COAGULATION OF COLLOIDAL RAW WATER WITH KAOLIN FOR WATER

SITI RAHAYU BT. MOHAMED

Bachelor of Engineering (Hons.)Civil
UNIVERSITI TEKNOLOGI MARA
2009

COAGULATION OF COLLOIDAL RAW WATER WITH KAOLIN FOR WATER SUPPLY

By

SITI RAHAYU BT. MOHAMED

Report is submitted as
the requirement for the degree of
Bachelor Engineering (Hons) Civil

UNIVERSITI TEKNOLOGI MARA

OCTOBER 2009

DECLARATION BY THE CANDIDATE

I, Siti Rahayu bt. Mohamed (ID UITM: 2007269788) confirm that the work is my own and that appropriate credit has been given where the reference has been made of the work of others.

……………………………

(Date: 14th October 2009)

ABSTRACT

The treatment of water depends on the source of supply and the amount of impurities it contains. Coagulation process is effective and important process for turbidity removal in a water supply system. However the presence of kaolin in raw water contributes to the failure of coagulation process at Sg. Serai Water Treatment Plant. This study focus on establishing the effectiveness of turbidity removal for raw water taken from Sg.Serai by using selected coagulants. It involved taking raw water sample from the inlet of water treatment plant located at Sg. Serai and jar test were conducted. The raw water samples were analysed by many series of jar test to determine the optimum dosage of selected coagulants to remove the turbidity. This study considers only two coagulants namely aluminium sulphate and PAC and evaluation of their performances only. It was found that the optimum dosage of aluminium sulphate is 15 mg/l with 49 % of turbidity removal. The optimum dosage of PAC is 5 mg/l with 64 % of turbidity removal. However in the case of pH adjustment, aluminium sulphate greatly removes the turbidity of the raw water as it achieved 94 % turbidity removal

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to express my sincere gratitude and appreciation to my supervisor, Professor Ir. Dr. Suhaimi Abdul Talib for his guidances, critics, advices, knowledges and motivation. Without his continued supports and interest, this study would not been the same as presented here.

I would also like to extend my appreciation to the following panels; Associate Professor Ir. Dr. Aminuddin Baki and Associate Professor Hamidon Ahmad for their comments,opinions and recommendations during the proposal and final presentations.

I would like to add my loving friends into my list of appreciation who have provided precious assistance at various occasions. Last but not least, my heartiest appreciation and thankful to my family members especially my beloved parents for their precious love, warmest encouragement and tremendous support during the entire duration of my study. May Allah reward them all.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEWS

CHAPTER 3: METHODOLODY

CHAPTER 4: RESULTS AND DISCUSSIONS

CHAPTER 5: CONCLUSIONS AN DRECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AWWA	American Water Works Association
DOE	Department of Environment
DWAFSA	Department of Water Affairs and Forestry of South Africa
JKR	Jabatan Kerja Raya
MWP	Malaysian Water Partnership
PAC	Poly Aluminium Chloride
PNSB	Puncak Niaga Sdn. Bhd
SC	Sodium Carbonate
WHO	World Health Organization

LIST OF APPENDICES

APPENDIX A **PAGE**

APPENDIX B **PAGE**

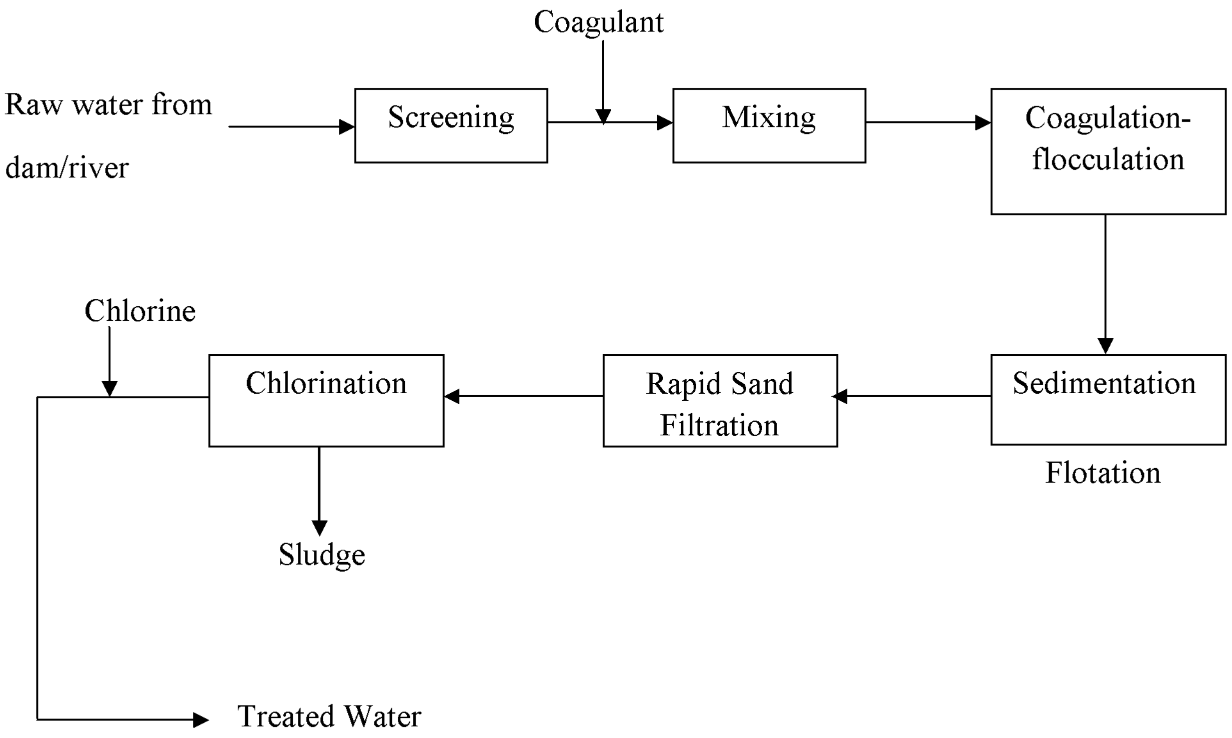
CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water is essential for life and all human communities must have some kind of water source. Water uses varies depending on the population, environmental condition, industrialization and other factors. The choice of source for water supply is an important aspect of any water supply scheme. The source should be permanent, reliable and contain minimum impurities. Water sources can be either from groundwater or surface water. The raw water from different sources cannot be used unless it is safe. Due to the increasing of water pollution rate in most developing countries, there are more demand for better water treatment (Chan, 2007). The treatment of water depends on the source of supply and the amount of impurities it contains. The objective of water treatment is to remove the undesirable impurities that make water unsafe causing negative effect to human health (Davis and Cornwell, 1998). Water treatment involved processes that remove pathogens present in untreated water, unpleasant taste and odor, colour, dissolved gases and murkiness of water, corrosive properties of water and render the treated water suitable for domestic purposes. The most common type of surface water treatment includes clarification and disinfection. Clarification is usually achieved through combination of coagulation-flocculation, sedimentation and filtration. Figure 1.1 shows the flow diagram of a typical water treatment process.

In Malaysia, technologies for water treatment are still being developed as not many researches have been done. Most water treatment plants are still using the conventional treatment system compared to the other developed country.



Notes:

1. The processes shown in this flow diagram are typically used in conventional treatment plant. These processes are used to treat raw water that contains relatively high levels of turbidity › 50 NTU, as well as microbes.

2. If the raw water contains organic substances that cause odour and taste problems, advanced processes such as activated carbon may be used to remove them. Activated carbon is normally added as powdered carbon with coagulant in the mixing step. The carbon is then removed by sedimentation and sand filtration.

3. Sedimentation is used if the turbidity in the raw water is caused mainly by silt. If the turbidity is due to algae, floatation may be used as an alternative to sedimentation.

Figure 1.1: Typical Water Treatment Scheme (DWAFSA, 2002)

1.2 Problem Statement

Nowadays, most rivers are largely affected by pollution from industries, municipalities, agricultural activities and runoff. Even rivers located far from the human activities, surface raw water generally contains suspended soil particles, organic and bacteria. Consequently, after rainfall events the turbidity of the raw water may increase substantially and become colloidal. The colloidal raw water if not treated will fail to floc and not settle readily during the coagulation process. This will cause filter clogging and premature filter breakthrough at filtration plants. In some cases, the water treatment plant needs to be shut down. Recently, it was reported that some water treatment plants need to be shut down due to increasing levels of turbidity. Therefore studies on removal of turbidity focusing on coagulation of colloidal raw water with presence of kaolin need to be conducted.

1.3 Objectives

The goal of this study is to enhance the understanding of the coagulation flocculation process in water treatment system. The specific objectives of this study are:

a) To determine the optimum dosage of selected coagulants for turbidity removal of raw water at Sg. Serai.
b) To evaluate the performances of selected coagulant in turbidity removal.

1.4 Scope of Work

This study involves two components of works which are field and laboratory works. Field works involve taking water sample from the inlet of the Puncak Niaga Sdn.Bhd water treatment plant at Sungai Serai. On the other hand, laboratory works involve measurement of turbidity and pH level in the water sample. Furthermore, jar test were conducted on the water samples to determine optimum dosage of coagulant. Figure 1.2 summarized the scope of work for this research.

