USE OF RECYCLE FERRIC CHLORIDE EXTRACTED FROM GROUNDWATER TREATMENT PLANT SLUDGE IN THICKENING OF MUNICIPAL SLUDGE AND TREATMENT OF LEACHATE.

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CERTIFICATION OF APPROVAL

Use of Recycle Ferric Chloride (RFC) Extracted from Groundwater Treatment Plant Sludge in Thickening of Municipal Sludge and Treatment of Leachate

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ALIA HAFIZA BINTI ABD HAMID

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ABSTRACT

This study investigated the effectiveness of a coagulant, Recycled Ferric Chloride (RFC) for reused in thickening the municipal sludge and treating landfill leachate. The RFC is generated from sludge produced from a groundwater treatment plant through a digestion process. The study had been divided into two (2) phase. For both phases of the study, jar tests were conducted for the treatment process. In the jar test, coagulants such as alum, ferric chloride, ferrous sulphate and RFC were evaluated. In the first phase of the experimental study, jar tests were conducted on sludge obtained from a wastewater treatment plant. Settleability tests were conducted in the thickening process. The supernatant were then measured for chemical oxygen demand (COD), colour, and total suspended solids (TSS). Tests were conducted in triplicates. The raw sludge settling rate was found to be 2.4 cm/min. The optimum settling rates for alum, ferric chloride, ferrous sulphate and RFC was found to be 3.13 cm/min, 1.86 cm/min, 2.5 cm/min and 4.5 cm/min. RFC improved the settling rate by 88% and also removed colour, COD and TSS at 42%, 54% and 88%, respectively at the optimum settleability dosage. For the second phase of the experimental study, the jar tests were conducted on leachate obtained from Pulau Burung Landfill Site. The supernatant were then measured for chemical oxygen demand (COD), colour, and total suspended solids (TSS). RFC improved the colour and COD removed at 64% and 60% respectively at the optimum dosages. However further research need to be done on the suspended solid removal since the result shows that the suspended solid is increasing after the treatment process. RFC managed to remove the suspended solid for 32% at the optimum dosage.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

A groundwater treatment plant produces 5 tonnes of sludge daily that require off site disposal. The sludge produced contained high amount of metals such as iron, aluminum and manganese. Most of these metals are component of chemicals that are being used as a coagulant in water treatment plant.

The main problem that the groundwater treatment plant faced is to treat and disposed the sludge produced daily. Thus this project was conducted in order to control the pollution by extracting the sludge to produce a new RFC. The sludge was digested using the concentrated hydrochloric acid to produce RFC. The commercial coagulants are normally being used to treat the wastewater are alum (aluminum sulphate, Al_2 $(SO_4)_2$, ferric chloride ($FeCl_2$) and Ferrous Sulphate ($FeSO_4$).

The main purpose of this project is to evaluate the effectiveness of the RFC compare to the commercial coagulants. Alum and ferric chloride are normally being used in the water treatment process due to the availability, reasonable cost and better performance in treating and removing the solid in the water. The project was divided into two (2) phase, the first phase was treating the municipal sludge taken from UTP water treatment plant while the second phase of this project, the effectiveness of the recycled coagulant was compared for treating the landfill leachate taken from Pulau Burung Landfill Site. The dosing of each coagulant had been varied at optimum pH for type of coagulants. The project mainly focusing on the sludge thickening process in the first phase of the project besides focusing on the optimum dosage of coagulant to removed COD, TSS, colour and heavy metal in the water treated in the second phase of the projects.

1.2 Problem Statement

The groundwater treatment plant produced 5 tonnes of sludge daily. The industry main problem are disposing and treating the sludge produced since the cost needed to treat the sludge is very high. However the sludge cannot simply being disposed into the river since the presence of various kinds of metal such as iron, aluminum and manganese in the sludge. All of these non hazardous metals will caused changes in taste, staining and accumulation problem if the sludge being discharge into the river.

1.3 Objective

The project is to study the effectiveness of the RFC as compare to the commercial coagulants in thickening the municipal sludge for the phase of the study and treating the landfill leachate for the second phase of the study. This project is focusing on minimizing the expenditures on the usage of the commercial coagulant in the water treatment plant besides controlling the pollution.

1.4 Scope of Works

This project treatment includes:

Phase 1: Thickening the Municipal Sludge

i) Settleability of the water after the coagulation and flocculation process.
ii) The colour measured after water treatment process.
iii) The TSS measured after the treatment process.
iv) The COD measured of the supernatant after the treatment process.

Phase 2: Treating the Landfill Leachate

i) Determine the optimum pH for the coagulation and flocculation process to occur using the RFC.
ii) The Chemical Oxygen Demand (COD) removal of the supernatant after the treatment process.
iii) The colour removal after the treatment process.
iv) The Total Suspended Solid (TSS) of the sample after the treatment process.

The experiment was conducted using four (4) different types of coagulants at various dosages in order to determine the effectiveness of the RFC.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Recovery coagulant has widely being used in treating water including treating municipal wastewater and leachate. The main objective of producing the RFC is to control the pollution besides minimizing the cost to treat the wastewater. There are four (4) stages of water treatment process. The first stage is preliminary stage where all the grit and solid being removed. Only physical treatment involved in this stage. The waste being discharged is still with pathogen and viruses. On the second stage, 50-70% of the suspended solid being removed from the wastewater through settling process. In this these stage, there are still no biological treatment being conducted. The water discharged with full of pathogen and viruses. The third stage and final stage involved the biological treatment where 90% of the pathogens and viruses being removed in the third stage. However in the final stage, almost 99.9% of the pathogens and viruses had been removed and the water discharged for daily used.

