that for PRCE experiment was 7.5%). This difference is very small and it is common to occur in laboratory tests.

Because sometimes this variation occurs even between the replicates of the same sample. The removal efficiency of alum and that of PRCE at the optimum dosage are 95.2, and 90.2 % and the corresponding optimum dosages are 3 and 10 mg/l. This indicates that the aluminum sulfate is more effective concerning coagulant dosage, as well as in turbidity removal. The cost of the two coagulants is shown in Table 4.1.

Table 4.1: Comparison between the average cost of alum and that of peanut residual cake (PRC)*

Alum Cost per metric ton (US\$)	PRC	
	Alum Cost per Kg (US\$)	PRC Cost per Kg (US\$)
210	0.21	4.5
		0.09

*The cost of alum is taken from Ali Baba online shopping, while the cost of PRC is taken from Sudan news, 2020. The data was obtained in August, 2020.

**One bag = 50 Kg and it cost 630 Sudanese pound

It is clear that the price of PRC is almost less than the half price of aluminum sulfate. Furthermore, the difference in turbidity removal between the two coagulants was only 5%; and generally, in water treatment, the filtration process follows the sedimentation process to remove the remaining turbidity up to the drinking water standards level (Davis, 2011). Therefore, in this regard, 90.2% removal after sedimentation could be adequate. Other than that, PRC is a natural coagulant, and therefore, unlike alum, it cannot cause a health problem (Toomer, 2020).

Considering the merits of PRC mentioned above, with some more future research on its application in water treatment; PRC could be introduced as a coagulant, to replace or to supplement aluminum sulfate.

4.3.3.1 Effect of PRCE and aluminum sulfate on the pH of the water

The pH of the synthetic turbid water used for this study varied between 7.8 to 7.4, of which lies in the endorsed pH range 6.5–8.5 (Taiwo et al., 2020). Even though pH of drinking water is not directly harmful to the human health, it can however, indirectly affect the suitability of ion as well as the existence of pathogens. Moreover, alkaline and acid water can cause bitter taste water and corrosive water respectively (Radfard et al., 2018).

Consequently, from Figure 4.9, the residual pH of the synthetic turbid water used in the study versus the PRCE coagulant dosage in mg/l is presented.

