MORINGA OLEIFERA SEED AS COAGULANT AND COAGULANT AID IN WATER TREATMENT

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ABSTRACT

The study investigated the use of *Moringa oleifera* seed as coagulant and coagulant aid in water treatment. *Moring oleifera* seed showed effectiveness as coagulant aid with alum in the clarification of turbid water. An amount of 60 % of alum can be saved when *Moringa oleifera* seed is used as coagulant aid for the Kerian river water (turbidity 15 – 90 NTU). Optimum dosage for combination of alum and *Moringa oleifera* seed extract was 10 mg/l and 8 mg/l, respectively. Highest turbidity removal was obtained at the pH of 7. Combination of aluminium sulphate and *Moringa oleifera* seed gave a much better and more consistent clarification.

ABSTRAK

Kajian ini telah dijalankan ke atas sejenis tumbuhan yakni *Moringa olefera* mengenai kegunaan bijiannya sebagai pengental dan agen pengelompokan dalam proses rawatan air. Bijian *Moringa oleifera* telah menunjukkan keberkesanannya sebagai agen pengelompokan bersama dengan aluminium sulfat dalam pengurangan kekeruhan air sungai. Sebanyak 60 % aluminium sulfat dapat dijimatkan dengan penggunaan bijian *Moringa oleifera* sebagai agen pengelompokan bagi pembersihan air Sungai Kerian yang mempunyai kekeruhan antara 15 NTU ke 90 NTU. Optimum dos yang dicapai oleh gabungan alum and bijian Moringa oleifera masing-masing ialah sebanyak 10 mg/l dan 8 mg/l. Selain itu, pengurangan kekeruhan air mencapai tahap yang tertinggi pada pH 7. Natijahnya, penggabungan aluminium sulfat dan bijian Moringa oleifera berupaya menjadikan proses pengolahan air lebih berkesan serta konsisten.

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CHAPTER 1

INTRODUCTION

1.1 General

Malaysia is rich in water resources. Mean annual precipitation is about 2,985 mm/year and the average annual run-off of whole country is 566 billion mm^3 / year. There are approximately 150 river systems and a total length of over 38,000 kilometer. Recently, the water supply for the country has changed from one of relative abundance to one of scarcity. Population growth and urbanization, industrialization and the expansion of irrigated agriculture are imposing rapidly increasing demands and pressure on water resources. Besides, these also contribute to the rising of water pollution which causes the process of water purification to become more complicated. The water resources mostly come from the surface runoff which consists of 566 billion m^3. Streams and rivers with or without impounding reservoirs contribute 98% of the total water resources (Ti and Facon, 2001).

There are quite a number of water treatment plants in this country practicing the conventional method to treat water by using large quantity of chemicals. Aluminium sulphate (alum) is one of the most popular chemicals used in water treatment due to its effectiveness. Some other chemicals are lime, soda ash, polymers and chlorine. Even though the quality of the water that been treated is safe to be consumed, alternative ways need to be developed to reduce the cost and other disadvantages caused by the chemicals. As for that, local available materials (natural coagulants) need to be identified and tested as alternatives to the chemicals.

The present study was undertaken to assess the effectiveness of *Moringa oleifera* seed extract, a natural polyelectrolyte, as coagulant and coagulant aid in water treatment.

1.2 Importance of the Study

The first and foremost importance of this study would be to ascertain the efficiency of *Moringa oleifera* seed extract as coagulant and coagulant aid in water treatment. By using the locally available material, the water treatment cost is expected to be lower, thus be an alternative to the existing chemical coagulants. Consequently, it will create a more economical method for water clarification. The comparison between *Moringa oleifera* seed and aluminium sulphate as primary coagulant is essential in determining the effectiveness of the *Moringa oleifera* seed in treating river water with different turbidity. Other than that, application of *Moringa oleifera* seed as coagulant aid with aluminium sulphate as primary coagulant definitely will give an idea in reducing the amount of alum by just adding a little bit *Moringa oleifera* seed extract, thus reduce the cost of purchasing aluminium sulphate. As we know, *Moringa oleifera* seed can be found anywhere in Malaysia. Therefore, it is momentous to explore the innate coagulating ability of the plant seed. In addition, *Moringa oleifera* seed extract does not give any significant impact to the pH of the water.

Many of the chemicals used in water treatment are also associated with human health and environmental problems (Crapper et al., 1973; Christopher et al., 1995; Kaggwa et al., 2001) and a number of them have been regulated for use in water treatment. Aluminium sulphate (alum) is a well known industrial chemical which is available in both solid and liquid forms. It occurs naturally as the mineral alunogenite and has been developed to significantly enhance the treatment of water, wastewater, industrial effluent and process water in the paper, food, dairy, oil, textile and chemical industries. Even though it is widely used as the primary coagulant in water treatment in most countries, it may pose a health risk to the water consumer. There is equally good evidence that aluminum exposure is not a risk factor as there is evidence that it is a risk factor (Harrison and Fauci, 1998). The aluminium residual in the water after treatment may cause Alzheimer's disease which is a progressive brain disorder that gradually destroys a person's memory and ability to learn, reason, make judgments, communicate and carry out daily activities. As Alzheimer's disease progresses, individuals may also experience changes in personality and behavior, such as anxiety, suspiciousness or agitation, as well as delusions or hallucinations. Besides, alum also lowers the pH of the water, thus extra processes needs to be done on the water. Therefore, exploring an alternative by using natural coagulant might help in developing an economical, environmental friendly and low risk (health) method in water treatment.