2.2 Recovery of Coagulants from water treatment sludge

Water treatment sludge has been extracted in treatment of textile waste water [Vaezi et al, 2001]. Iron based coagulants have been found to be suitable in removing the arsenic in the groundwater [German, 2004]. Extraction of recycled coagulants has also been proven to be effective in wastewater treatment through sulphuric acid digestion [Ishikawa et. al., 2006]. Aluminum has also been recovered from sludge through acidic and alkaline leaching process [Rui et. al., 2000]. This project was conducted in Portugal since they produced 66000 ton/yr and it being disposed of on land or at municipal solid waste (MSW) landfill [Rui et. al., 2000].

Japanese researchers study indicated that in treating raw influent obtained from a sewage treatment plant and wastewater from a coastal landfill site, the removal of chemical oxygen demand (COD), total nitrogen, and total phosphorous with the recovered coagulant was higher than that with commercial aluminum sulfate or poly aluminum chloride [Ishikawa et. al., 2006]. The coagulant recovered from water supply plant sludge by sulphuric acid extraction could be successfully reused for the clarification of domestic and food industry wastewaters [Ishikawa et. al., 2006]. The sludge settling properties, the extra sludge mass formation, the supernatant quality, and the cost of reagents were also studied [Ishikawa et. al., 2006].

2.3 Municipal Sludge

Municipal waste water effluent are complex mixture that contained human waste, suspended solid, debris and variety of chemicals that come from residential and commercial industries [NWRI, 2004]. It is one of the largest sources of pollution in the water bodies in Canada (by volume) [NWRI, 2004, CCME, 2008]. Wastewater treatment needed so that river and stream water suitable to be used in our daily life such as for fishing, swimming and drinking water [EPA 832-R-04-001, 2004]. Chemical substances such as pharmaceuticals, therapeutics product and endocrine disrupting compound may cause adverse effect in the ecosystem and also the drinking water supply [NWRI, 2004]. The pollution can result to the amount of pathogen in the water will be increased such as e-coli and this will caused affect to human health. Beside that, the amount of suspended solid, significant nutrient input and the oxygen demand will be increased in the water [UN Atlas, 2007].

Sludge generated in the municipal wastewater treatment plant is applied to agricultural lands as fertilizer. However the side effect of the usage on the local surface and groundwater quality or on human health had not been found yet [NRWI, 2004]. Excess nutrient from the agriculture run off and municipal or private sewage was over fertilizing the ocean and coastal area. This is known as "dead zone" where it will increase the oxygen demand in the water – affecting the marine life [UN Atlas, 2007]. During the early effort of water pollution prevention is avoiding the human waste from reaching the drinking water supply [EPA 832-R-04-001, 2004].

The basic function of wastewater treatment system is speeding up the natural process by purifying itself. This method was only effective in the early year of the natural treatment process [EPA 832-R-04-001, 2004]. As the population and the industry development grew, increased levels of treatment prior to discharging domestic wastewater become necessary [EPA 832-R-04-001, 2004, GE Water, 2008, A. Malakahmad, 2008].

Sewage dumping is also poses main sources of pollution to coastal water. In 2002, more than 2600 of beaches in United States were closed to the public due to sewage problem [UN Atlas, 2007]. Sewage can fertilize parts of the ocean to death. It brings phosphates and nitrates into the water and causes blooms of algae so prolific that the oxygen is depleted to the point where a "dead" zone results [UN Atlas, 2007].

2.4 Landfill Leachate

Landfill is the controlled deposited of waste to land and the waste usually being deposited on the ground and build up a waste deposited site due to limitation on ground to be used [ETSU, 1998]. Leachate is a complex and highly polluted wastewater [Rasit et.al 2006]. It can be very hazardous due to the composition of chemical contained in it which may contaminate land and water especially the groundwater [ETSU, 1998].

Leachate is formed when water passes through the waste in the landfill cell or when the waste being compressed out and water entering the site from surface stream. As the liquid moves through the landfill, various kind of organic and inorganic compound will be transported through the leachate [Monroe, 2001, ETSU, 1998]. In Florida, the typical young leachate may contain 36 times higher Chemical Oxygen Demand (COD) than the raw sewage. However for the matured leachate, the COD of the leachate is as the same as the raw sewage but the amount of the biological recalcitrant organic is higher than the raw sewage [D. Englehardt et. al 2006].

A study of leachate quality and treatment of semi aerobic landfill at Ampang-Jajar, Penang landfill had been conducted for a year starting from March 2000 to February 2001 by Papa Secka. 23 parameters had been characterized and assessment of the organic compounds was also conducted resulting in the identification of 45 compounds. The leachate sample was taken from the aerated pond and the charcoal loaded adsorption tank effluent. The range and mean concentrations of all parameter were consistently higher in the raw leachate rather than the sample taken from the aerated pond and treatment tank. For the raw leachate, the mean pH is 7.9 while the mean concentration for BOD, COD, ammonia and chloride are 99.6 mg/L, 1437.7 mg/L, 1315 mg/L and 747.8 mg/L respectively. The mean concentration for BOD, COD, chloride and ammoniacal nitrogen at the pond were 14.5, 271.8, 210.2 and 16.2 mg/L. The mean concentrations of the samples taken from the treatment tank effluent were 10.8, 140.7, 119.3, 5.7 mg/L respectively [Papa Secka, 2002].

Another study on Pulau Burung Landfill Site, PBLS (semi-aerobic landfill leachate) on leachate colour removal had been conducted by Hamidi Abdul Aziz from USM. Four type of coagulant had been used in order to treat the samples which are aluminum (III) sulphate (alum), ferric (III) chloride, ferrous (II) sulphate and ferric (III) sulphate. The results show that ferric chloride shows the best result which is 94% of the colour are removed at optimum dosage of 800 mg/L at pH4. The effect of the coagulant dosages on colour removal shows similar trend as for COD, turbidity and suspended solid [H.A.Aziz et.al.2007]. Table 1 shows the characteristic of the raw leachate taken from the detention pond at Pulau Burung Landfill Site in year 2003.

Table 1: The raw leachate from new detention pond at PBLS taken from January to December 2003.