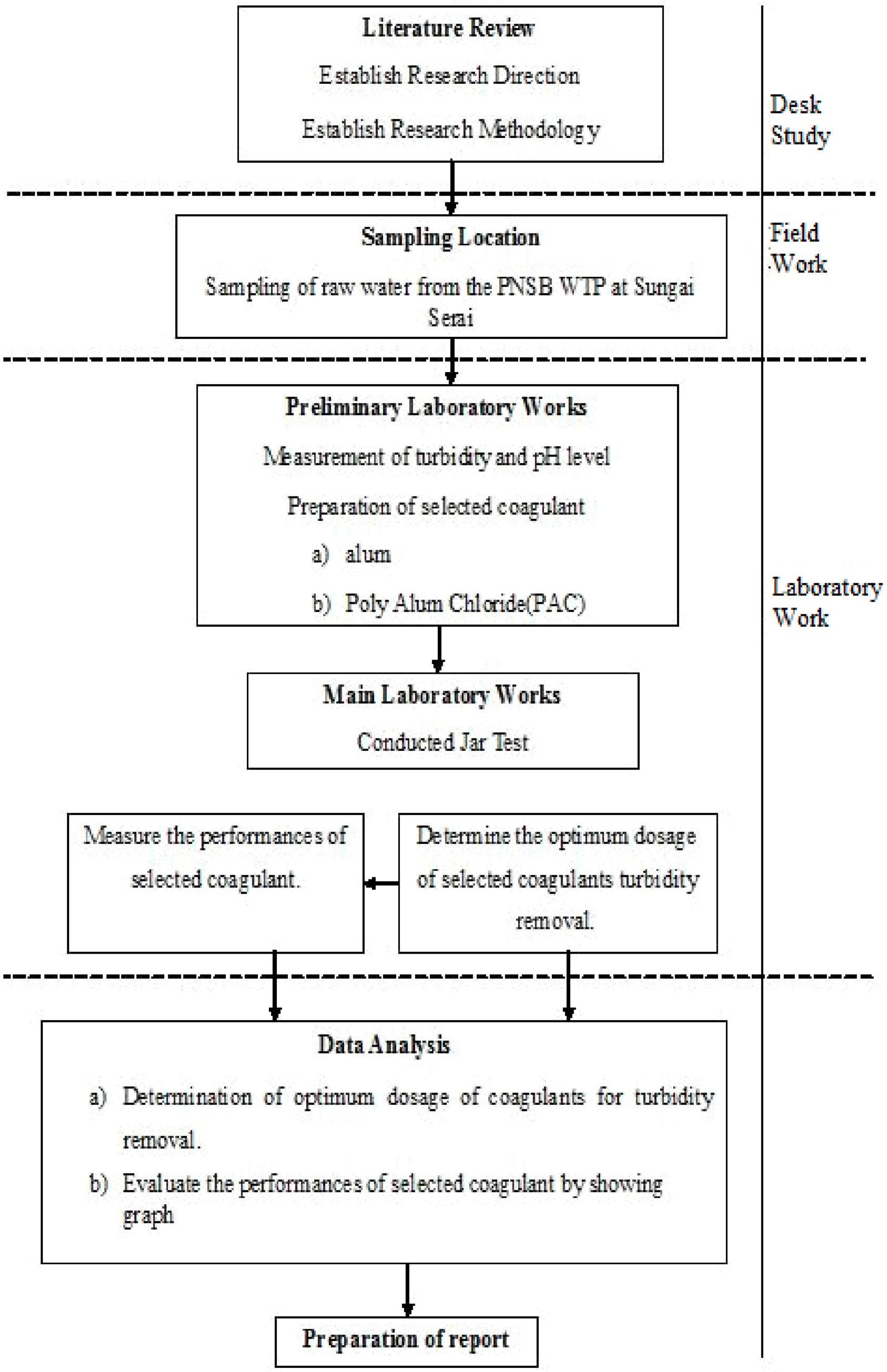


Figure 1.2: Scope of work for this study

1.5 Significance of Study

The results of this study will improve understanding on coagulation of raw water with kaolin for water supply. The understanding also can be used to develop efficient water treatment system as the demand for clean water is increasing over the next few years. Besides, the knowledge derived from this study will provide solutions to the problems related turbidity removal at the Puncak Niaga Sdn. Bhd water treatment plant at Sg. Serai.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical Development of Water Supply

In the early 19th century, water supply system was introduced in the Federated Malay States and in the Straits Settlements. The first formal arrangement for a water supply system in this country was initiated in Pulau Pinang in 1804 to serve a population of about 10,000 people. Clear stream water from the hills was brought through a brickwork channel to the town, where earthern pipes were laid through the streets and tin pipes conveyed water to the houses. Modern rapid gravity filtration plants were later introduced in this country in the 1930's. Treatment plants were built mainly to serve large towns. The oldest plants being those located in Pulau Pinang and Kuala Lumpur. The water supply system in Pulau Pinang and the Ampang Impounding in Kuala Lumpur which are still in service are some of the earliest public water supply systems constructed. Prior to the Second World War all the major towns had treated water supplies. During the Japanese Occupation between 1941 and 1945, no expansion in the water supply systems was conducted and most of the existing water supply installations deteriorated due to lack of maintenance. Immediately after the war, the development of water supply continued and these installations were rehabilitated and new schemes were implemented to meet the demand. By 1950, the country had 100 treatment plants producing 195 megalitres per day (Ml/d) supplying a population of 1.15 million. Major developments, however, took an upturn during the era after Malaysia gained independence from the British in 1957.

The first major scheme was the Klang Gates Dam and the Bukit Nanas treatment plant which were completed in 1959 to provide and supply for the capital city of Kuala Lumpur. Intensive efforts and emphasis given to rural water supply in the subsequent development plans have brought more and more piped water to rural areas. As the population of Malaysia increased, larger schemes have been developed. As of May, 1998 there are more than 478 treatment plants producing about 9,870 Ml/d serving a population of about 19.8 million people (JKR, 2007).

2.2 Challenges of Water Supply in Malaysia

Malaysia has more than 150 river systems that contribute 98% of the total national water use, while the remainder is contributed by groundwater. Water supply systems that are too dependent on surface water sources are at the mercy of the weather. To fulfill the increasing water demand, the development of distant water resources is not always the best option, and groundwater resources offer the possibility of on-site development of water supply. Groundwater accounts for 90 percent of the freshwater resources in Malaysia (MWP, 2001). Recognising the future potential of groundwater as significant options source of water, the Department of Environment in 1997 established the National Groundwater Monitoring Programme (DOE, 2009). The need to develop ground water resources is enhanced by the high environmental costs incurred in the development of surface water storage (Raja Zainal Abidin, 2005). Water beneath the earth's surface is stored in and flows through dirt, sand, and porous, fractured rock. This sponge-like formation is referred to as an aquifer. Only eight to ten percent of precipitation penetrates the soil surface moving downward into the aquifer (Earp *et al.*, 2006).

Groundwater exploration programmes will be carried out, especially in the main river basins, to identify potential aquifers. Aquifer zones will be identified and protected to safeguard this important resource. Guidelines and appropriate laws will be formulated and enforced to control development with potential polluting activities (MWP, 2001).

In addition, poor enforcement of law regulations in Malaysia to control water pollution need to be addressed. Nowadays, water legislation is contained within the laws that are enforced by the various water-related government agencies, and many of these laws are outdated, redundant or ambiguous. This diversified water legislation focuses on limited aspects of water resources and water supply directly related to the responsibilities of the respective government agencies and thus difficult to enforce effectively (MWP, 2001). Local Authorities has been urged to monitor and act against factories and other business activities situated along river sources to curb river pollution (Zubin, 2009). Recently it was found that a motor workshop had allegedly discharged diesel into Sungai Semenyih leading to the shutdown of water treatment plant and cut off water supply to 1.4 million consumers in Sepang, Petaling, Hulu Langat and Kuala Langat districts.

2.3 Water Treatment System

The water treatment processes developed in the 19th century and upgraded during the 20th century are simple in nature. Water treatment is defined as any unit process that changes or alters the chemical, physical, and the bacteriological quality of water with the purpose of making it safe for human consumption and appealing to the consumer (Spellman, 2008). Water treatment is an essential element in any water supply system in order to make the water fit for domestic use.

In a conventional treatment system raw water is abstracted from the different sources, the raw water is then conveyed to the treatment plant where it is treated in different treatment process. Water is carried through pipes from sources to the water treatment plant. In general, water treatment processes can be classified into the following categories based on their functions (PNSB, 2009):

a) Aeration

The process that involving of bringing air to contact with water to improve the taste and odor and also oxidize iron and manganese.

b) Coagulation and flocculation

Coagulants are added to react with the suspended particles in the water to form large particles enough to settle out and remove the turbidity.

c) Sedimentation

Physical treatment process that utilizes gravity to separated suspended solid from water. Floc settles by gravity to the bottom of a sedimentation basin. Then, clean water spills over to the filters.

d) Filtration

To remove any remaining particles that carried over after sedimentation. The force of gravity moves the water through filter media.

e) Disinfection

Chlorine adds to prevent bacterial contamination as the treated water flows through the distribution system to customers.

After treatment the water is stored and then distributed to individual users. Treated water stored in clear water reservoir from where it is distributed to the consumers through the distribution system of pipes. Many more processes will emerge as regulations in the attempt to produce water that complies with all the regulations, despite source water conditions. According to WHO (2008), the objective of treating water is to ensure that the raw water do not represent a health risk to the user.

2.3.1 Coagulation-Flocculation

Water generally has suspended, dissolved and colloidal impurities (Davis and Cornwell, 1998, Spellman, 2008). In surface water, suspended particles generally caused turbid or murky appearance of water. Colloidal particles which do not settle at all even if left for a long period of time adds further problem to the water treatment plant. A variety of impurities in water is shown in Table 2.1.

Table 2.1: Impurities in water (Omar, 2005)

Impurities	Causes
A. Inorganic	
a) Suspended	Particle of silt and clay
b) Dissolved	Carbonates, Sulphate, Nitrates, Chloride of Na, Fluorides of Na, Manganese
B. Organic	
a) Suspended	Decayed leaves, algae and fungi, dead animals and insects
b) Dissolved	Large quantities of albuminoid nitrogen with a little free ammonia and chlorides (vegetable and animal origin).

One of the natural pollutants in surface waters especially rivers are suspended particles that cause of turbidity in waters. The common source of turbidity is clay particles resulting from the erosion of soil in the catchments area (Mahvi and Razavi, 2005). Colloidal particles are very small (smaller than 0.1 micron), and since they are electrically charged they have very specific characteristics. The most important characteristic is that they form a stable colloidal suspension that do not settle readily, but remain in suspension (even for periods of days or weeks). In order for such particles to settle, they must be chemically destabilised or coagulated to neutralise the charge on them and to form larger flocs that can settle, thereby facilitating their removal from water.

In 1885 when sand filtration was developed, it became immediately apparent that filtration alone would not produce a clear water. Experience has demonstrated that direct filtration is largely ineffective in removing bacteria, soils particles, and colour (Davis and Cornwell, 1998). The purpose of coagulation is to turn the small particles of color, turbidity and bacteria into larger flocs, either as precipitates or suspended particles (Davis and Cornwell, 1998).

Coagulation/flocculation processes are very effective at removing fine suspended particles that attract and hold bacteria and viruses to their surface. Research has shown that these processes alone are capable of removing up to 99.9 per cent of the bacteria and 99 per cent of the viruses from water supplies. However, not all of this natural organic matter is removed by coagulation, certain taste and odour problems may remain.

In coagulation, a chemical (coagulants) is fed to the raw water to neutralize and destabilize particle charges on the colloids (Spellman, 2008; Davis and Cornwell, 1998). Coagulation can also be affected by the addition of water-soluble organic polymers with numerous ionized sites for particle charge neutralization (GE, 2008). Destabilized colloidal particles will adhere to each other. Because many colloidal particles are present in the water, charge neutralization among all particles requires immediate and even dispersion of the coagulant. Moreover, the larger the surface change, the more stable the suspension. The destabilization reactions occur very rapidly. Therefore, incomplete or slow mixing results in wasted chemical and uneven flocculation (Pike, 2005).

Once colloidal destabilization has occurred, random particle motion causes particle collision, resulting in formation of a larger particle or floc (Pike, 2005). Most colloids are stable because they possess a negative charge that repels other colloidal particles. The colloids are continually moved in Brownian Movement (Davis and Cornwell, 1998). These neutralized particles stick together forming floc masses. Bacteria particles are also neutralized (but not physically deactivated) and become entangled in the floc. As this massing continues, particle size and weight increase to a point where the larger floc can be removed by filtration (Figure 2.2 and Figure 2.3). Coagulation-flocculation is an important method in aggregating colloidal suspension in water treatment (Runkana e*t al.*, 2006). The stability of colloids is a prime consideration in determining their behaviour including the formation of sediment, dispersion, and removal of pollutant (Manahan, 2007).