1.3 Objectives

a) To evaluate the efficiency of *Moringa oleifera* seed extract as primary coagulant in treating river water.

b) To evaluate the efficiency of aluminium sulphate as primary coagulant in treating river water.

c) To evaluate the efficiency of aluminium sulphate as primary coagulant while *Moringa oleifera* seed extract as coagulant aid in river water treatment.

d) To compare the effectiveness of aluminium sulphate and *Moringa oleifera* seed extract as coagulant in water treatment.

e) To determine the optimum dosage and pH for both *Moringa oleifera* seed and aluminium sulphate.

1.4 Scope of Study

This study mainly focuses on laboratory work which is batch clarification test – jar test. By running the test on different turbidity of the river water with sedimentation and filtration, the optimum dosage of the natural coagulant, *Moringa oleifera* seed, as primary coagulant or coagulant aid will be obtained. Besides that, the optimum dosage of the chemical coagulant, aluminium sulphate needs to be found out precisely. The results will be used for comparison with the natural coagulant. The pH will be measured before and after the test to determine the effect of pH on coagulation. The parameters in the study are pH and turbidity.

CHAPTER 2

LITERATURE REVIEW

2.1 General

There are some differences in water treatment plants at different places but mostly the main processes are the same. Selection of the processes mainly depends on the quality of the raw water supply. Surface water normally contains a wider variety of contaminants than groundwater and treatment processes will be more complex. Turbidity of the surface water most of the time are much higher than the drinking water standard, which is less than 1 NTU. In the fast moving stream, the turbidity of the water is very high where it contains lots of bigger size particles and most of the solids will be colloidal in size and require chemical coagulation for removal. As for the river water in Malaysia, the hardness problem does not occur. The existences of the microorganisms, some of which may be pathogenic, are also common constituents of surface water. Typical surface water treatment systems are shown in Fig. 2.1 (Peavy et al., 1985)

2.2 Coagulation and Flocculation

In water treatment operation, the processes of coagulation and flocculation are employed to separate colloidal suspended solids from water. Although the terms coagulation and flocculation are often used interchangeably, or the single term "flocculation" is used to describe both, they are, in fact, two distinct processes.

Pre-sedimentation: Necessary if water comes from fast flowing streams. Removes larger suspended solids. Chemicals may be added to oxidize inorganics or to arrest biological oxidation of organics.

Mixing, flocculation, settling: Removes turbidity by coagulating colloids and settling them out.

Filtration: Remove remaining turbidity; disinfectant may be added to prevent biological growth on filter medium.

Absorption: Necessary if water contains dissolved organics. May consist of activated carbon columns or activated carbon may be added in powdered form in operation.

Disinfection: Destroy pathogens, enough disinfectant added to provide residual in distribution system.

Storage: Provides contact time for disinfection and stores water for peak demand.

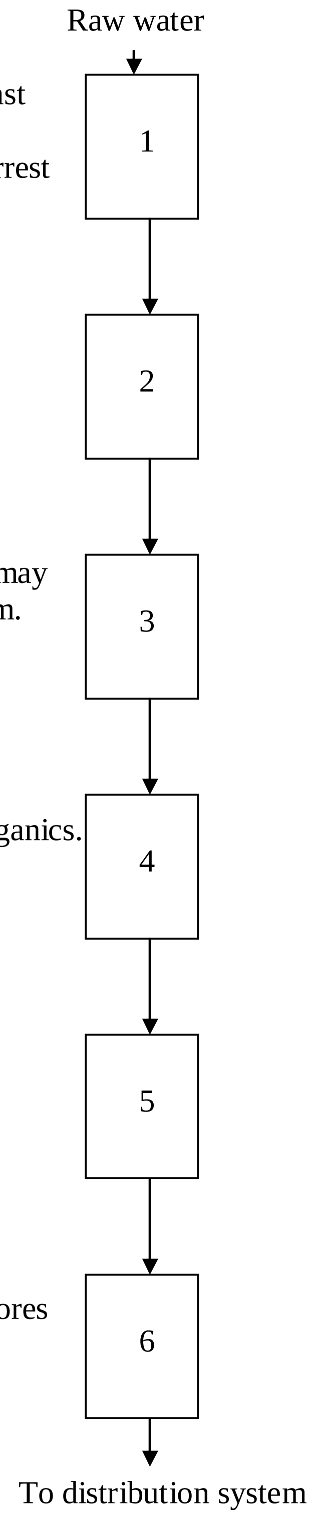

Figure 2.1 Typical surface water treatment system (Peavy et al., 1985)

Finely dispersed solids (colloids) suspended in waters are stabilized by negative electric charges on their surfaces, causing them to repel each other. Since this prevents these charged particles from colliding to form larger masses, called flocs, they do not settle. To assist in the removal of colloidal particles from suspension, chemical coagulation and flocculation are required. These processes, usually done in sequence, are a combination of physical and chemical procedures. Chemicals are mixed with water to promote the aggregation of the suspended solids into particles large enough to settle or be removed.