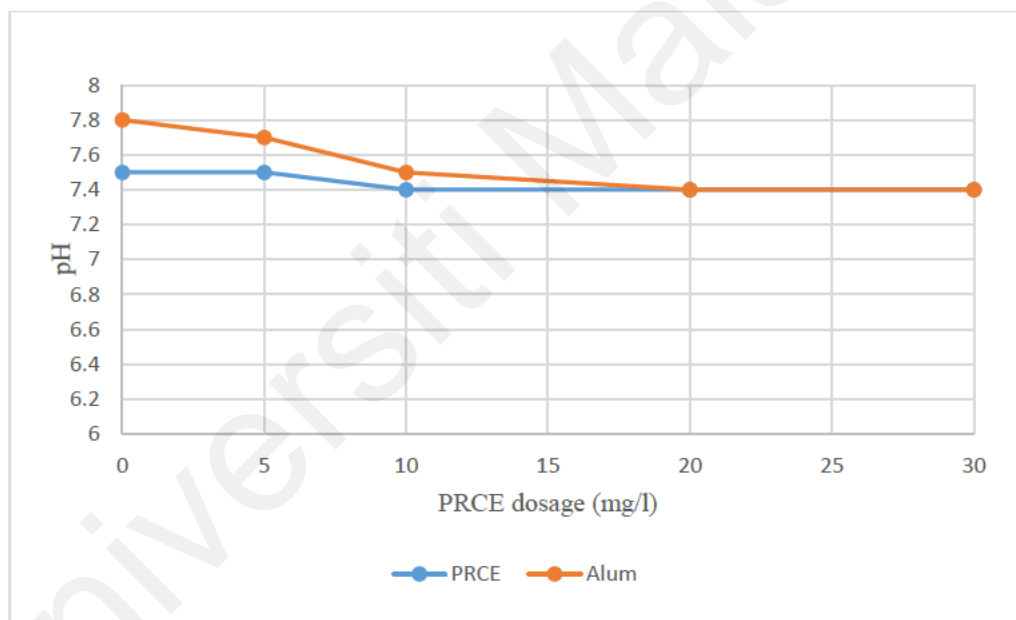


Figure 4.9: Effect of PRCE and aluminum sulfate on pH of the water

The result represents two experiments carried out using PRCE and aluminum sulfate (alum) as coagulants to remove synthetic turbid water turbidity with an initial turbidity of 210 NTU. Furthermore, it is observed that the water pH had no notable reduction as a result of the dosage increase (up to 30 mg/l) for both PRCE and alum, as the pH for the first experiment dropped from 7.5 to 7.4 and for the second one it dropped from 7.8 to

7.4. This finding conflicts with studies carried out by Taiwo et al. (2020) and Gandiwa et al. (2020), using plant-based coagulant, specifically *Moringa oleifera* and *Cactus opuntia*, compared with aluminum sulfate. They concluded that for *Moringa oleifera* and *Cactus opuntia*, there was no remarkable reduction in pH of water resulted from increasing coagulant dosage, in contrast, aluminum sulfate showed remarkable decrease in pH.

The current finding is in agreement with the first part, since PRCE is a plant-based coagulant, it is found to not decrease the pH of water, similar to *Moringa oleifera* and *Cactus Opuntia*, however, for the alum, the current result showed remarkable reduction in pH, while the two mentioned studies showed remarkable reduction in the pH. The reason of this is basically the difference in alum dose between the three studies, thus in Gandiwa et al. (2020) and Taiwo et al. (2020) studies, the maximum dose of the coagulant was 60 and 80 mg/l, respectively, whereas, in the present study the maximum dose was 30 mg/l. In both studies, the notable drop of pH was observed after 40 mg/l alum dose. The present finding is one of the PRCE strength as coagulant for water treatment.

A general comparison between PRCE and alum, based on the aims and objectives of this study is shown in Table 4.2.

Table 4.2: Comparison between PRCE and Alum

Type of coagulant	Natural	Synthetic
Dosage (mg/l) for an initial turbidity of 200 NTU.	10	3
% Of turbidity removal for an initial turbidity of 200 NTU.	90.2 %	95.2 %
Effect of the coagulant on the pH of the treated water.	At a 30 mg/l dosage, the drop in pH was not notable (from 7.5 to 7.4).	At a 30 mg/l dosage, pH dropped from 7.8 to 7.4, however, higher dosage (greater than 40 mg/l) the drop in pH was notable.
Cost (US\$/Kg)	0.09	0.21

The summary of the findings with respect to the objectives and their corresponding methodology is shown in Table 4.3.

Table 4.3: Research objectives and their corresponding methods and findings

S. No.	Objective	Methodology	Finding
1	To obtain the effective time of extracting the coagulant from PRC.	PRCE was extracted at different time via varying the blending time (section 3.2.2). Then was used in the coagulation test and the turbidity removal was evaluated.	Optimum extraction time was 10 minutes.
2	To optimize the physical and chemical operation variables during coagulation, by examining the effects of rapid mixing time, slow mixing time, and initial pH. In addition to validating the effectiveness of PRCE as a coagulant under various turbidities	<p>The coagulation test (jar test) with fixed rapid mixing speed, slow mixing speed, and settling time was conducted as in section (3.5).</p> <p>For optimizing rapid mixing time, slow mixing time was fixed, while rapid mixing time was varied as 1, 2, 3, and 4 minutes.</p> <p>For optimizing slow mixing time, rapid mixing time was fixed at its optimum value, and the slow mixing time was manipulated between 15 to 30 minutes, using a period of 5- minute intervals.</p> <p>For studying the effect of initial pH, dilute sodium hydroxide (NaOH) solutions and sulfuric acid solutions were used to adjust the pH as in section 3.2.3, to obtain pH varied from 5 to 9 with increment of 1 interval. Then jar test was conducted for each initial pH.</p> <p>For validating the effectiveness of PRCE under various turbidities, Initial turbidity was diluted for 50 NTU and from 100 to 500 NTU with interval of 100 NTU (section 3.1).</p>	<p>Coagulation was found to be significantly affected both by rapid mixing time as well as slow mixing time.</p> <p>Optimum rapid mixing time was 1 min, while slow mixing time was 30 minutes.</p> <p>PRCE was very effective in the range of 5 – 8 raw water pH (initial pH).</p> <p>PRCE was very effective (high turbidity removal) for turbidity range between 100 – 500 NTU, however, for initial turbidity of 50 NTU, the removal efficiency was low both synthetic and river water.</p>
3	To compare the performance of PRCE coagulant to that of aluminum sulfate, the standard coagulant.	A jar test was conducted using the optimum rapid mixing time and slow mixing time with an initial turbidity of 200 NTU; to compare between the PRCE and alum.	The removal efficiency of alum and that of PRCE were 95.2, 90.2 %, and the corresponding optimum dosages resulted to 3 and 10 mg/l, respectively