The characteristics of raw leachate from new detention pond at PBLS (landfill age about 3 years) taken from January to December 2003		
Parameter	Value	Standard B[a]
pH	7.8–9.4	5.5–9.0
COD (mg/l)	1533–3600	100
BOD (mg/l)	48–1120	50
Turbidity (NTU)	50–450	–
Suspended solid (mg/l)	159–1120	100
Colour (PtCo)	2430–8180	–
Zinc (mg/l)	0.1–1.8	1.0
Copper (mg/l)	0.1–0.4	1.0
Manganese (mg/l)	0.6–1.1	1.0
Cadmium (mg/l)	<0.04	0.02
Iron (mg/l)	0.32–7.5	5.0
[a] Standard B of the Environmental Quality (Sewage and Industrial Effluents) Regulations 1979, under the Quality Act of Environmental 1974.		

Landfill leachate is a very dark colour liquid formed primarily by the percolation of precipitation through open landfill or through the cap of the completed site. The decomposition of organic matter such as humic acid may cause the water to be yellow, brown or black (Zouboulis et al., 2004). Combinations of physical, chemical, and biological treatments are usually used to improve the treatment efficiency of landfill leachate (Kargi and Pamukoglu, 2004). There are several techniques used for colour removal. These include chemical precipitation, adsorption through granular activated carbon, nanofiltration, ozonation, radiation, UV photolysis, chemical coagulation, biological treatment with various additives, anaerobic process, fluidized bio film process, and advanced oxidation with UV/ H2O (Ahmedna et al., 2000; Kadirvelu et al., 2003; Manu and Chaudhari, 2002). However, there is no specific guideline for the treatment of colour in landfill leachate, especially in Malaysia. Coagulation followed by flocculation process is an effective way for removing high concentration of organic pollutants (Wang et al., 2002). Aluminum and iron salt coagulants have been widely used for removing humic substances from water (Amokrane et al., 1997).

2.5 Settleability of Municipal Sludge

Settleability is a phenomenon that occurs when a concentrated suspension initially of uniform concentration throughout the water was being placed in a graduated cylinder. The liquid tend to move up through the intersection of contacting particles due to high concentration of particles [Metcalf et. al., 2004]. The settleability test is often used with all kind of activated sludge in order to find out the amount of solid in aeration units [MRWA, 2007]. It is also used to determine the settling characteristic of suspension [Metcalf et. at., 2004].

2.6 Dewatering and Sludge Thickening Process

Dewatering is a process of removing water from the sludge non-thermally (without heating the sludge) [Water Solve LLC, 2008]. According to Elf Environmental in 2006, before the dewatering process, clarifier and sludge digestion need to be considered first since they are closely related to each other. If the clarifier and sludge digester are running not at the optimum conditions, the quality of the sludge dewatering process also will be affected. This process is conducted in a tertiary raw sewage treating procedure [BSP Corporation, 1971]. Normally the biosolids that need to be dewatered contained 6 – 8% of solid concentration [Jason, 1998]. Polymer such as coagulant is added into the sludge for the amount of the solid content to increase [Jason, 1998]. The coagulant coats particles to allow the solid to join together [Roy, 2005]. Sludge is thickened to improve the settling process and it will be pumped to a drier system [Roy, 2005]. After the drying process, the sludge is knows as cake because the consistency has changed with solid content of 30 – 90% [Roy, 2005]. Primary and secondary sludge thickening is useful for the anaerobic digestion process to occur because it reduces biomass volume tank size and heating requirements [WEAO].

2.7 Measurement of Settleability Rate

Poor settleability is the most problem that associated with activated sludge in water treatment plant [Gray, 2005]. There are three settleability indices which are sludge volume index (SVI), specific sludge volume index (SSVI) and diluted sludge volume index (DSVI) available [Gray, 2005]. However the most popular indices are sludge volume index and specific sludge volume index [Gray, 2005]. Juang (2005) and Seka et.al (2001) found that the sludge settleability decreasing after addition of synthetic polymer [Juang et.al 2007].

SVI is measured by filling 1 liter of sample in graduated cylinder and allow it to settle for certain duration. The volume of settled sludge is measured in mL. SVI = (V x 1000)/MLSS mL g-1. SSVI method is more widely being used since it needs more accurate sludge assessment [Gray, 2005]. SSVI measured using a special settling column 0.5m deep and 0.lm in diameter, with settlement impeded by a wire stirrer rotating at 1 rpm [Gray, 2005]. SSVI is reproducing the non-ideal situation found in the sedimentation tank [Gray, 2005]. However SVI only measured measured under complete quiescence [Gray, 2005]. According to Gray (2005), SSVI is measured by pouring 3.5 L of homogeneous mixed liquor into the cylinder to the 50 cm level. Then the stirrer is connected and the height of the sludge interface in the column measured (h_o). After 30 minutes the height of the sludge interface is measured again (h_i). The initial concentration of the suspended solid, C_o need to be known first in order for SSVI to be calculated [Gray, 2005]. SSVI calculated as, SSVI = $[(100\, h_i)/(C_o h_o)]$ mL g^{-1} [Gray, 2005].

2.8 Coagulation and Flocculation Process

Coagulation and flocculation is a process of separating the suspended solid from the water during the water treatment process [Degremont, 1991]. This process includes all of the reactions and mechanism involved in the chemical destabilization of particles and the formation of larger particles through perikinetic flocculation [Degremont, 1991]. Besides destabilizing the particles, the coagulation process also assist in removing colour and turbidity of the treated water [WSAA 41. al. 1992].Coagulant is a chemical that is added to destabilize the particle in the wastewater to be flocculated.