Coagulation is the destabilization of colloids by neutralizing the forces that keep them apart. Cationic coagulants provide positive electric charges to reduce the negative charge (zeta potential) of the colloids. As a result, the particles collide to form larger particles (flocs). Rapid mixing is required to disperse the coagulant throughout the water. Care must be taken not to overdose the coagulants as this can cause a complete charge reversal and re-stabilize the colloids.

Flocculation is the action of polymers to form bridges between the flocs and bind the particles into large agglomerates or clumps. Bridging occurs when segments of the polymer chain adsorb on different particles and help particles aggregate. An anionic flocculant will react against a positively charged suspension, adsorbing on the particles and causing destabilization either by bridging or charge neutralization. In this process, it is essential that the flocculating agent be added by slow and gentle mixing to allow for contact between the small flocs and to agglomerate them into larger particles. The newly formed agglomerated particles are quite fragile and can be broken apart by shear forces during mixing. Care must also be taken not to overdose the polymer as doing so will cause settling/clarification problems. Anionic polymers themselves are lighter than water. As a result, increasing the dosage will increase the tendency of the floc to float and not settle. Once suspended particles are flocculated into larger particles, they can usually be removed from the water by sedimentation, provided that a sufficient density difference exists between the suspended matter and the water. Such particles can also be removed or separated by direct media filtration or floatation. When direct filtration is used, the addition of a flocculant may not be required since the particles formed by the coagulation reaction may be sufficiently destabilized or of sufficient size to allow removal. The flocculation reaction not only increases the size of the floc particles to settle them faster, but also affects the physical nature of the floc, making these particles less gelatinous and thereby easier to dewater. (Peavy et al., 1985)

2.3 Coagulation and Flocculation Mechanism

Some particle sizes are very small and their terminal settling velocities are very slow. This shows that plain sedimentation will not be efficient to remove small suspended particles. Agglomeration of particles into groups, increasing the effective size and therefore the settling velocities, is possible in some instances. However, particles posses certain properties that prevent agglomeration and they are known as stable when the particles do not agglomerate naturally. The stability of the colloidal suspensions depends on the large surface to volume ratio resulting from their small size. The surface phenomena predominate over mass phenomenon. The accumulation of electrical charges at the particle surface is the most important surface phenomenon. In most surface waters, the colloidal particle is negatively charged.

Ions contained in the water around the colloid will be affected by the colloid. A negatively charged colloid will attract all the positively charged ions to it as shown in Fig 2.2. The cations will form a layer around the colloid and will bind to it and will travel with the colloid. Other ions in the vicinity of the colloid arrange themselves as shown, with greater concentration of positive, or counter ions being closer to the colloidal surface. The arrangement produces a net charge that is strongest at the bound layer and decreases exponentially with distance from the colloid. (Peavy et al., 1985)

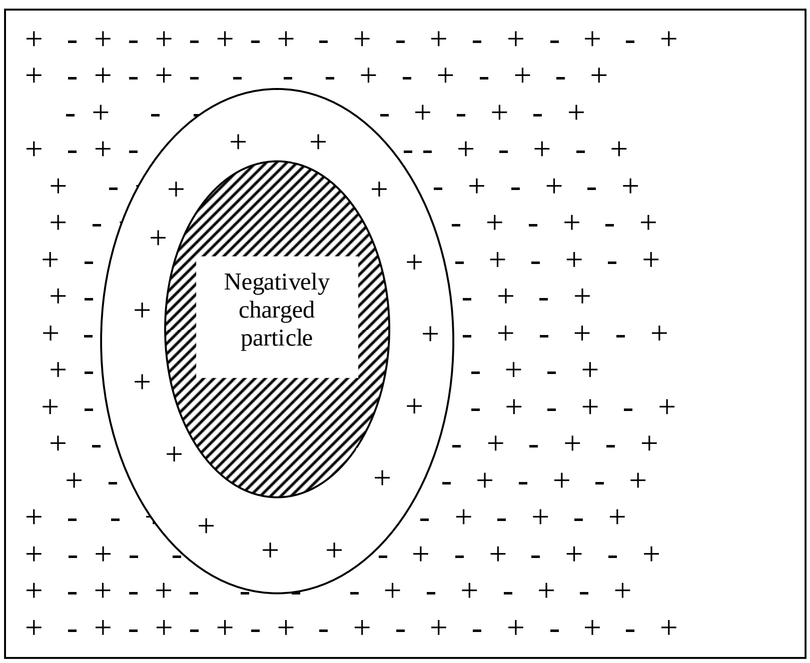

Figure 2.2 A negatively charged colloid with a possible configuration of ions around it.