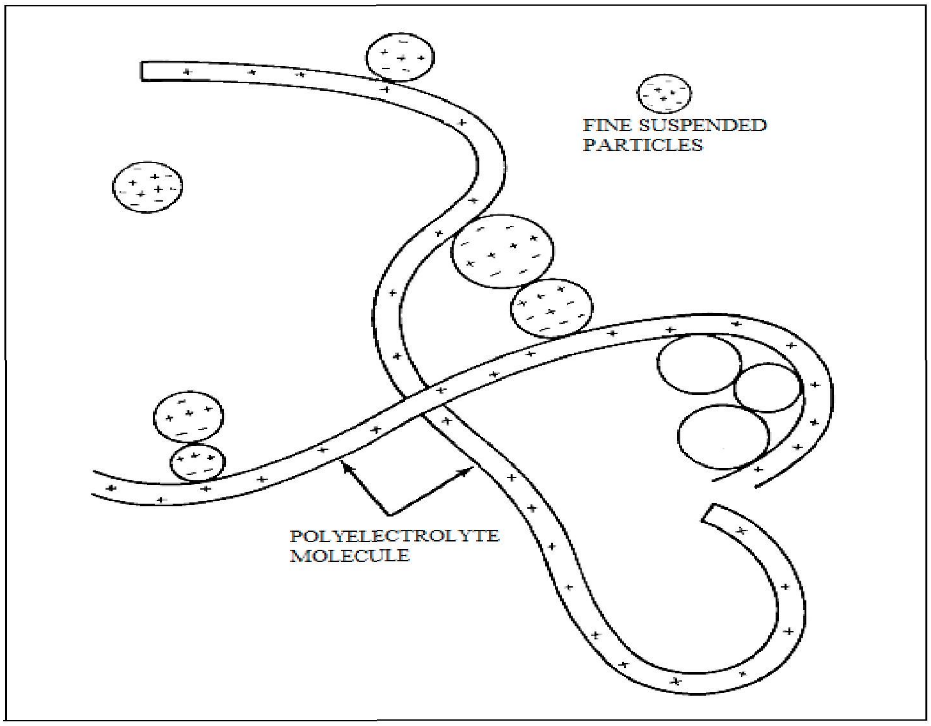


Figure 2.2: Forming a floc particles (Pike, 2005)

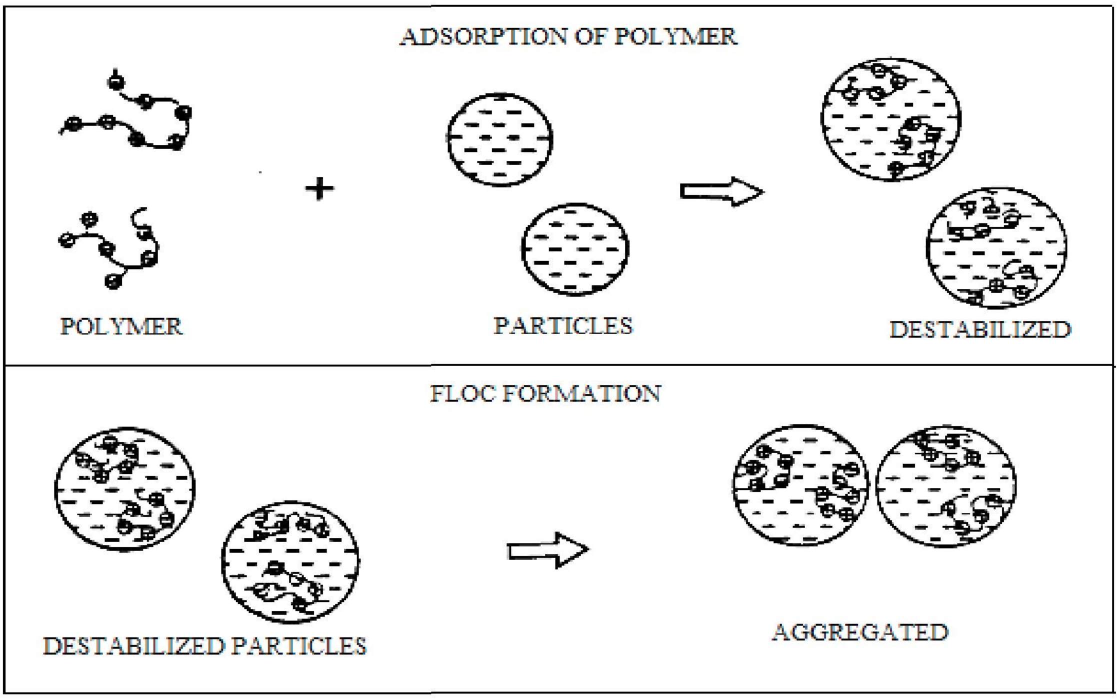


Figure 2.3: Floc Formation Process (Pike, 2005)

2.3.2 Coagulants

A coagulant is the substance (chemical) that is added to the water to accomplish coagulations. A coagulant that is positively charged causes compression and thus the neutralization of the electrostatic surface potential of the particles. The resulting destabilized particles stick sufficiently together when contact is made. Rapid mixing (a few seconds) is important at this stage to obtain uniform dispersion of the chemical and to increase the opportunity for particle-to-particle contact. Subsequent gentle and prolonged (several minutes) mixing cements the still microscopic coagulated particles into larger floes. These flocs then are able to aggregate with suspended polluting matter. When increased sufficiently in size and weight, the particles settle to the bottom.

In rural households in developing countries, however, various naturally occurring materials are traditionally used as coagulants e.g., fluvial clays from rivers and wadis (in Sudanese Arabic called "rauwaq", clarifier), clarifying rock material from desert regions, earth from termite hills. Their main constituents are quartz, montmorillonite, kaolinite, calcite and feldspar; their coagulating mechanisms differ greatly from those of metal salts. The processes and reactions which occur upon the addition of these various mineral coagulants to waters of different quality are not yet sufficiently known (Wikipedia, 2008). Several categories of chemical coagulants are also used in water treatment, such as ferric series, aluminum series, lime, organic polymer, polyelectrolyte, etc. However, these reagents are harmful to health because they leave unwanted monomer, aluminum, and unnecessary side products in effluent, especially for excessive usage. (Srinivasan and Viraraghavan 2002). Traditionally, Alum had been the main coagulant used in potable treatment in Malaysia as it is relatively cheap and is readily available from local suppliers. As the quality of the raw water become more problematic to treat, the need to look for other coagulants becomes imperative (JKR, 2007). Even though they possess good particle removal efficiency, these coagulants may contaminate drinking water via aluminum residue, which has been recognized as a factor in Alzheimer’s disease (Lau, 2007).

Besides conventional chemicals such as Alum and Ferric chloride to remove the impurities in surface water, polymers as coagulant are getting common. Four different types of Magnafloc polyelectrolyte were used to remove the different levels of turbidity. Polymers with small dosage can be used for water purification. The results showed that 97.15% of turbidity removal was achieved by using Magnafloc 1569 (Mahvi and Razavi,2005). Figure 2.4 shows the results of polyelectrolyte application in removing the turbidity.

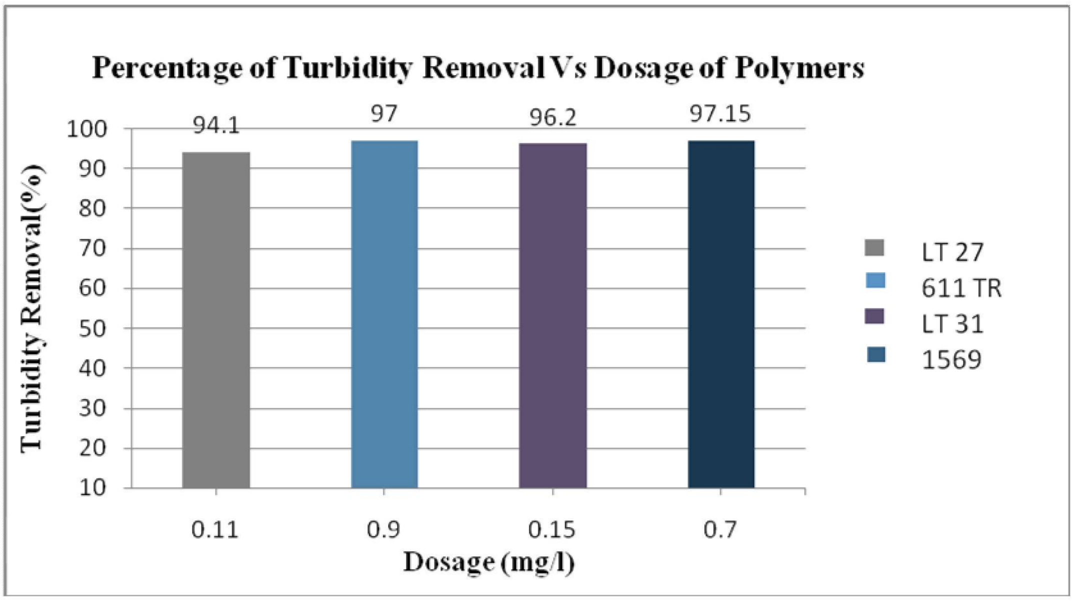


Figure 2.4: Effects of polymers on turbidity removal (Mahvi and Razavi, 2005)

Removal of kaolinite turbidity from the effluents before discharging into the environment is a problem faced by the clay processing industry. Divakaran and Pillai (2001) applied chitosan to remove the kaolin in surface water. Chitosan is obtained by deacytylation of chitin and now available as commercial product, manufactured by crab and prawn shells. The results indicate that chitosan is very efficient in removing kaolinite turbidity in the entire turbidity range.The results showed that 95% was achieved. Figure 2.5 shows the results obtained by using the chitosan.

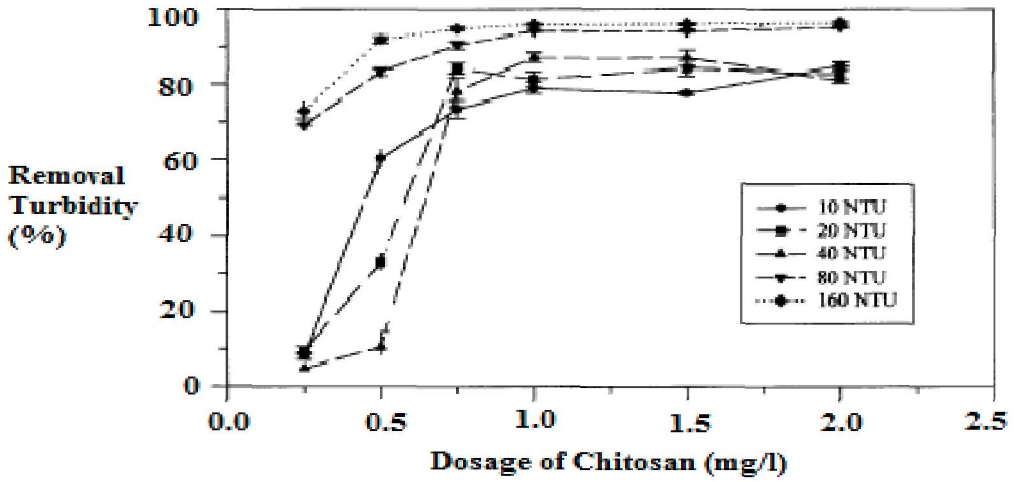


Figure 2.5: Percentage of removal turbidity by using chitosan (Divakaran and Pillai, 2001)

Lau (2007) used cactus as a substitute for alum. The cactus solution used as coagulant aid. The turbidity removal achieved 95%±2%. The results were better than used the alum as sole coagulant as it achieved 80%±2%. Even though all these researchers indicated that chitosan and/or biocoagulant can serve as an alternative for alum coagulant, few researchers have paid attention to the superturbid water treatment via biocoagulant (Hong *et al.,* 2008). In the 1980s, researchers attempted to develop biocoagulant to serve as an alternative for traditional chemical coagulants. Biocoagulant is made of natural materials, biodegradable and possesses a high ecological affinity. After application of biocoagulant, no harmful contaminants present in the effluent and therefore contribute to the reducing of sludge dumping problem and other environmental risk. Based on the charge neutralization and interparticle bridging effects, biocoagulant works well in removing the suspended particles especially for water with extremely high turbidity. (Hong *et al,* 2008).