Flocculation is a process that involved physical transportation of destabilization of particles resulting in particles and floc formation [MRWA, 2007]. However flocculation process only affecting the physical process of flocculation. They may reduce turbidity of the water by interparticle bridging but does not help in removing the colour. Flocculation process is divided into two types. The first type is microflocculation (perikinetic flocculation) – particle aggregation is brought about by the random thermal motion of fluid molecules known as Brownian motion. The second type of flocculation is macroflocculation (orthokinetic flocculation) – particles aggregation is produced by inducing the velocity gradients and mixing in the fluid containing the particles to be flocculated [Metcalf et. at., 2004]. Flocculation is a complicated process that needs extra attention. The mixing velocity and amount of energy during the process conducted need to be control in order to prevent to the floc from tearing apart or shearing. The mixing velocity and energy input are usually tapered off as the size of the floc increase. It is difficult to get the floc to reform to their optimum size once the floc torn apart. The amount of operator control needed in flocculation process is depending on the type and design of equipment [MRWA, 2007].

A study had been conducted by Marco Guida on optimization of alum-coagulation/flocculation for COD and TSS removal for five municipal wastewaters. The study was focusing on coagulation process in treating municipal wastewater that on basis of organic material (COD and TSS removal efficiency). The alum-coagulation was optimized on 24 samples taken from 4 water treatment plants and 1 sample from a pilot plan from the university laboratory (Naples, Italy) in order to meet the Italian water quality discharge limit. A series of jar test was run at different speed and time besides various pH and dosage of alum concentration at room temperature. Raw and coagulated wastewater samples were analyzed for their COD, TSS and aluminium (RA) concentrations [M. Mattei et. al 2007].

The jar test process shows that the coagulation process could not sufficient efficiency for all municipal wastewater treatment plant. The highest COD removal was obtained at pH 6.0 – 8.0 at Nola treatment plant where 80% of the COD had successfully been removed. However the concentration of COD in Marcianese wastewater was lesser than Nola wastewater although the initial COD of the sample was in the range of Nola plant. COD removal of the university plant improved from 55 to 75–85% in parallel to TSS removal by pH increase (up to 8.0). The statistical analyses showed different correlation values/behavior between COD and TSS removals in each plant due to wastewater origin, pH and applied alum dose. RA was found significantly related to pH of coagulation process. RA concentration increased at pH value <5.0 [M. Mattei et. al 2007].

2.9 Coagulants

The effective coagulant treats water by their self. However the choice of coagulant highly depend on the suspended solid to be removed, the water condition to be treated, the facility design and the cost of amount of chemical necessary to obtain the optimum result. There are two (2) types of coagulant: organic coagulant and inorganic coagulant [WSAA 41]. Coagulants are significantly to enhance the coagulation of suspended solids across a range of industrial applications involving process water treatment, wastewater and effluent treatment [Accepta™, 2007]. Coagulant, such as aluminum sulphate, is added to the water in a volume determined by pre-testing the water. This pre-test is called a 'beaker test.' A beaker test determines the amount of chemical required to treat a dugout or cell, and also indicates the expected results [L. Braul et. al. 2003].

The most common inorganic coagulant is alum and iron salts. The coagulant will be furnished into highly charged iron to neutralize the suspended solid when it being added into the water [MRWA, 2007]. The most common coagulant being used in the industry is alum since alum easy to be used and does not hazardous to human being at lower concentration. The optimum pH for alum is in the range of 6.5 to 7.0. However the usage of alum in the water treatment plant may cause addition of dissolve solid in the water.

Alum can be replaced by using ferric chloride or ferrous sulphate as a coagulant. The optimum pH range of both iron salt is higher than the optimum pH of alum. The iron salts caused the additional amount of solid in the water and alteration to the water alkalinity need to be done in order to obtain the optimum result [Metcalf et. at., 2004]. The inorganic coagulant is also capable in removing the some portion of organic precursor which may combine with chlorine to form disinfection by products [MRWA, 2007]. The coagulant will react with calcium that contained in the treated water and producing the iron salt (floc), calcium and carbon dioxide. This coagulant is a catalyst to form a larger size of floc which can trap the bacteria when they settled [MRWA, 2007].

However some of the inorganic coagulants that been applied in the water treatment system having few disadvantages such as large dosages, low effect and harmful to body while the synthetic organic coagulant are very expensive and contained high amount of toxic [Z.Lu 2000]. A corrosion scientist who tested Durham's water samples conclude that, the increment of the lead amount in the Dunham drinking water that poisoned a child there, probably due to the changes that occur in the coagulant that been used in removing the organic matter during the water treatment process [R. Renner, 2006]. Due to the lead problem in the drinking water, few cities in US changed their coagulant from alum to ferric chloride. This is because ferric chloride having better performance in removing the bacteria and reduce disinfection of byproduct [R. Renner, 2006]. The basic reaction of ferric chloride coagulant in coagulation process is as follow:

$2FeCl_3 + 6HCO_3^- \leftrightarrow 2Fe(OH)_3 (\downarrow) + 6Cl^- + 6CO_2$ (H.A.Aziz et.al. 2007)

CHAPTER 3
METHODOLOGY

3.1 Introduction

The water treatment plant will be disposing the sludge by returning it to the surface water. This is due to limited disposal area for the sludge generated. The RFC was obtained by digesting the sludge produced by the groundwater treatment plant using the highly concentrated acid. Once the digestion process is finished, the digested sludge will be filtered. The filtered sample obtained is the RFC that will be used in the jar test as a coagulant. The selection of coagulant and the optimum dosage for each coagulant is obtained by conducting the jar test. The amount of chemical oxygen demand (COD), biological oxygen demand and heavy metal removed had been checked after the treatment process being conducted.

The project had been divided into two (2) phase where on the first phase, the effectiveness of the RFC to thicken the sludge was checked. The municipal sludge is taken from UTP Water Treatment Plant. For the second phase of the project, the effectiveness of the RFC to treat the landfill leachate was checked compare to the commercial coagulant that available in the industries. The raw leachate was taken from the Pulau Burung Landfill Site. Normally commercial coagulants were being used to treat the leachate and the municipal sludge.