There are two forces acting on them when two colloids come close to each other. One of them is the electrostatic potential which is created by the “halo” of counter ions surrounding each colloid and reacts to repel the particles. The second force, an attraction force called the van der Waals Force, supports contact. This force is inversely proportional to the sixth power of the distance between the particles and also decays exponentially with distance. This force decreases more rapidly than the electrostatic force but it is strong at closer distances. The sum of the two forces, the net force, as they relate to one colloid in close proximity to another, is repulsive at greater distances and becomes attractive only after passing through a maximum net repulsive force, called the energy barrier, at some distance between the colloids (Fig. 2.3). For agglomeration to occur, the energy barrier needs to be overcome. Brownian motion may provide enough momentum to colloidal particles to overcome the energy barrier. Mechanical agitation of the water may impart enough momentum to larger particles to move them across the energy barrier. These processes are too slow and neither results in agglomeration of medium-sized colloids. In water treatment, the colloids are chemically coagulated into clusters, or flocs, which are large enough to be removed by settling. Chemical coagulation is normally accomplished by the addition of trivalent metallic salts such as aluminum sulphate or ferric chloride. The mechanism of coagulation include ionic layer compression, adsorption and charge neutralization, entrapment in a flocculent mass (sweep coagulation), and adsorption and interparticle bridging. (Peavy et al., 1985)

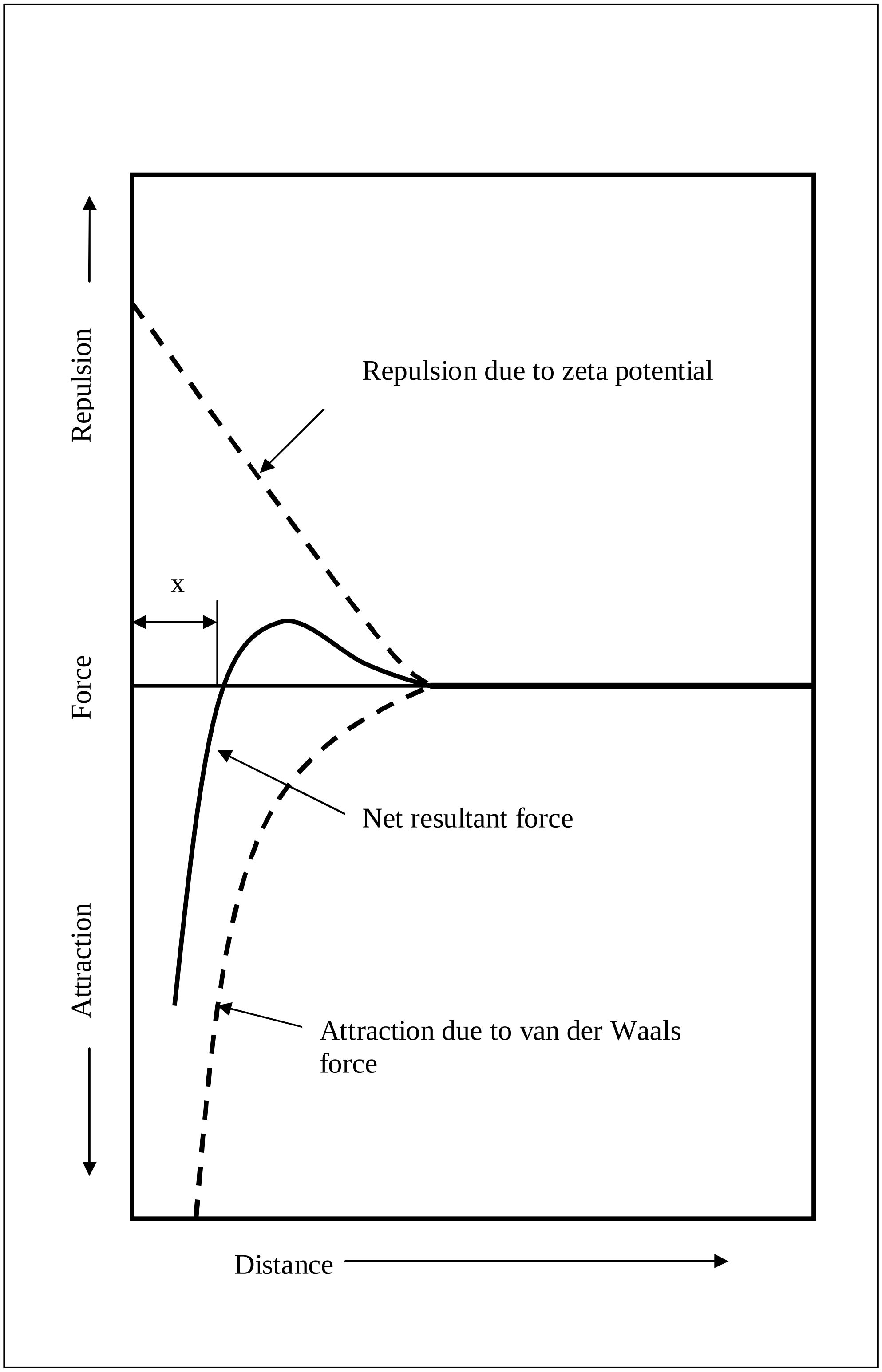

Figure 2.3 Colloidal interparticulate forces versus distance

2.3.1 Ionic Layer Compression

Ions in the water have an effect on the decay function of the electrostatic potential. A high ionic concentration compresses the layers composed predominantly of counter ions toward the surface of the colloid. If this layer is sufficiently compressed, then the van der Waals force will predominate and the net force will be attractive and no energy barrier will exist. However, at the concentration that is commonly used in water treatment, the coagulant would not be able to increase the ionic concentration sufficiently to affect ionic layer compression.