Natural resources as coagulant that is derived from plant or animals are possible to become substitute for alum to purify the raw water. At rural places in India and Africa, Moringa Oleifera seeds is widely used to treat the contaminated well if the alum is unvailable. The results obtained shows that M.Oleifera as sole coagulant was not so effective. However the turbidity removal achived 90-100% when the M.Oleifera combined with alum (Chan,2007).

Polyaluminium chloride (PAC) is also increasingly used for water treatment. Against the conventional use of aluminium sulphate (alum) PAC gives distinct advantages. The inorganic flocculant, PAC, enhances the turbidity removal through neutralization of the charge density of the kaolin particles. Prior to PAC addition, the Zeta of particles were negatively charged, but with the dosage of PAC, the Zeta dramatual turbidity increased and restabilization took place (Pal *et al.*, 2005). This is due to the repulsion between the added polymer molecules and the polymer chains that already adsorbed on the particle surface. Polyaluminium chlorides are synthetic polymers dissolved in water. They react to form insoluble aluminium poly-hydroxides which precipitate in big volumetric flocs. The flocs absorb suspended pollutants in the water which are precipitated with the PAC and can together be easily removed. PAC can be used as a flocculant for all types of water treatment treatment, drinking water, industrial waste water, urban waste water and in the paper industry. The slightly higher unit price of PAC is compensated by (ENCO Engineering, 2008):

a) lower dosage requirement
b) no requirement for any neutralising agent (soda, lime)
c) shorter flocculation time
d) smaller amount of sludge
e) reduced number of back washing steps
f) higher quality of the treated water.

The studies on PAC and Ferric salts are also conducted on some of water treatment plant in Malaysia (JKR, 2007). Table 2.5 summarized the previous study on different coagulants and researchers.

Table 2.2: Summarized of the previous study on different coagulants

References	Coagulant Used	Efficiency Turbidity Removal (%)
Chan (2007)	Moringa Olifera and Alum	90-100
Pal *et al.*,(2005)	PAC	-
Divakaran and Pillai (2001)	Chitosan	80
JKR (2007)		
a) WTP Sg.Linggi, N.Sembilan	Ferric Chloride	-
b) WTP Pedas Baru, N.Sembilan	PAC	-
c) WTP Sg.Terip, N. Sembilan	Ferric Sulphate	-
d) WTP Timah Tasoh, Perlis	PAC	-
Lau (2007)	Alum and cactus	95±2
Mahvi and Razavi (2005)	Polyelectrolyte	93-94

2.3.3 Kaolin

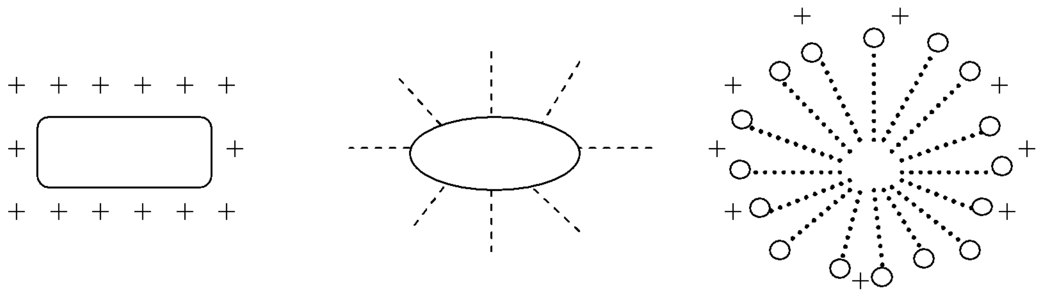
Kaolinite is a clay mineral with the chemical composition $Al_2Si_2O_5(OH)_4$. It is a layered silicate mineral, with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedra (Wikipedia, 2008). Rocks that are rich in kaolinite are known as china clay or kaolin. Kaolin has a variable surface charge. Kaolin usually emitted into the surface water caused by land development and storm runoff during rainy seasons especially a country like Malaysia. The quality of the raw water become not stable due to suspended solids and colloidals particles thus contribute to the turbidity. Clay is a large part of natural turbidity in raw waters, but is not directly responsible for harmful effects to human (Culp, 1986). Kaolinite has a low shrink-swell capacity and a low cation exchange capacity (1-15 meq/100g.) It is a soft, earthy, usually white mineral (dioctahedral phyllosilicate clay), produced by the chemical weathering of aluminium silicate minerals like feldspar.

2.3.4 Hydrophobic and Hydrophilic Nature of Colloids

Hydrophobic and hydrophilic are frequently used descriptors of surfaces (Arkles, 2006). Colloidal systems have a high ratio area/volume among the surface of the particles and their volume. In other words, as in the colloids the amount of dispersed particles is very large, their overall surface is very large too and by consequence the interaction of the two phases is important (Carboni, 2002).

Colloidal can be classified as hydrophobic (water-hating) and hydrophilic (water-loving). The differentiation between the two colloids is not fundamental, and a continuous series of substances exists with properties intermediate between the two extreme types. A unique property of hydrophilic substances is their ability to react spontaneously with water to form colloidal suspensions which can be dehydrated to the original material and then redispersed repeatedly. Meanwhile, the hydrophobic substances are generally prepared by physical or chemical means. If such dispersion is dehydrated, they do not spontaneously redisperse in water.

Clays and metal oxides are largely hydrophobic in nature. The distinction between the two classes of compounds is important in coagulation because in hydrophilic systems the particles chemically react with the water in which they are dispersed and with metal coagulants. Purely hydrophobic systems do not react with the water phase, and coagulation is achieved by reactions that are largely physical rather than chemical (AWWA, 1971).The characteristic light scattering phenomenon of colloids result from their being the same order of size as the wavelength of light and is called the Tyndall Effect (Manahan, 2007; Carboni, 2002). There are three classes of colloidal particles as illustrated in Figure 2.7. Hydrophilic colloids generally consist of macromolecules such as protein and synthetic polymers that are characterized by strong interaction with water. Hydrophilic colloids participate in the coagulation process in a different way. These colloids tend to attract water molecules and attach these water molecules to their surfaces. This is also a hydration process, and the water molecules act as a barrier to contact between particles. Coagulant products react chemically with the negatively charged groups attached to the hydrophilic colloids, forming an insoluble product which is electrically neutral and destabilized. Hydrophobic colloids interact to a lesser extent with water and are stable because of positive or negative electrical charges. Association colloids consist of special aggregates of ions and molecules called micelle (Manahan, 2007).



Hydrophobic Hydrophilic Association (Micelle)

The negatively charged hydrophobic and association colloidal particles are shown surrounded by positively charged counter ions. The dashed line in the hydrophilic colloidal of the particles how bonds to water. In the micelle association colloid, the jagged lines represent organophilic (usually hydrocarbon) tails and the circle represents anionic heads attracted to water.

Figure 2.6: Representation of hydrophobic, hydrophilic and association colloidal particles (Manahan, 2007)

CHAPTER 3

METHODOLOGY

3.1 Sampling Location

The water samples were taken directly from the inlet of the Puncak Niaga Sdn. Bhd Water Treatment Plant at Sungai Serai, Selangor. The design capacity of this water treatment plant is 0.90 million litre per day. The water is mainly distributed to the small population at Hulu Langat, Selangor. The location of the water treatment plant is shown in Figure 3.1.

Figure 3.1: The location of Puncak Niaga Water Treatment Plant at Sungai Serai, Selangor

3.2 Sampling Method

The water samples were taken directly from the inlet of the water treatment plant. The water sample was collected directly from raw water pump house at the water treatment plant. The water sample were collected and stored in four plastic bottles with 25 litre capacity each before being transported to the laboratory. During transportation, expose to sunlight was kept minimum to prevent reaction in the sample.

3.3 Sample Preparation

Before any experimental works was performed on the water samples, each of the poly eutherene bottles that contained the water sample were shaken thoroughly as the fine particles settles or adhere at the bottom or the wall of the plastic bottles as preparation to conduct the jar test.

3.4 pH Test

The pH meter used in the laboratory works is the Sens**ion**™3 Laboratory pH Meter manufactured by Hach Company. This meter features digital LCD display which displays the temperature and measurement result. This pH meter can be set to measure values to tenths (0.0), hundredths (0.00) or thousand (0.000). This instrument can display temperature in the range of –10.0 to +110°C and pH in the range of -2.0 to 19.99 pH units simultaneously. Besides that, the Sens**ion**™3 pH Meter is designed to auto-recognize and calibrate on 4.01, 6.86 or 7.00 and 10.01 pH buffers. The pH test was done before and after the jar test was conducted.

3.5 Turbidity Test

To determine the level of turbidity in the water samples, the Hach 2100P Portable Turbidimeter was used. This instrument is supplied with accessories that include three sample cells; three Gelex® Secondary Standard; one bottle each of ‹ 0.1 NTU, 20 NTU, 100 NTU and 800 NTU StablCal® Stabilized Formazin Standard. The measurement method that be used was ratio nephelometric signal (90°). This turbidimeter measure turbidity in range of 0 to 1000 NTU with automatic point placement or manual range selection of 0 to 9.99, 0 to 99.9 and 0 to 1000 NTU. The Gelex® Secondary Standard used for this study was 0.1 NTU. The samples were tested for the turbidity levels to indicate the level of impurities contained before and after the jar test.

3.6 Jar Test

The objective of the jar test is to determine the optimum dosage of coagulants required to remove the turbidity. The jar test apparatus used was Phillips & Birds-900™ Jar Tester. It is a multifunctional stirring apparatus capable of operating in a non-programmed (CONTINOUS) or programmed (RUN SINGLE 1-4, SEQUENTIAL) mode.

The stirring speed for this equipment is 0 or 5 to 5300 revs./min with mimimum stirring time of 59 minutes. This jar tester contains six paddles which stir the contents of six 1 liter containers. One container acts as a control while the operating conditions can be varied among the remaining five containers. A rpm gauge at the top-center of the device allows for the uniform control of the mixing speed in all of the containers. Figure 3.2 shows the apparatus of the jar test.