3.2 Optimization of Sludge Digestion

3.2.1 Acid Dosage Optimization

The digestion of sludge was performed using the sludge digester that contained six digestion tubes and a scrubber. The function of a scrubber is to absorb the toxic gasses released due to the digestion process.

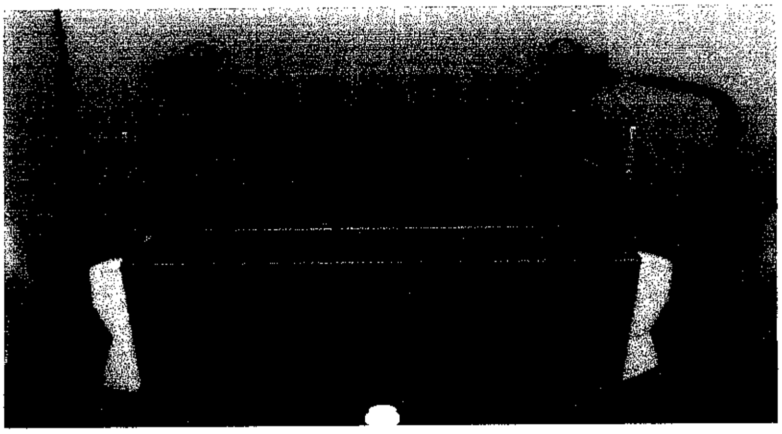


Figure 1: Sludge Digestion Equipment

The digestion tubes were filled with samples each containing 1g of sludge and 10 ml of distilled water. Tube 1 is used as a controller where no hydrochloric acid being added. Tubes 2 to 6 were added with 1 ml, 3 ml, 5 ml, 7 ml and 10 ml of hydrochloric acid respectively. The tubes were heated at 60°C for slow heating to avoid total evaporation of distilled water for 5hours. Then the samples were filtered using 45 mm filter papers. The filtered samples were measured using spectrophotometer to determine the ferrous (Fe^{2+}) concentration. A graph of hydrochloric acid dosages versus the ferrous concentration digested was plotted to determine the optimum value of digestion.

3.2.2 Optimal Time Digestion

After the optimum dosage of hydrochloric acid was obtained, the sludge digestion process performed in order to determine the optimum time to digest the sludge. Each tube was filled with samples contained 1g of sludge, 10 ml of distilled water and 5 ml of hydrochloric acid. The tubes were heated at 60°C but different time. Tubes were heated 45 minutes, 90 minutes, 135 minutes, 180 minutes, 225 minutes and 270 minutes respectively. Then the samples were filtered using 45 mm of filter papers and the concentration of ferrous was determined by using spectrophotometer. A graph of digestion time versus the ferrous concentration digested was plotted to determine the optimum time of digestion.

3.3 Stock Sludge Digestion

The sludge was digested using the method of "Standard Methods for the Experiment of Water & Wastewater, AHPA method: Nitric Acid Digestion. Digestion process is required in order to produce very high concentration iron. For this project, sludge from Kelantan Water Treatment Plant had been used. The sludge contained high concentration of iron and alum which been used for the coagulation process. This experiment required 15% solution. In order to obtain this, the concentration of the solution prepared was at 150000 mg/L. This is obtained by digesting 50 g of sludge had been mixed with 500 ml of distilled water and continuous addition of hydrochloric acid.

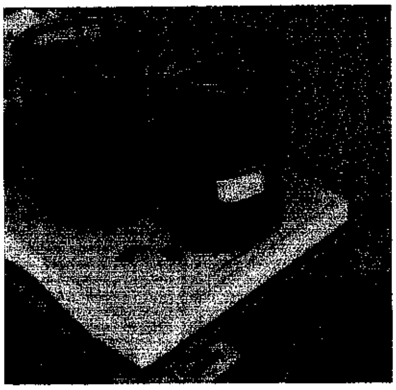


Figure 2: Stock Sludge Digestion

A 1000 ml beaker was acid washed and rinsed with water. 50 ml of hydrochloric acid (HCl) was added. On the hot plate, the mixture was stirred at low temperature while adding more acid continuously. The mixture was allowed to evaporate to the lowest volume possible for nearly 4 hours. After cooling, the solution had been filtered using 45 mm filter paper. The concentration of iron in the solution was checked by the spectrophotometer.

3.4 Preparation of Commercial Ferric Chloride Stock Solution

The ferric chloride is one of the coagulants used in the jar test to compare the effectiveness of the RFC with the commercial coagulant. Firstly, 12.63 g of powder ferric chloride was weighted. Then the chemical is poured into a beaker. From the calculation that has been done, 250 ml of distilled water needed to obtain 46 g/l of ferric chloride solution. The solution is stirred using the stirrer for the chemical to dilute in the water. The concentration of the chemical is checked using the spectrophotometer after the chemical is totally diluted in the distilled water.

3.5 Preparation of Commercial Ferrous Sulphate Stock Solution

The ferrous sulphate is one of the commercial coagulants that usually being used in the water treatment plant as the coagulation aid in the system. Firstly, 22.86 g of ferrous sulphate was weighted. Then the chemical is poured into a beaker. From the calculation that has been done, 250 ml of distilled water needed to obtain 150 g/l of ferrous sulphate solution. The solution is stirred using the stirrer for the chemical to dilute in the water. The concentration of the chemical is checked using the spectrophotometer after the chemical is totally diluted in the distilled water.

3.6 Jar Test

Six beakers were being added with 1000 ml of waste water sample to be coagulated. Using the prepared coagulant, solution dose was stock in each beaker. After dosing each beaker, the stirrer was opened for the rapid mixed at 120 rpm for approximately 1minutes. Then the stirrer was turned off and reopens for the slow mixed at 25 rpm for about 25 minutes. After 25 minutes, the stirrer was turned off and the samples have been poured into 1 liter cylinder and allowed it to settle. The sample is allowed to settle for 20 minutes and the supernatant of for every samples were taken to measure the COD, BOD, TOC and colour removal of the samples after treatment process

Jar tests were conducted to determine the optimum dosage of the sample to settle for each coagulant; alum, ferric chloride, ferrous sulphate and RFC. After the samples had completely settled, the supernatant of the sample had been taken for COD Test, Total Suspended Solid Test and Colours Test.