2.3.2 Adsorption and Charge Neutralization

In water, aluminium sulphate will ionize and produces sulphate anions (SO_4^{2-}) and aluminum cations (Al^{3+}). The Al^{3+} cations will react with water to form a variety of aquometallic ions and hydrogen.

$$Al^{3+} + H_2O \longrightarrow AlOH^{2+} + H^+ \quad \text{..... (2.1)}$$

$$Al^{3+} + 2H_2O \longrightarrow Al(OH_2)^{+} + 2H^+ \quad \text{..... (2.2)}$$

$$7Al^{3+} + 17H_2O \longrightarrow Al_7OH_{17}^{4+} + 17H^+ \quad \text{..... (2.3)}$$

$$Al^{3+} + 3H_2O \longrightarrow Al(OH)_3 + 3H^+ \quad \text{..... (2.4)}$$

The aquometallic ions thus formed become part of the ionic cloud surrounding the colloid and, because they have a great affinity for surfaces, are adsorbed onto the surface of the colloid where they neutralize the surface charge. Once the surface charge has been neutralized, the ionic cloud dissipates and the electrostatic potential disappears so that contact occurs freely. Overdosing with coagulant can result in restabilizing the suspension. If enough aquometallic ions are formed and adsorbed, the charges on the particles become reversed and the ionic clouds reform, with negative ions being the counter ions.

2.3.3 Sweep Coagulation

Aluminum hydroxide [Al $(OH)_3$] will be formed as last product of the hydrolysis. It forms in amorphous, gelatinous flocs that are heavier than water and settle by gravity. Colloids may become entrapped in a floc as it is formed or enmeshed by its sticky surface as the flocs settle. Thus, the colloids are swept away from the suspension.

2.3.4 Interparticle Bridging

Large molecules may be formed when aluminum or ferric salts dissociate in water. Synthetic polymers (polyelectrolytes) also may be used instead of, or in addition to metallic coagulants. There polymers may be linear or branched and are highly surface reactive. Thus, several colloids may become attached to one polymer and several of the polymer-colloid groups may become enmeshed, resulting in a settle able mass. In addition to the adsorption forces, charges on the polymer may assist in the coagulation process. Metallic polymers formed by the addition of aluminum or ferric salts are positively charged, while synthetic polymers may carry positive or negative charges or may be neutral. (Peavy et al., 1985)

2.4 Natural Polyelectrolytes

Polyelectrolytes can be derived from natural source or synthesized by chemical manufacturers. Both types consist of repeating units of small molecular weight, chemically combined to form a larger molecule of colloidal size and each of that carrying electrical charges or ionizable groups. Classification of the polyelectrolyte is made by the type of charge they carry. The polymers that possess negative charges are called anionic while those possessing positive charges are called as cationic and those carrying both charges are called ampholytic.

Synthetic polyelectrolytes are used instead of metallic coagulants as prime coagulant, or along with metallic coagulants as coagulant aid. As for the natural polyelectrolytes, they are quite common in the developing countries for water purification. Sanskrit writings from India reported that seeds of the nirmali tree (*Strychnos potatorum*) were used to clarity turbid river water 4000 years ago. In Peru, water has been traditionally clarified with the mucilaginous sap of "tuna" leaves obtained from certain species of cacti (Kirchmer et al., 1975). This shows that the natural polyelectrolytes are widely used by villagers to remove turbidity or unpleasant taste and odor from water. The British were among the first to use natural polyelectrolytes as coagulant aids in urban water supplies (Manual of British Water Engineering Practice, 1969). Sodium alginate, a natural polyelectrolyte extracted from brown seaweed, was used as an aid to alum, particularly during periods of low temperatures. It is widely used as thickening and stabilizing agents in the food, textile printing, and paper industries.

Plant seeds that have been studied to assess their effectiveness as coagulant are: *Strychnos potatorum*, *Tamerindus indica*, *Cyamopsis psoraloides*, Red Sorella, *Hibiscus sabdariffa* and *Moringa oleifera*. (Schulz and Okun, 1984)

2.5 *Moringa oleifera*

Moringa oleifera which is known as horse-radish (arising from the taste of a condiment prepared from the roots) or drumstick tree (arising from the shape of the pods) was originally an ornamental tree in the Sudan, planted during British rule. That was where a German scientist conducted a laboratory test to confirm the presence of a very effective coagulant in seeds of *Moringa oleifera*. *Moringaceae* is a single-genus family with 14 known species thus far, which are indigenous to Africa, Madagascar, Arabia and India (Jahn, 1981). Half of them are quite common and are sporadically cultivated. Because *Moringa oleifera* have many uses; it is planted in the whole tropical belt. In Malaysia, it can be easily found as the Indians use the pods as vegetable.