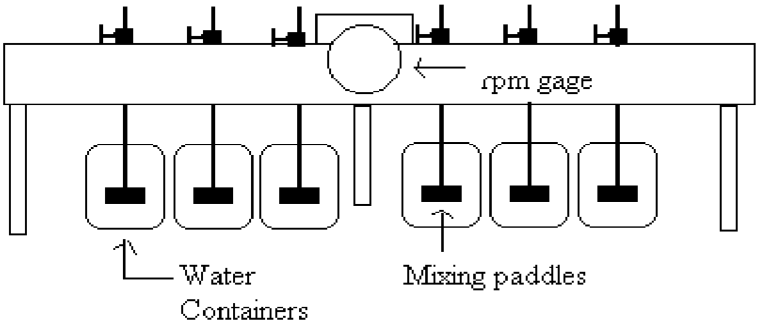


Figure 3.2: Jar Test Apparatus

The coagulants used in this jar test were 0.1 % aluminium sulphate, $Al_2 (SO_4)_3$ and 1.8 % Poly Aluminium Chloride (PAC) Al_2SO_3. This test was repeated a number of times to determine the optimum dosages. The first trials of coagulants dosage were 5 ml, 10 ml, 20 ml, 30 ml and 40 ml. After that other trials to minimize the coagulant dosage in the range of decreases in turbidity levels were done to get the optimum dosage required to remove the turbidity in the water sample tested. The stirring speed used was 170 rpm for the rapid mixing and 70 rpm for slow mixing with the same stirring time of 5 minutes. Meanwhile, the settling time was set to 30 minutes.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this study, a total of 3 raw water samples were obtained and analyzed to determine the percentage of turbidity removal of the colloidal raw water by using two different coagulants. Six series of jar tests were done to determine the optimum dosage of coagulants for turbidity removal for raw water taken from Sg. Serai. However, only several results from the many series of jar test were successful as shown in the Appendix A. The unsuccessful results were included in Appendix B. Five alphabets namely A, J, P, S and U were used to label the results in the Appendices as shown in Table 4.1. The optimum dosages of the selected coagulants were determined from the different dosages used with the percentages of the turbidity removal. Aluminium sulphate and PAC used as coagulants show ineffective performances based on their low percentages of turbidity removal. Some jar tests were conducted by using sodium carbonate to adjust the pH before the coagulants were added. The results obtained were quite successful in achieving the objectives of this study as the percentage of turbidity removal is high.

Table 4.1: Description of labelling in Appendices

Label	Description
A	Aluminium sulphate
P	PAC
SC	Sodium Carbonate
S	Successful result
U	Unsuccessful result

4.2 Analysis of Unsuccessful Result

The result obtained during the first test using PAC was not as expected. Many errors were made for example during sucking up the raw water to be tested, the raw water was bubbling. This caused small particles that had settled at the bottom raised to the upper surface. As a result, the readings of turbidity were increased from the initial value and affected the percentage of turbidity removal. Figure 4.1 shows the unusual results due to errors made.

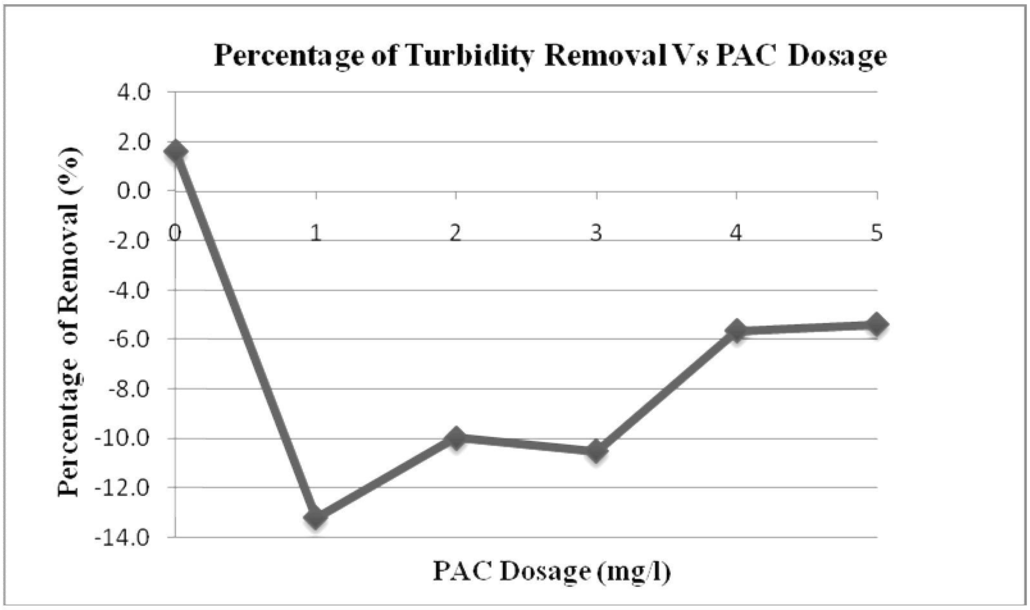


Figure 4.1: Percentage of turbidity removal by using different dosing of PAC

Based on Figure 4.1, it was observed that lowest turbidity removal is -13.2% at 1 mg/l of PAC. The percentage is continously in negative value with the increment of PAC dosage.The maximum percentage of turbidity removal is 1.6% where no coagulant was added. After errors were detected, the following lessons were noted,

a. One must always ensure that the procedures adopted to conduct the experiments are correct.

b. One must always observe changes in sample during the experiment and use common sense to see wherever procedures are correctly followed.

In subsequent experiments the followings precautions were made:

a. Make sure that there is no bubble in the syringe.

b. The procedure must be conducted in systematic manner.

Similarly, the result obtained during the first test by using Aluminium Sulphate $Al_2 (SO_4)_3$ as coagulants was not as expected. There were a lot of errors made that greatly influence the results. The first error made was wrong calculation to determine the actual volume of aluminium sulphate in preparing the stock solutions. The distilled water was added too much and that affected the volume of aluminium sulphate added into each beaker, resulting in low coagulation flocculation process. As a result, the percentage of turbidity removal was very low as shown in Figure 4.2.

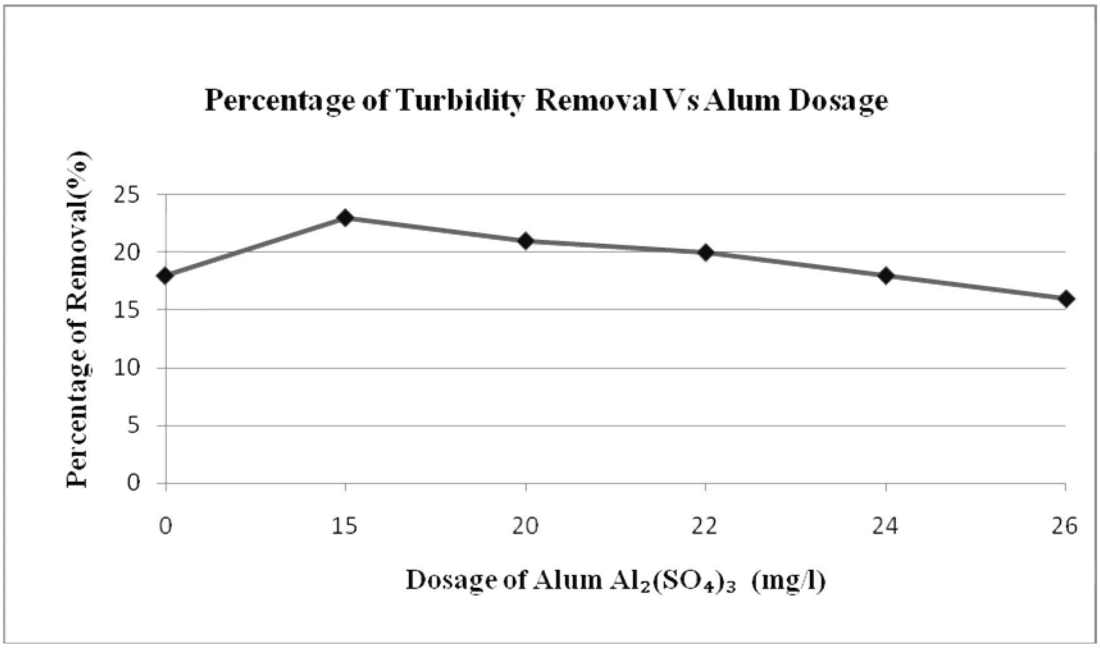


Figure 4.2: Percentage of Turbidity Removal by using aluminium sulphate $Al_2(SO_4)_3$

Based on Figure 4.2, the maximum percentage of turbidity removal achieved 23% with 15 mg/l of aluminium sulphate. However, the percentage decreased over the increment dosage of aluminum sulphate. The errors were detected as the percentage of turbidity removal without no coagulant is same although the coagulant was added. The following lessons were learned from the errors;

a. One must always make sure that the calculations carried out in experiment are correct.
b. One must always ensure that the equipment being used is in good condition.
c. One must being focused, patient and observant throughout conducting the experiments.

As a result, the following improvements in procedures were adopted,

a. A correct calculation on proportion distilled water and aluminium sulphate were made.
b. The preparation of stock solution is carried out carefully.

4.3 Analysis of Successful Result

The result obtained in the second stage of the work were quite successful for both aluminium sulphate or PAC. Figure 4.3 shows the percentage of turbidity removal using PAC as coagulant.

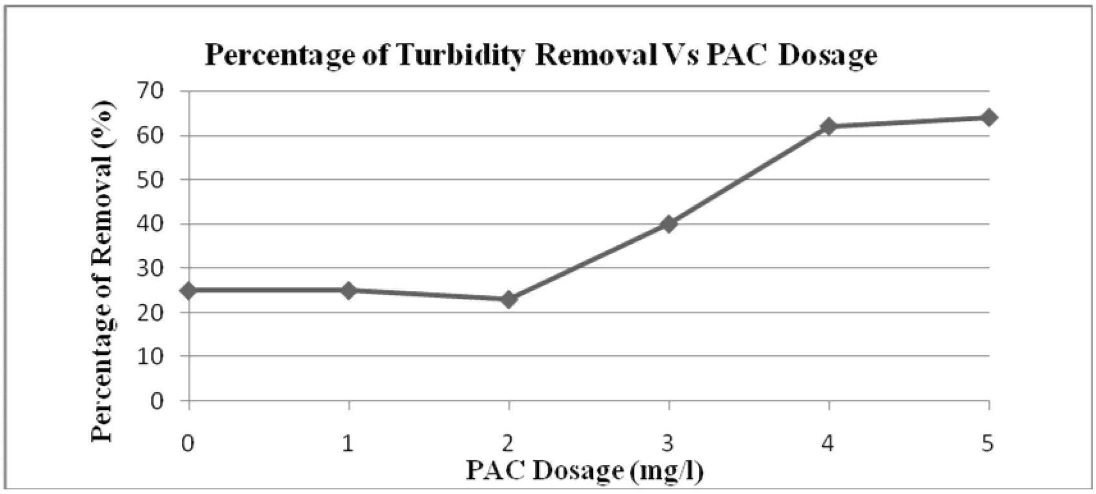


Figure 4.3: Percentage of turbidity removal by using different dosing of PAC

It was observed that turbidity removal initially decreased but starting from the 2 mg/l of PAC dosage the percentage of turbidity removal increased. The maximum percentage of turbidity removal is 64% at 5 mg/l of PAC and the minimum percentage of turbidity removal is 23 mg/l. It shows that the percentage of turbidity removal is not uniform over the range of dosage of PAC. Another jar test was also conducted in the range of 6 to 10 mg/l of PAC. Figure 4.4 shows the percentage of turbidity removal by using 6 to 10 mg/l of PAC.