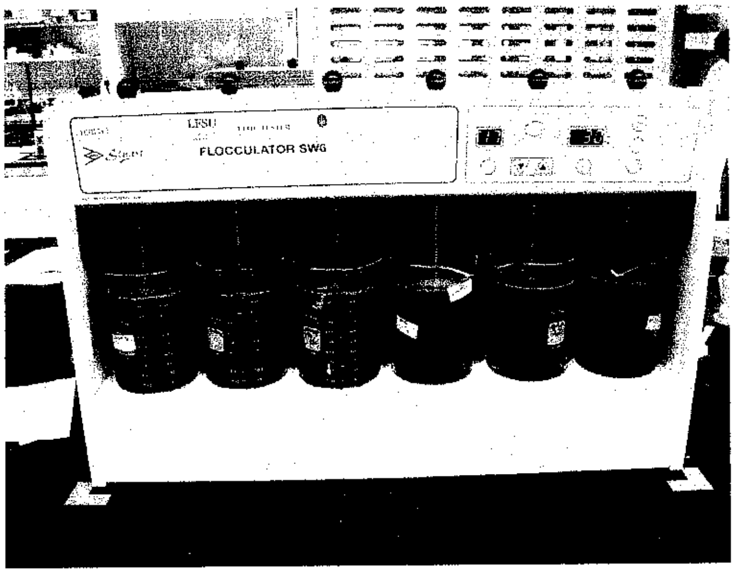


Figure 3: Jar Test Apparatus

3.7 Measurement of Colour

The colour of the landfill leachate was measured to determine the optimum dosage of colour removal after the treatment is done. The test was carried out by pouring 25 ml of distilled water into a spectrophotometer bottle for the blank sample preparation. Then the spectrophotometer had been set up for the colours test. Each sample being poured into 3 bottles of samples and the reading of the sample is determined by the spectrophotometer for each sample. The result given is based on the average reading for every sample. A graph colours vs dosage is plotted.

3.8 Measurement of Chemical Oxygen Demand (COD)

The COD measurement is a test to determine the amount of chemical oxygen demand in a sample after the sample being treated. The test was conducted by adding 2 ml of supernatant of the sample into a vial. 3 vials had been prepared for each sample. The samples were heated at 150°C for 2 hours in the heater. The blank sample was prepared by pipetting the distilled water into the vial and heats it for 2 hours at 150°C. After the sample finished heated, wait for the samples to cool down after being heated, and the COD reading was taken using the spectrophotometer.

3.9 Measurement of Total Suspended Solid (TSS)

The total suspended solid (TSS) was measured to determine the amount of suspended solid removed for every 100 ml of sample. The initial weight of the filter paper (W_o) was recorded. The test was carried out by taking 100 ml of the supernatant of each sample to be filtered using the 45mm filtered paper. After that the weight of the 'filtered' filter paper being measured (W_f). The different is considered as the wet weight of filter paper. The filter papers were dried for 1 hour at 150°C in the oven. The weights of dry filter papers were measured (W_d). The suspended on the filter paper is as follow:

$$TSS = \frac{W_d - W_f}{\text{Sample size (L)}}$$

For each samples, three samples was taken to be tested. The result obtained was the average reading for each test.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

The groundwater sludge was obtained from Chicha Groundwater Treatment Plant, Kelantan. As the groundwater is used, the main problem that has to be faced in groundwater treatment process is the sludge produced contained high amount of iron and manganese. Normally, the groundwater sludge is rich of iron oxide. This had been proven based on the x-ray fluorescent test where 23.3% of the sludge contained iron oxide. Improper treatment process will caused the water to turn into yellowish colour due to the present of several chemical compositions in the groundwater.

This project was divided into two (2) phases where for the first phase of the project, the effectiveness of the RFC in treating the municipal sludge taken from UTP water treatment plant. However for the second phase of the project, the RFC was used to treat the landfill leachate taken from Pulau Burung Landfill Site.

The jar test was conducted on different types of coagulants at various dosages to study the effect of the coagulants in the wastewater sample and established the optimum dosage required for the treatment to be effective. The jar test was conducted using three (3) different coagulants which are lab graded alum (aluminum sulphate), ferric chloride, ferrous sulphate and recycle ferric chloride.

The settleabilty tests were conducted in the thickening process of the municipal sludge. The supernatant were then measured for chemical oxygen demand (COD), colour, and total suspended solids (TSS). Tests were conducted in triplicates. The jar test was conducted to determine the optimum dosage to remove colour, COD and TSS that contain in the landfill leachate.

4.2 X-Ray Fluorescent Test

The XRF Test being conducted in order to determine the characteristic of the chemical composition contained in the groundwater sludge.

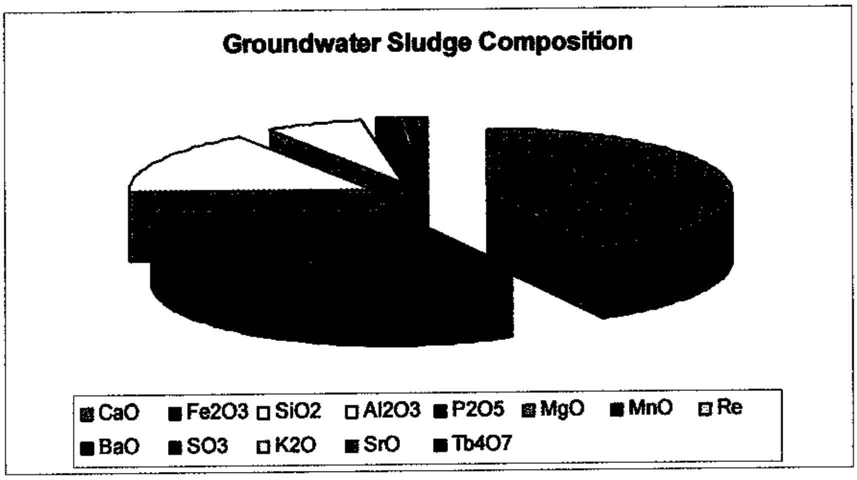


Figure 4: Chemical Composition of Groundwater Sludge

Figure 4 shows the main chemical composition of the groundwater sludge is Calcium Oxide (30.4%) follow by the Ferric Oxide (23.3%). The chemical elements of the groundwater sludge are shown in Figure 5.