The *Moringa oleifera* is a small, fast-growing, drought deciduous tree that ranges in height from 5 to 12 m, with an open, umbrella shaped crown, straight trunk (10-30 cm thick), with corky and whitish bark. The evergreen foliage (depending on climate) has leaflets 1-2 cm in diameter; the flowers are white or cream colored. The fruits (pods) are initially light green, slim and tender, eventually becoming dark green, firm and up to 120 cm long, depending on variety. Fully matured dried seeds are round or triangular shaped, the kernel being surrounded by a lightly wooded shell with three papery wings. The plant can be easily cultivated by cutting or by seed. Seeds can be sown either directly or in containers and no seed treatment is required. The plants rise from 1 m cutting beat pods from the second year and grow onwards with maximum production in 4 to 5 years. In a favorable environment, an individual tree can yield 50 to 70kg of pods in one year. It has also been found to be well adapted to hot, humid, wet conditions with annual rainfall in excess of 3000 mm. However it does best where temperature ranges from 26 to 40^{o}C and annual total rainfall at least 500 mm (Schwarz, 2000).

Moringa oleifera is a multipurpose tree for semi-arid and drought-prone areas. It is being referred to as “miracle tree” (Fuglie, 1999). Even though it is a non nitrogen fixing tree, its different parts can be useful for other purposes. The pods, leaves and seeds can be eaten as vegetable and are highly nutritious. The extracted oil from the seeds is used for cooking, soap making, cosmetics, fuels and lamps. The wood pulp may be used for paper making. The wood is light and can’t be used for heavy constructions but it provides a fairly good fuel for cooking. The leaves can be also used as fertilizer and the very last usage is that the powdered seeds are used to heal bacterial skin infection (all parts of the plant are used in a variety of traditional medicines) (Schwarz, 2000).

2.6 *Moringa oleifera* Seed as Coagulant

As an alternative to conventional coagulants, *Moringa oleifera* seeds can be used as a coagulant in household water treatment as well as in community water treatment systems. Coagulant properties were found in 6 different *Moringa* species by laboratory studies. The active component from the seed of *Moringa oleifera* contains significant quantities of low molecular-weight (4755Da), water-soluble proteins which carry a positive charge (isoelectric point above 10), (Ghebremichael et al., 2004). The seed pods are allowed to dry naturally on the tree prior to harvesting. (Folkard et al., 1993). When the crushed seeds are added to raw water, the proteins produce positive charges, attracting the predominantly negatively charged particles, such as clay, silk, bacteria, and other toxic particles in water. Flocculation occurs when the proteins bind the negatively charged particles, forming flocs through the aggregation of particles. These flocs are easy to remove by settling or filtration. The seed can clarify not only highly turbid muddy water but also water of medium and low turbidity. The level of turbidity influences the required time for flocculation. As with all coagulants, the effectiveness of the seeds may vary from one type of raw water to another. The practical application of dosing solutions is exactly the same as for all other coagulants. Studies have been carried out to determine the potential risks associated with the use of *Moringa oleifera* seed in water treatment. To date, no evidence has found that the seeds cause secondary effects in humans, especially at the low doses required for water treatment (Schwarz, 2000).

Table 2.1 Advantages and disadvantages of using *Moringa oleifera* coagulant (Schwarz, 2000)

Advantages	**Disadvantages**
Cheap and easy method for developing countries (especially at household level).	The treatment makes the water clear and drinkable but the purified water might still carry some (very few) pathogenic germs or microorganisms.
The efficiency is independent of raw water pH.	A secondary increase of the bacterial content after the water coagulation is possible.
The processing does not modify the pH of the water.	Coagulant is not available in pure form (should be prepared fresh).
The low volume of sludge precipitated is biodegradable and hence an environmentally sound technology.	
It doesn't alter the water taste (unless a very high dose is added).	

From "jar test" using alum and *Moringa oleifera* seed as coagulant, Jahn and Dirar (1979) showed that alum just gave only a further 1% reduction in turbidity. In jar test of Ndabigengesere and Narasiah (1998), at optimum dosage (50mg/l), turbidity decreased from 105 to 10 NTU, corresponding to a turbidity removal of 90% in the case of alum and *Moringa oleifera* seed. According to the standard, the turbidity of the drinking water should be less than 1 NTU; therefore, further treatment such as filtration is needed. In laboratory test, direct filtration a turbid surface water (turbidity 15-25 NTU, heterotrophic bacteria 280-500 CFU/ml and fecal coliform 280-500 MPN/100 ml), with seeds of *Moringa oleifera* as coagulant, produced a substantial improvement in esthetic and microbiological quality (turbidity 0.3-1.1 NTU, heterotrophic bacteria 5-20 CFU/ml, and fecal coliforms 5-10 MPN/100 ml), and virus reduction effected was 3-4 log (Babu and Chaudhuri, 2005). For the river water with turbidity levels in excess of 400 NTU, solids removal within the plant was consistently above 90% following a gravel bed flocculation stage and plain horizontal flow sedimentation. Subsequent rapid gravity filtration gave a final, treated water turbidity generally well below 5 NTU. *Moringa oleifera* seed dose ranged from 75 – 250 mg/l depending on the initial water turbidity (Sutherland et al., 1990).

CHAPTER 3

METHODOLOGY

3.1 General

The methodology for this project is summarised in the flowchart below.