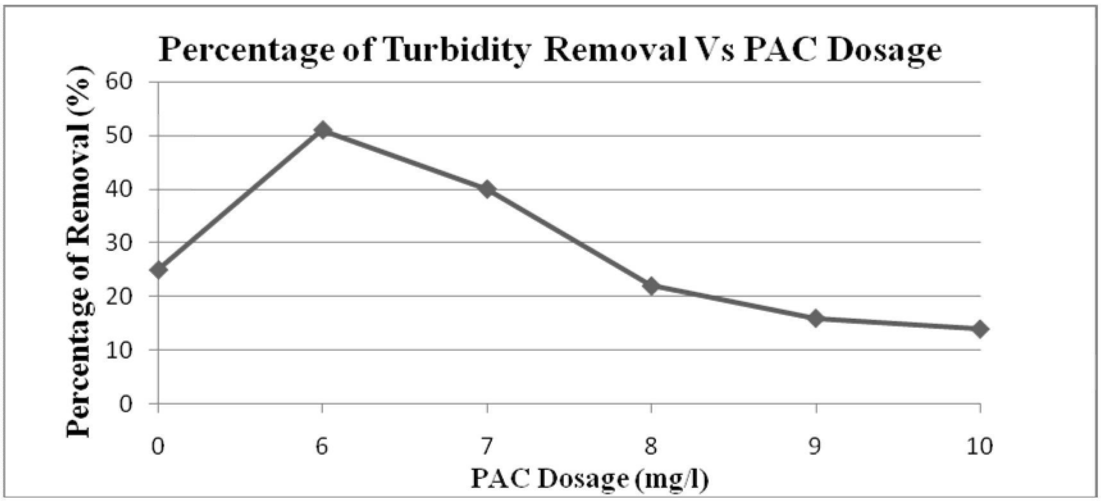


Figure 4.4: Percentage of turbidity removal by using 6 to 10 mg/l of PAC

However the result obtained shows that the maximum percentage of turbidity removal is only 51% at 6 mg/l of PAC. Then the percentage of turbidity removal suddenly drop when the dosages of PAC increased. The minimum percentage removal achieved 14% at 10 mg/l of PAC.

Analysis of results for a series of jar test, using aluminium sulphate as coagulant in the range of 10 to 30 mg/l was performed to evaluate the effectiveness of coagulation process. Figure 4.5 shows the percentage of turbidity removal with aluminium sulphate as coagulant.

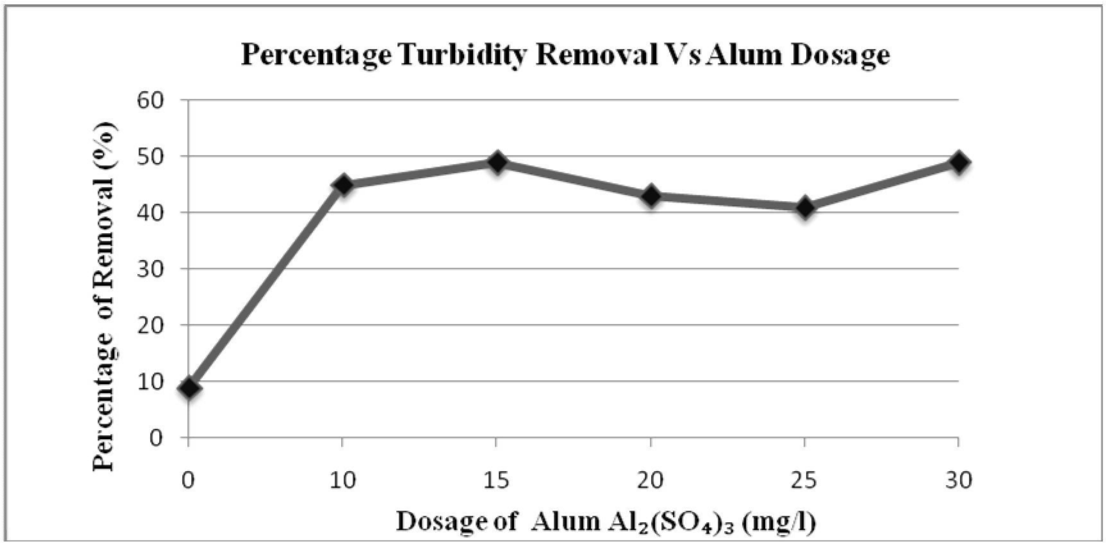


Figure 4.5: Percentage of turbidity removal by using Aluminium Sulphate $Al_2(SO_4)_3$

The optimum dosage of aluminium sulphate is 15 mg/l with 49% turbidity removal. 10% turbidity removal was achieved as minimum percentage with no coagulant was added. In some cases fine colloidal material may be present in the raw water which may cause some difficulties in the coagulation process.

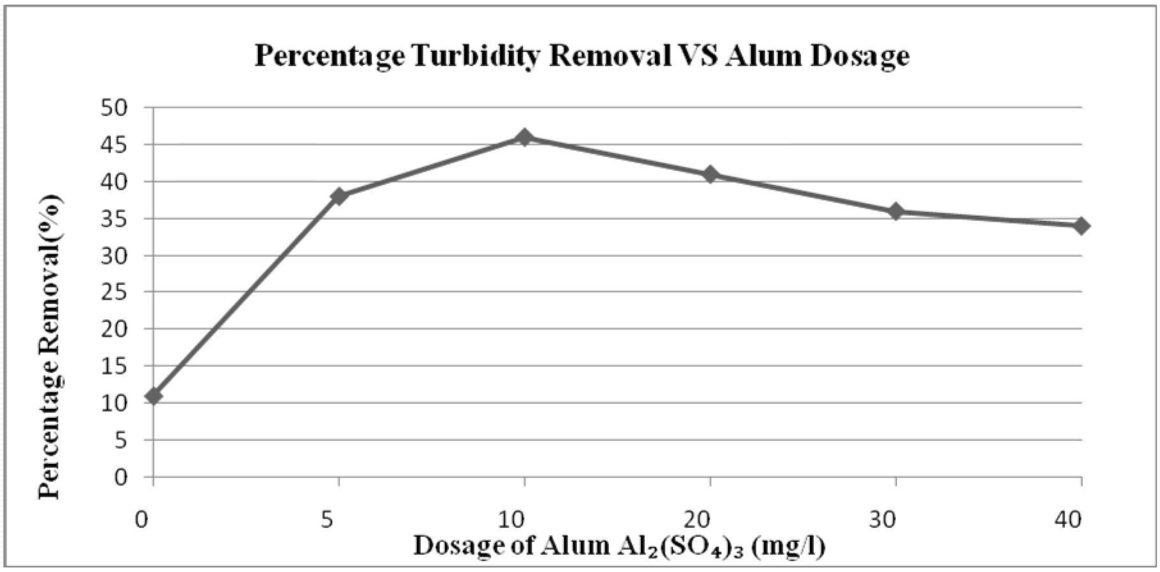


Figure 4.6: Percentage of Turbidity Removal by Using Aluminium Sulphate $Al_2(SO_4)_3$

Figure 4.6 otherwise shows the percentage of turbidity removal in range of 5 to 40 mg/l of aluminium sulphate. It was observed that the percentage of turbidity removal increased as percentage of dosing increased from 0 to 10 mg/l. Further increment in dosages leads to decrease in turbidity removal. Over dosage of coagulant can hinder the coagulation process. It was established that maximum turbidity removal occurs at 10 mg/l of aluminium sulphate. Figure 4.5 and 4.6 shows the different results obtained using aluminium sulphate as coagulant.

Another series of jar test was also conducted with addition of sodium carbonate to adjust the pH before coagulant was added. The common problems of coagulation are related to improper pH levels. The sodium carbonate will lower the acidity of the raw water. Figure 4.7 shows the percentage of turbidity removal by using aluminium sulpahate as coagulant (with addition of sodium carbonate).

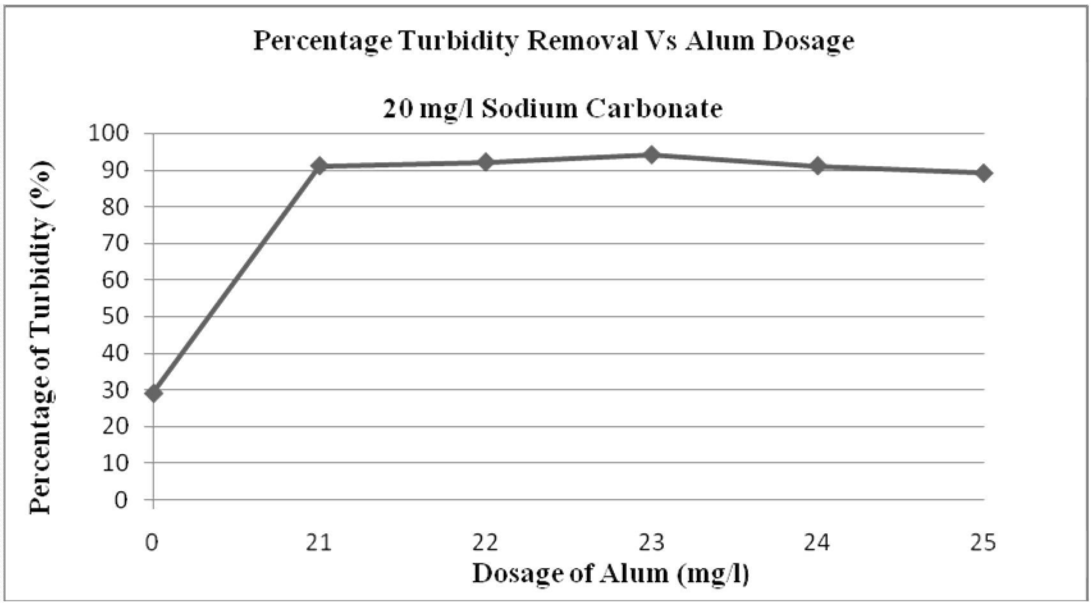


Figure 4.7: Percentage of turbidity removal by alum with sodium carbonate for pH adjustment

Based on Figure 4.7, the optimum dosage occur ~~is~~ with 23 mg/l of aluminium sulphate (and 20 mg/l of sodium carbonate) giving 94 % turbidity removal. It was observed that the percentage of turbidity removal suddenly increased to 91 % at 21 mg/l of aluminium sulphate (with 20 mg/l sodium carbonate). After that, the graph still increased slightly until the maximum turbidity removal is achieved and dropped slightly until the last dosage. Range of 21 to 25 mg/l of aluminium sulphate and 20 mg/l of sodium carbonate is the optimal dosage as 90% removal was achieved.