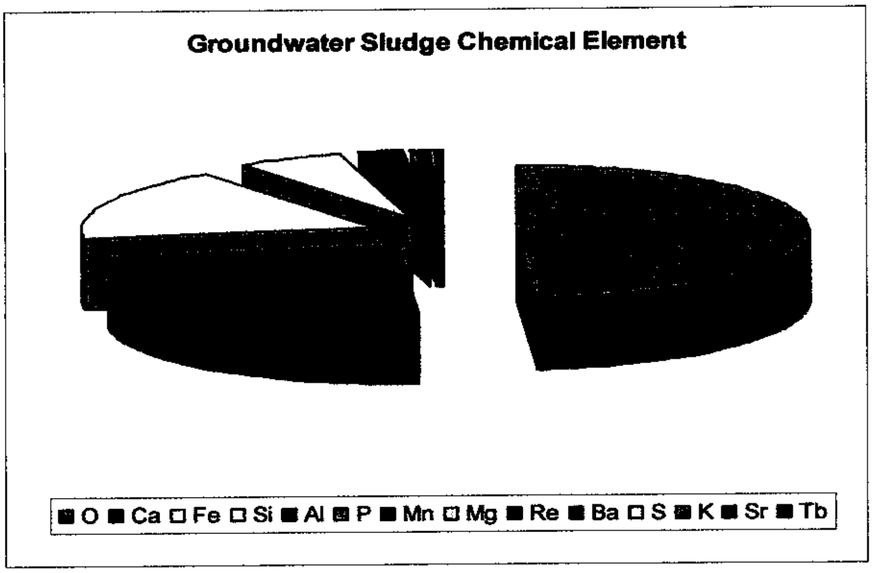


Figure 5: Groundwater sludge Chemical Element

Figure above shows that the highest chemical element contained in the groundwater sludge is the oxide followed by calcium and iron (Fe). 16.3% of the groundwater sludge contained iron.

4.3 Optimum Dosage of Sludge Digestion Determination

The ferrous concentration at various dosages of acid was recorded. A graph of ferrous concentration vs. acid dosages had been plotted and the optimum dosage of ferrous was determined.

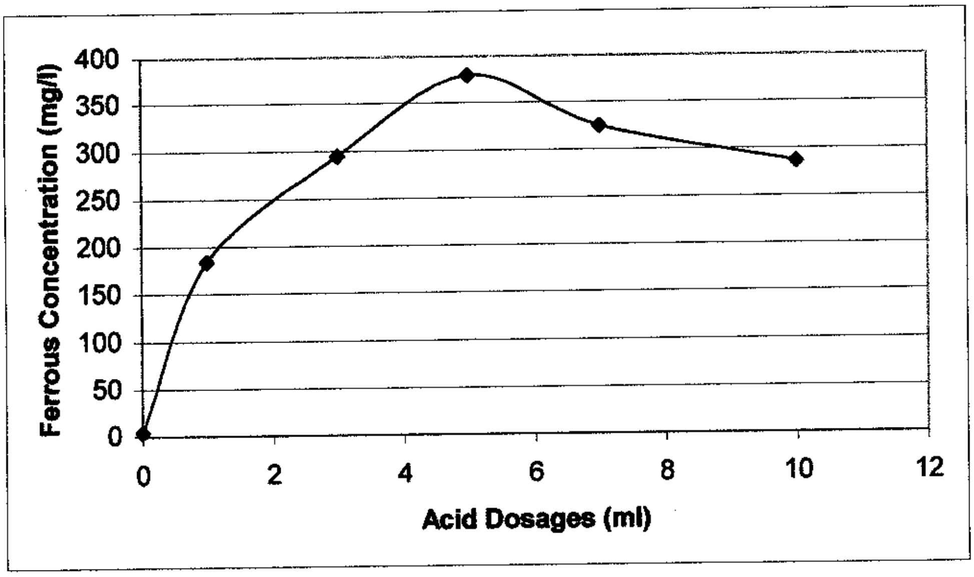


Figure 6: Ferrous Concentration vs Acid Dosages graph

Figure 6 shows the optimum dosage of the acid after 6 hours sludge digestion. The optimum dosage of the hydrochloric acid is 5 ml. The ratio of the groundwater sludge to distilled water and acid are 1 g: 10 ml: 5 ml.

4.4 Optimum Time of Sludge Digestion Determination

The ferrous concentration at various times of digestion was recorded. A graph of ferrous concentration vs. time had been plotted order to determine the optimum time for sludge digestion process. Figure 7 shows the ferrous concentration vs. time of the sludge digestion.