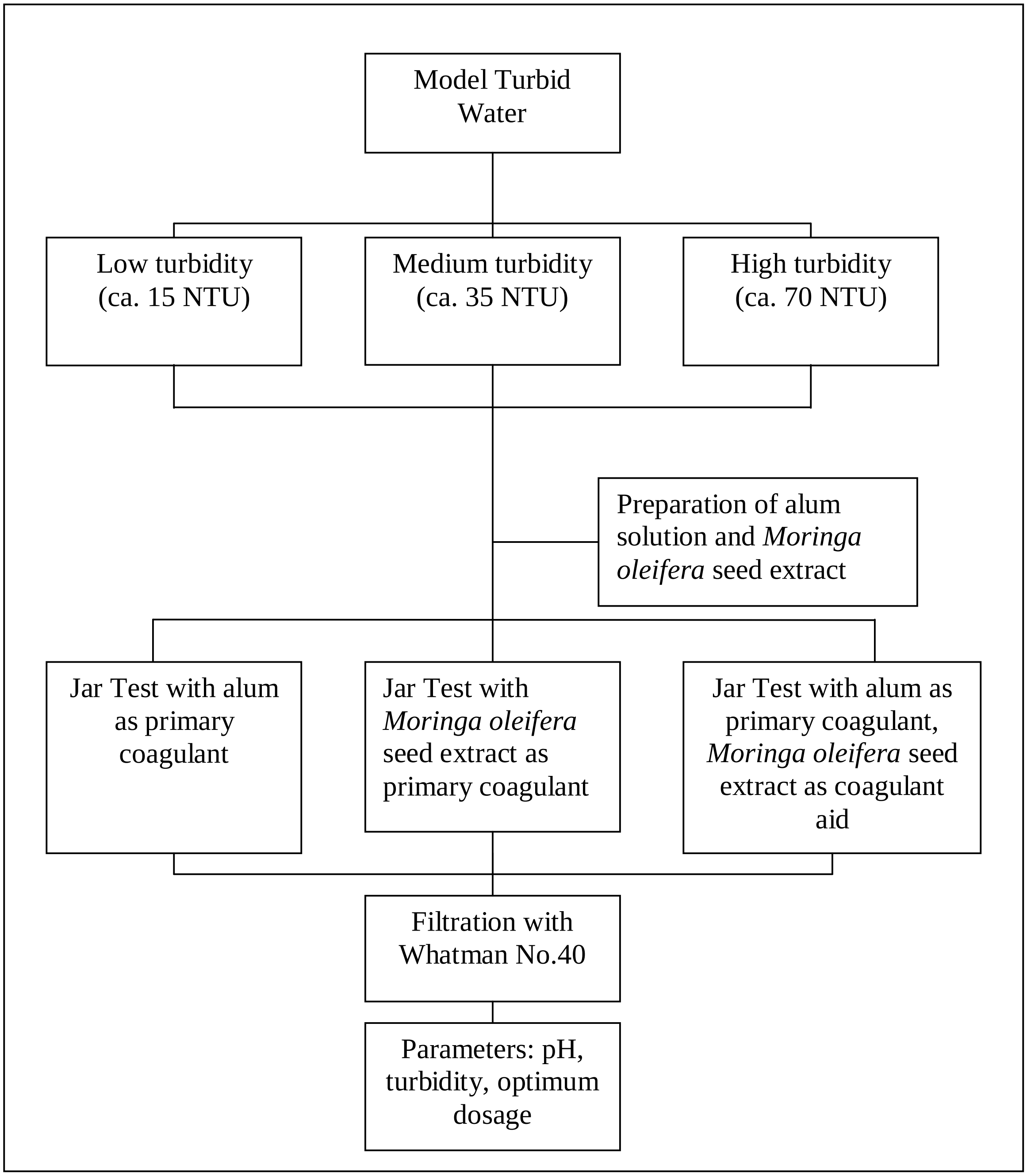

Figure 3.1 Flowchart for the coagulation test

3.2 Preparation Phase

In this phase, several preparations need to be done before running the following phases. Through the literature review, the basic idea about this project is known and this contributed to a successful lab works.

3.2.1 Model Turbid Water

The water samples used in the lab work were taken from the nearby river, Sg. Kerian (Kerian River), Perak. Samples were taken on random basis and lab work was carried out on the day of the sample collection. The turbidity of the river water is varied between 15 NTU to 90 NTU. Sample pH and turbidity were recorded each time the samples were collected. To obtain higher turbidity water, sediment from the riverbank was well stirred with river water and allowed to settle for 30 minutes. Supernatant was then measured to determine the turbidity of the sample. If the turbidity was too high, the sample was diluted to obtain the required turbidity.

3.2.2 Aluminium Sulphate Solution

Aluminium sulphate (alum) was used as primary coagulant at the beginning of the test to determine the optimum dosage for comparison with *Moringa oleifera* seed extract in following tests. Solution with the concentration of 1 % was prepared and stored in a reagent bottle. 1.0 gram of alum was weighed and transferred into the 100 ml volumetric flask. Distilled water was added for about ½ of the volume of the volumetric flask and well shaken. Additional distilled water was added exactly up to the mark of 100 ml.