Jar test with PAC as coagulant was also conducted with pH adjustment using sodium carbonate. Figure 4.8 shows the turbidity removal with PAC as coagulant with addition of sodium carbonate.

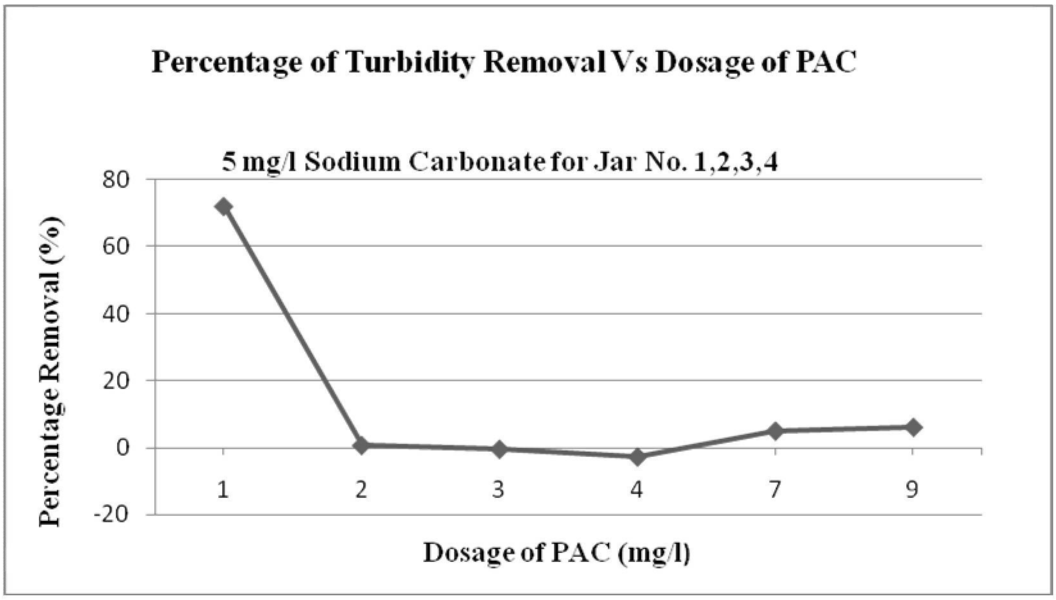


Figure 4.8: Percentage of turbidity removal by PAC and sodium carbonate for pH adjustment

As shown in Figure 4.8, the optimum dosage occurred at 1 mg/l of PAC (with 5 mg/l of sodium carbonate) that removes 72 % of turbidity. However the percentage of turbidity removal suddenly dropped to negative value after the maximum percentage of turbidity removal was achieved. It was established that the dosage increment leads to the low turbidity removal. With pH adjustment, aluminium sulphate greatly removes the turbidity compared to PAC.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has established the effectiveness of turbidity removal for raw water taken from Sg.Serai by using two selected coagulants, namely aluminium sulphate $Al_2(SO_4)_3$ and PAC. Based on the results obtained, the optimum dosage of aluminium sulphate is 15 mg/l with 49 % of turbidity removal. The optimum dosage of PAC is 5 mg/l with 64 % of turbidity removal. In the case with pH adjustment through addition of sodium carbonate, the optimum dosage for aluminium sulphate is 23 mg/l (with 20 mg/l of sodium carbonate) where 94 % turbidity removal was achieved. The optimum dosage for PAC is 1 mg/l (with 5 mg/l of sodium carbonate) that removes 72 % of turbidity.

Without PH adjustment, PAC is more effective in turbidity removal compared to aluminium sulphate. The optimum dosage of PAC required to removes the turbidity is also low compared to aluminium sulphate. However in the case of pH adjustment, alumin ium sulphate greatly removes the turbidity of the raw water as it achieved 94 % turbidity removal. The dosage of aluminium sulphate required is higher compared to the PAC to remove the turbidity.

5.2 Recommendations

Based on the results, the recommendations on future research should be as follows;

a) Study on other coagulants that potential to remove the kaolin in surface water

b) Further studies to characterize the water in establishing the hydrophilic or hydrophobic nature of the solids.

c) Study on that effect the coagulation flocculation process thus resulting in getting good results.

REFERENCES

AWWA (1971), **Water Quality and Treatment; A Handbook of Public Water Supply**, American Water Works Association, 3rd Edition, Mc Graw Hill Book Company, United States

Arkles, B. (2006), **Hydrophobicity, Hydrophilicity and Silanes**, Paint & Coating Industry Magazine

Carboni, G. (2002), **Surface Phenomena and Colloids**, http://www.funsci.com/fun3-en/exper2/html, Accessed on (20 JAN/2009)

Chan, E.Y. (2007), **Turbidity Removal Using Moringa Oleifera as Coagulant** , Project of Bachelor of Civil Engineering Project Report, Faculty Civil Engineering, Universiti Teknologi Malaysia

Culp ,W. (1986), **Handbook of Public Water Systems** , edited by Robert B.Williams and Gordon L.Culp,Van Nostrand Reinhold Company Inc, New York

Davis, M.L, Cornwell, D.A. (1998), **Introduction To Environmental Engineering**, 3rd Edition, Mc Graw Hill, United States

DOE (2009), **Groundwater Monitoring**, Department of Environment, http://www.jas.sains.my/en/content/groundwater-quality-monitoring, accessed on (8 AUGUST/2009)

Divakiran, R., Pillai V.N.S. (2001), **Flocculation of Kaolinite Suspensions In Water by Chitosan,** Wat. Res. Vol. 35, No. 16, pp. 3904–3908, Elsevier

Earp, D., Postlethwait, J. and Witherspoon, J. (2006), **Environmental Topic-Water**, http://www.cabq.gov/aes/s5water.html, Accessed on (25 FEB/2009)

ENCO Engineering (2008), http://www.enco.ch/pac.html**,** **Polyaluminium Chloride Technology**, Switzerland, Accessed on (20 JAN/2009)

GE (2008), **Chapter 5-Clarification**, GE Water & Process Technologies, http://www.gewater.com, Accessed on (20 JAN/2009)

Ho,Y.C, Ismail, N., Mohamad Abbas, N., Al Karkhi, F.M. (2008), **Pectin as Bio-flocculant For Turbidity Reduction in Waste Water Treatment,** International Conference on Environmental Research and Technology (ICERT), Pulau Pinang

Hong, Z.W., Yu, L.H, How L.H., Jui, P.C., Chien, S.C., Pearl Hsiu, P.L. (2008), **Application of Biocoagulant on Drinking Water Treatment**, American Society of Civil Engineer Journal

JKR (2007**), Historical Development of Water Supply**, Public Works Department, http://www.jkr.gov.my/air/hist/hisdet.html, Accessed on (22 JAN/2009)

Lau, L.S (2007), **Cactus Potential As Natural Coagulant in Water Treatment,** Bachelor of Civil Engineering Project Report, Faculty Civil Engineering, Universiti Teknologi Malaysia

Manahan, S.E (2007), **Environmental Science and Technology, A Sustainable Approach to Green Science and Technology**, 2nd Edition, CRC Press, United State

Mahvi, A.H., and Razavi, M. (2005), **Application of Polyelectrolyte in Turbidity Removal From Surface Water**, American Journal of Applied Science 2(1):397

Omar, R. (2005), **Water and Wastewater Engineering**, Uitm Publications

Pal, S., Mal D, and Singh R.P. (2005), **Cationic Starch:An Effective Flocculating Agent**, Elsevier Journal, 59:417-423

Pike, J. (2005), **Water Treatment**, http://www.globalsecurity.org/military/library/army/html, (25 FEB/ 2009)

PNSB (2009), **Water Treatment Process**, Puncak Niaga Sdn. Bhd, http://www.puncakniaga.com.my/services/watertreatmentprocess/typicalsystem/tabid/103/default.aspx (7 JULY/2009)

Raja Zainal Abidin, R. D. Z. (2005), **Water Malaysia 2005**, http://www.epu.jpm.my/New%20Folder/speech/kpspeech/WM2005_text_final.html, (22 JAN / 2009)

Runkana, Venkataramana, Somasundaran, P., Kapur, P.C. (2006), **A Population Balance for Flocculation of Colloidal Suspensions by Polymer Bridging**, Chemical Engineering Science,61:182-191

Srinivasan, P.T.,and Viraraghavan T. (2002), **Characterization and Concentration Profile of Aluminium During Drinking Water Treatment**, Water SA

Spellman, F.R. (2008), **The Science of Water; Concepts and Applications**, 2nd Edition, CRC Press, United States

DWAFSA (2002), **Quality of Domestic Water Supplies,Volume 4: Treatment** Guide, Department of Water Affairs and Forestry of South Africa, 1st Edition, South Africa

MWP (2001), **Malaysia's Water Vision:The Way Forward**, Malaysian Water Partnership, Kuala Lumpur

Wikipedia (2008), **Kaolinite,** http://en.wikipedia.org/wiki/kaolinite, (30 DEC/ 2009)

WHO (2008), **WHO Seminar Pack For Drinking-Water Quality**, World Health Organization

Zubin, K. (2009), **Enforcement Failure** , http://www.mmail.com.my/, (23 JAN/2009)

APPENDIX A

Table A1: Data results for JPS_1

Jar No	1	2	3	4	5	6
Raw Water Quality						
Turbidity (NTU)	17					
pH	5.76					
Chemical Dosage						
PAC (mg/l)	0	1	2	3	4	5
After Rapid Mixing Water Quality						
Turbidity (NTU)	17	15.1	15.6	16.1	16.3	16.2
pH	5.73	5.81	5.96	5.96	5.92	5.88
After Sedimentation Water Quality						
Turbidity (NTU)	12.7	12.8	13.1	10.2	6.44	6.1
pH	5.97	5.82	5.8	5.73	5.7	5.67
Percentage of Removal						
Turbidity (%)	25	25	23	40	62	64

Table A2: Data results for JPS_2

Jar No	1	2	3	4	5	6
Raw Water Quality						
Turbidity (NTU)	17					
pH	5.76					
Chemical Dosage						
PAC (mg/l)	0	6	7	8	9	10
After Rapid Mixing Water Quality						
Turbidity (NTU)	14	16.9	16.3	16.7	17.4	17.1
pH	5.73	5.81	5.96	5.96	5.92	5.88
After Sedimentation Water Quality						
Turbidity (NTU)	12.7	8.38	10.2	13.2	14.3	14.7
pH	5.86	5.66	5.62	5.51	5.56	5.56
Percentage of Removal						
Turbidity (%)	25	51	40	22	16	14

Table A3: Data results for JPS_SC2

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	7.9					
pH	6.27					
Chemical Dosage						
PAC (mg/l)	1	2	3	4	7	9
Sodium Carbonate (mg/l)	5	5	5	5	0	0
After Slow Mixing Water Quality						
Turbidity (NTU)	2.2	7.85	7.94	8.12	7.51	7.42
pH	7.24	6.94	6.79	6.43	5.47	5.37
Percentage of Removal						
Turbidity (%)	72.2	0.6	-0.5	-2.8	4.9	6.1