CHAPTER 5: CONCLUSIONS AND SUGGESTIONS FOR FUTURE STUDY

5.1 Conclusions

Within the limitations of the present study, the following conclusions are drawn:

1. The application of peanut seeds/cake as a coagulant is dated back to 2012, however, there is a lack of research about optimizing the coagulant's extracting time, the physical and chemical operation parameters such as rapid mixing time, slow mixing time, and initial pH. In addition to that, a comparison between the performance of PRCE and a standard coagulant such as aluminum sulfate was also not investigated. Optimization of these parameters is important, as it reduces the cost of the coagulation process by reducing the energy consumption, reduces the time of the coagulation process, and reduces the amount of the required coagulant. Therefore, reduces the overall cost of water treatment.
2. The time for extracting the coagulation component from PRC was investigated within a range of 2 to 20 minutes, and the optimum time was found to be at 10 minutes.
3. Concerning the physical and chemical operation variables, coagulation was found to be significantly affected both by rapid mixing time as well as slow mixing time at $p < 0.05$ level ($F = 362.8$, $p = .000$ for rapid mixing time and $F = 42$, $p = .000$ for slow mixing time). The respective optimum rapid mixing time and slow mixing time were found to be 2 and 30 minutes. Meanwhile, for the initial pH adjustment, PRCE was found to be very effective in turbidity removal at a range of pH 5 to 8.
4. PRCE was found to be an effective coagulant for a varied range of initial turbidity, for both synthetic turbid and river water. In this regard, for river water with initial turbidity levels between 100 to 250 NTU, the corresponding removal efficiency

was found to be 76.2 to 95.6%; whereas, for synthetic water with initial turbidity between 100 to 300 NTU, the corresponding removal efficiency was found to be 64.2 to 94.3%. In addition, turbidity removal for 400 and 500 NTU, was 97 and 97.8 % respectively. Turbidity removal at a low level (50 NTU) was low for both synthetic and river water.

5. Comparing PRCE with alum, the removal efficiency of alum and that of PRCE towards an initial turbidity of 200 NTU were 95.2, 90.2 %, and the corresponding optimum dosages resulted to 3 and 10 mg/l, respectively.
6. Using of PRCE as a coagulant for water treatment economically shows promising results for the countries, which have an abundance of available source; for example, China, India, Nigeria and Sudan who lead the world in peanut production. Besides that, a coagulant is too safe to be used considering the long-term health effect as many had claimed upon the use of it. In addition to these, PRCE was found to be not affecting the pH of water.

5.2 Suggestions for future study

This feasibility study showed that PRCE has a high potential in removing turbidity from water at a varied range of turbidity. It also, showed that the studied coagulant is cost-effective and comparable with the standard coagulant (alum). Additionally, the operational variables are optimized. However, to introduce it with complete information, the following suggestions are offered:

1. Short- and long-term effects of the residual PRCE on treated water need to be examined.
2. Research is needed on the length of time the prepared coagulant can last.
3. Additionally, the proper method of storing the coagulant needs to be investigated.

4. A study on the characteristics of flocs and the rate of growth formation with respect slow mixing time needs to be investigated.

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