3.2.3 *Moringa oleifera* Seed Extract

Dry *Moringa oleifera* seed (Fig. 3.2) were used as alternative coagulant. To prepare the solution of the *Moringa oleifera* seed extract, the husk enveloping each seed was first removed manually, good quality seeds were then selected and the kernel (Fig. 3.4) was ground to a fine powder using a mortar and pestle (Fig. 3.5). (The active agents of coagulation were then extracted from the powder using distilled water). The powder was weighed and was added to the appropriate volume of distilled water. A concentration of 2 % (2 g of powder in 100 ml) was used throughout this study. The whole mixture was stirred for 30 min. at room temperature ($20\pm1\ ^oC$) using a magnetic stirrer (Fig. 3.6). The suspension was filtered and the resultant filtrate was then used as coagulant. In order to prevent any aging effects, such as change in pH, viscosity and coagulation activity due to microbial decomposition of organic compounds during storage, the solution was stored in the cold room at temperature under 4^oC (Fig. 3.3). Comparison between turbidity removal efficiency of *Moringa oleifera* kept in refrigerator and room temperature revealed that there was no significant difference between them (Katayon et al., 2005). However, the previous step was still taken on to avoid any unnecessary problem.

Figure 3.2 *Moringa oleifera* seed

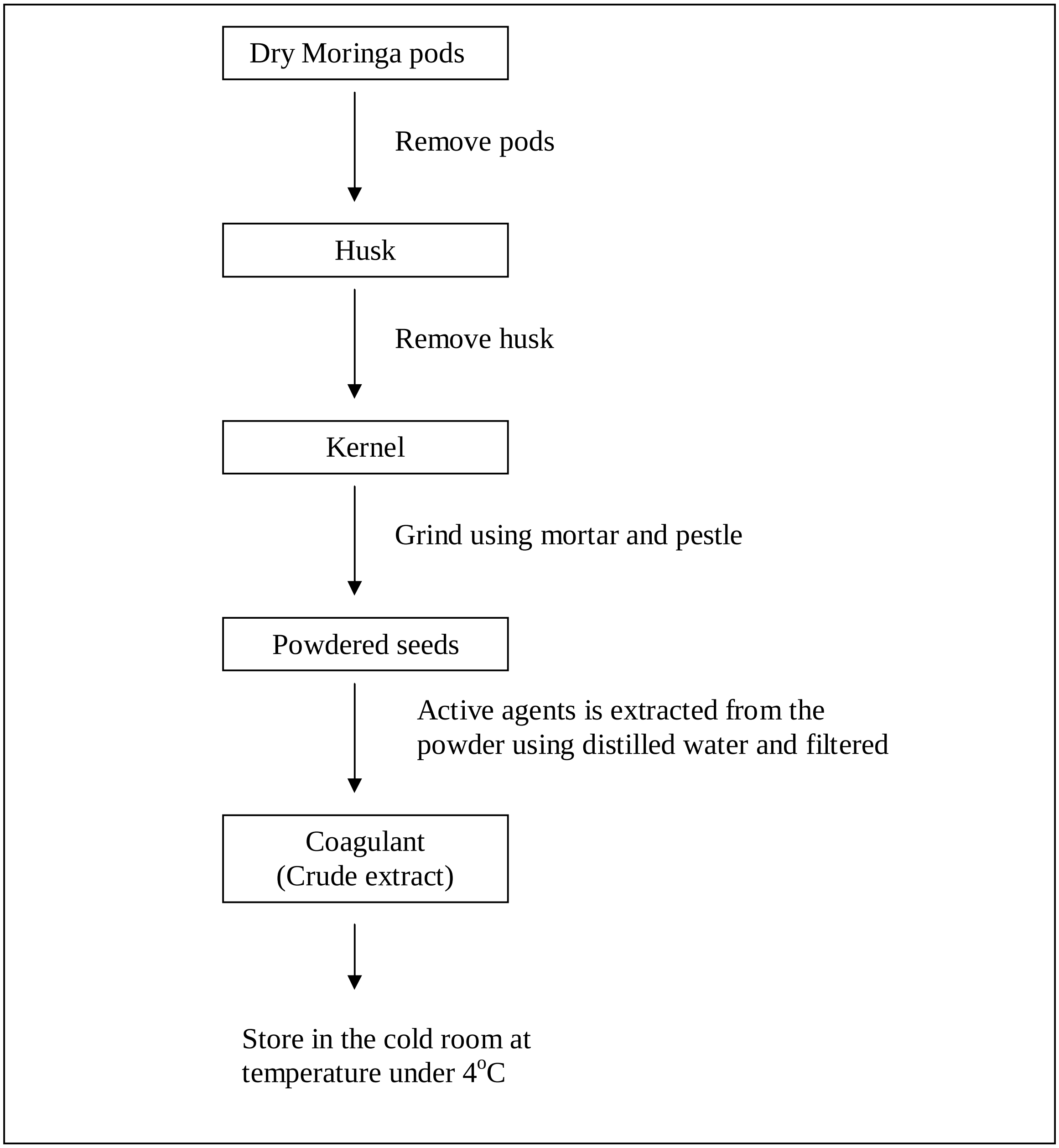

Figure 3.3 Extraction of coagulant component from *Moringa oleifera* seed

Figure 3.4 ***Moringa oleifera*** **kernels**

Figure 3.5 Mortar and pestle

Figure 3.6 Carolina hotplate stirrer