Table A4: Data results for JAS_1

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	17					
pH	5.76					
Chemical Dosage						
Alum (mg/l)	0	10	15	20	25	30
After Rapid Mixing Water Quality						
Turbidity (NTU)	15.5	15.5	15.1	16.3	15.4	15.4
pH	5.81	5.05	4.76	4.62	4.5	4.43
After Sedimentation Water Quality						
Turbidity (NTU)	15.5	9.27	8.73	9.63	10.1	8.72
pH	5.81	4.66	4.58	4.5	4.45	4.42
Percentage of Removal						
Turbidity (%)	9	45	49	43	41	49

Table A5: Data results for JAS_3

Jar No	1	2	3	4	5	6
Raw Water Quality						
Turbidity (NTU)	17.6					
pH	5.93					
Chemical Dosage						
Alum (mg/l)	0	5	10	20	30	40
After Rapid Mixing Water Quality						
Turbidity (NTU)	17.6	17.6	17.9	18	18.2	17.5
pH	5.93	5.06	4.97	4.66	4.47	4.39
After Sedimentation Water Quality						
Turbidity (NTU)	15.7	10.9	9.45	10.4	11.2	11.7
pH	5.85	5.1	4.82	4.68	4.56	4.48
Percentage of Removal						
Turbidity (%)	11	38	46	41	36	34

Table A6: Data results for JAS_3

Jar No	1	2	3	4	5	6
Raw Water Quality						
Turbidity (NTU)	17.6					
pH	5.93					
Chemical Dosage						
Alum (mg/l)	0	20	22	24	26	28
After Rapid Mixing Water Quality						
Turbidity (NTU)	17.3	17.7	18.5	18.2	17.8	18
pH	5.79	4.66	4.63	4.62	4.6	17.5
After Sedimentation Water Quality						
Turbidity (NTU)	15.7	11.2	10.8	9.75	10.9	11.4
pH	5.89	4.63	4.62	4.6	4.59	4.55
Percentage of Removal						
Turbidity (%)	11	36	39	45	38	35

Table A7: Data results for JAS_SC1

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	17					
Ph	5.76					
Chemical Dosage						
Alum (mg/l)	0	21	22	23	24	25
SA(mg/l)	0	20	20	20	20	20
After Rapid Mixing Water Quality						
Turbidity (NTU)	13.4	14.9	14.7	14.5	15.1	15.7
Ph	5.7	6.66	6.48	6.34	6.36	6.37
After Sedimentation Water Quality						
Turbidity (NTU)	12	1.45	1.41	0.98	1.56	1.89
Ph	6.06	6.61	6.55	6.44	6.4	6.3
Percentage of Removal						
Turbidity (%)	29	91	92	94	91	89

APPENDIX B

Table B1: Data results for JPU_1

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	7.42					
pH	6.04					
Chemical Dosage						
PAC (mg/l)	4	5	6	8	10	12
After Slow Mixing Water Quality						
Turbidity (NTU)	7.98	7.85	7.74	7.7	7.7	7.58
pH	5.75	5.6	5.23	5.19	5.06	5.02
Percentage of Removal						
Turbidity (%)	-7.5	-5.8	-4.3	-3.8	-3.8	-2.2

Table B2: Data results for JPU_2

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	7.42					
pH	6.04					
Chemical Dosage						
PAC (mg/l)	0	1	2	3	4	5
After Slow Mixing Water Quality						
Turbidity (NTU)	7.3	8.4	8.16	8.2	7.84	7.82
pH	6.04	5.97	5.99	5.86	5.63	5.54
Percentage of Removal						
Turbidity (%)	1.6	-13.2	-10.0	-10.5	-5.7	-5.4

Table B3: Data results for JPU_3

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	17					
pH	5.76					
Chemical Dosage						
PAC (mg/l)	0	11	12	13	14	15
After Rapid Mixing Water Quality						
Turbidity (NTU)	13.4	17	17.3	17.6	17.2	17.5
pH	5.95	5.62	5.6	5.57	5.61	5.52
After Sedimentation Water Quality						
Turbidity (NTU)	13.1	14.1	14.6	14.5	14.8	14.6
pH	5.84	5.63	5.56	5.51	5.5	5.44
Percentage of Removal						
Turbidity (%)	23	17	14	15	13	14

Table B4: Data results for JPU_4

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.5					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	1	2	3	4	6	7
After Rapid Mixing Water Quality						
Turbidity (NTU)	5.25	5.62	5.57	5.43	5.25	5.19
pH	6.93	6.8	6.59	6.43	6.31	6.13
After Sedimentation Water Quality						
Turbidity (NTU)	5.85	5.62	5.57	5.43	5.25	5.19
pH	6.8	6.61	6.45	6.37	6.17	5.99
Percentage of Removal						
Turbidity (%)	10.0	13.5	14.3	16.5	19.2	20.2

Table B5: Data result for JPU_7

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.5					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	8	9	11	13	15	16
After Rapid Mixing Water Quality						
Turbidity (NTU)	4.84	4.79	4.81	4.67	4.78	4.73
pH	6.2	6.51	6.24	6.35	6.11	6.17
After Sedimentation Water Quality						
Turbidity (NTU)	5.11	5.04	4.77	4.78	4.81	4.78
pH	6.2	6.14	6.03	5.9	5.91	5.98
Percentage of Removal						
Turbidity (%)	21.4	22.5	26.6	26.5	26.0	26.5

Table B6: Data result for JPU_8

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.5					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	1	2	4	6	8	10
After Rapid Mixing Water Quality						
Turbidity (NTU)	5.19	5.6	5.21	5.07	5.04	5.06
pH	6.57	6.85	6.6	6.9	6.48	6.44
After Sedimentation Water Quality						
Turbidity (NTU)	5.74	5.77	5.1	5.52	5.28	5.12
pH	6.39	6.66	6.03	6.38	6.22	6.09
Percentage of Removal						
Turbidity (%)	11.7	11.2	21.5	15.1	18.8	21.2

Table B7: Data results for JPS_SC1

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.17					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	0.5	1	1	1.5	2	2.5
Sodium Carbonate (mg/l)	5	4	5	5	5	5
After Rapid Mixing Water Quality						
Turbidity (NTU)	5.5	5.82	5.49	5.77	5.66	5.94
pH	6.44	6.74	6.89	6.79	6.74	6.63
After Sedimentation Water Quality						
Turbidity (NTU)	5.26	5.59	2.83	5.73	5.67	5.78
pH	7.12	6.99	7.04	6.99	6.87	6.83
Percentage of Removal						
Turbidity (%)	14.7	9.4	54.1	7.1	8.1	6.3

Table B8: Data results for JPU_SC2

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	7.42					
pH	6.04					
Chemical Dosage						
PAC (mg/l)	5	6	8	10	12	14
Sodium Carbonate (mg/l)	5	10	10	10	10	0
After Slow Mixing Water Quality						
Turbidity (NTU)	8.31	8.13	8.06	7.9	8.22	7.46
pH	6.36	6.69	5.75	4.54	4.56	3.34
Percentage of Removal						
Turbidity (%)	-12.0	-9.6	-8.6	-6.5	-10.8	-0.5

Table B9: Data results for JPU_SC3

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	7.9					
pH	6.27					
Chemical Dosage						
PAC (mg/l)	0	10	10	12	12	14
Sodium Carbonate (mg/l)	0	0	20	**0**	20	0
After Slow Mixing Water Quality						
Turbidity (NTU)	7.9	7.76	7.94	7.2	8.34	8.14
pH	6.27	5.31	6.84	5.21	6.68	6.66
Percentage of Removal						
Turbidity (%)	0.0	1.8	-0.5	8.9	-5.6	-3.0

Table B10: Data results for JPU_SC4

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.5					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	0	1	5	10	12	14
Sodium Carbonate (mg/l)	0	5	0	0	0	0
After Rapid Mixing Water Quality						
Turbidity (NTU)	5.99	6.44	6.6	6.11	6.01	6.04
pH	6.67	6.22	5.3	4.81	4.79	4.79
After Sedimentation Water Quality						
Turbidity (NTU)	5.63	6.03	6.22	6.09	5.66	5.76
pH	6.14	6.52	5.23	4.86	4.77	4.79
Percentage of Removal						
Turbidity (%)	13.4	7.2	4.3	6.3	12.9	11.4

Table B11: Data results for JPU_SC5

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.17					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	10	12	14	16	18	20
Sodium Carbonate (mg/l)	10	10	10	10	10	10
After Rapid Mixing Water Quality						
Turbidity (NTU)	5.98	5.9	6.11	5.66	5.68	5.74
pH	6.17	6.07	6	5.89	5.69	5.67
After Sedimentation Water Quality						
Turbidity (NTU)	5.82	5.81	5.84	5.74	5.72	5.82
pH	6.08	6.11	6.06	6.03	5.91	5.82
Percentage of Removal						
Turbidity (%)	5.7	5.8	5.3	7.0	7.3	5.7

Table B12: Data results for JPU_SC6

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	6.17					
pH	5.9					
Chemical Dosage						
PAC (mg/l)	0	1	2	4	6	8
Sodium Carbonate (mg/l)	0	5	5	5	5	5
After Rapid Mixing Water Quality						
Turbidity (NTU)	5.78	5.87	5.81	5.89	5.61	5.84
pH	5.68	5.94	6.05	5.54	5.81	5.85
After Sedimentation Water Quality						
Turbidity (NTU)	5.43	3.67	5.79	6.05	5.82	5.76
pH	5.84	6.87	6.3	6.1	6.09	6.07
Percentage of Removal						
Turbidity (%)	12.0	40.5	6.2	1.9	5.7	6.6

Table B13: Data results for JAU_1

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	17					
pH	5.76					
Chemical Dosage						
Alum (mg/l)	0	15	20	22	24	26
After Rapid Mixing Water Quality						
Turbidity (NTU)	16	16.2	15.8	14.9	16.8	17.5
pH	5.7	6.12	5.44	5.04	5.21	4.88
After Sedimentation Water Quality						
Turbidity (NTU)	13.9	13.1	13.4	13.6	13.9	14.3
pH	5.82	7.27	7.29	7.26	7.3	7.07
Percentage of Removal						
Turbidity (%)	18	23	21	20	18	16

Table B14: Data results for JAU_SC1

Jar No	**1**	**2**	**3**	**4**	**5**	**6**
Raw Water Quality						
Turbidity (NTU)	17					
pH	5.76					
Chemical Dosage						
Alum (mg/l)	0	11	12	13	14	15
SA(mg/l)	0	20	20	20	20	20
After Rapid Mixing Water Quality						
Turbidity (NTU)	16.6	15.7	16.5	16.8	16.1	16.4
pH	5.63	7.07	7.18	7.21	7.24	7.16
After Sedimentation Water Quality						
Turbidity (NTU)	14.5	13	13.2	12.9	12.5	12.9
pH	5.82	7.27	7.29	7.26	7.3	7.07
Percentage of Removal						
Turbidity (%)	15	24	22	24	26	24