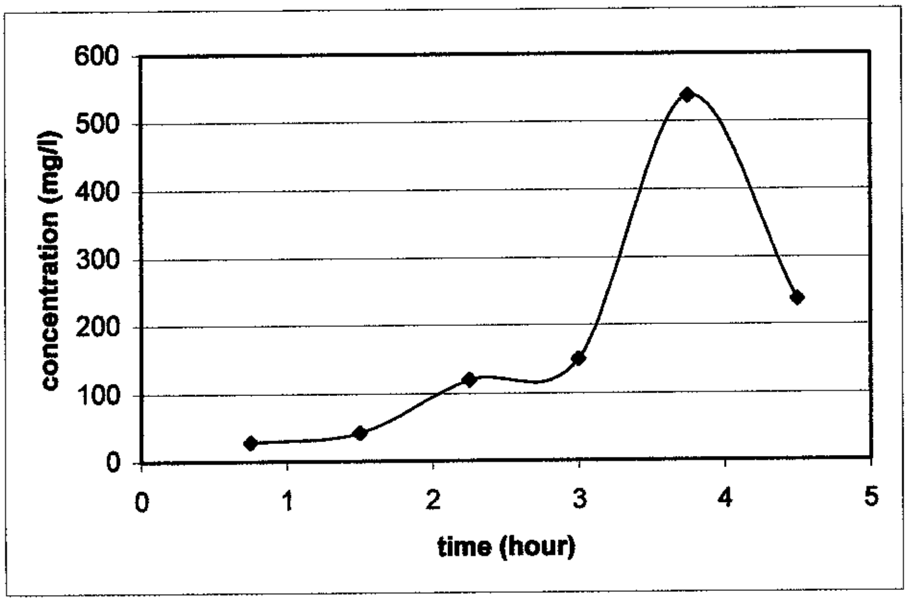


Figure 7: Ferrous Concentration vs Time for Sludge Digestion

Figure above shows the optimum time for sludge digestion when 1g of groundwater sludge being added to 10 ml of distilled water and 5ml of hydrochloric acid. Graph above indicates that, the optimum time for sludge digestion is approximately 4hours when 1g of groundwater sludge being added to 10 ml of distilled water and 5ml of hydrochloric acid.

4.5 Phase 1: Thickening of the Municipal Sludge

4.5.1 Raw Characteristic of UTP Treatment Plant Municipal Waste

Table 2 shows the raw characteristic of the UTP Treatment Plant Municipal Waste

Table 2: Raw Characteristic of UTP Treatment Plant Municipal Waste

Parameter	Value
Settleability Rate (cm/min)	2.4
Total COD (mg/L)	1044
Total Suspended Solid (mg/L)	665.2
Colour (PtCo)	444

4.5.2 Sludge Settleability

The settleability of the raw sludge sample was recorded and plotted in Figure 8 below. From the figure, it was found that the settleability rate was found to be 2.4 cm/min. This is the unhindered settling rate of the sludge at the hindered zone.

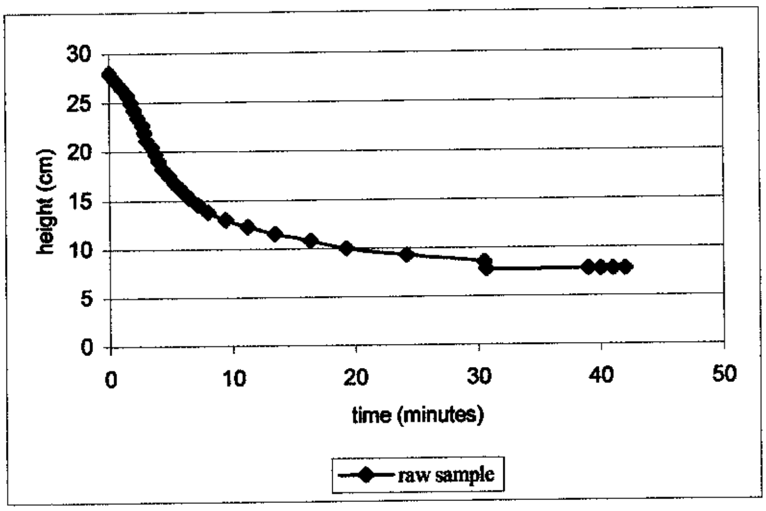


Figure 8: Settleability Curve vs Time for raw sample (without any coagulant).

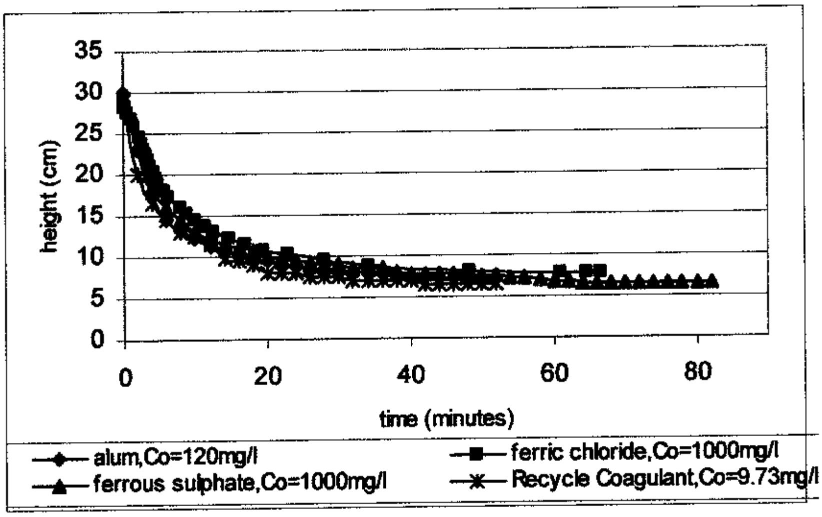


Figure 9: The settlebility curve of the optimum dosage for each coagulant used.

Figure 9 above shows the settling curves of the optimum dosages of the coagulants used in the study. From each graph, the unhindered settling rate for each sample was calculated.

When alum was used as the coagulant, the highest unhindered settling rate was found to be 3.13 cm/min at an alum dosage of 120 mg/L. When ferric chloride was used as the coagulant, the highest settling rate was calculated to be 1.86 cm/min at a dosage of 1000 mg/L. The highest settling rate for the sludge sample using ferrous sulphate as the coagulant was calculated to be 2.5 cm/min at a dosage of 1000 mg/L. However, the highest settling rate for RFC was 4.5 cm/min at a dosage of 10 mg/L.

T-test had been conducted for all test conducted in order to check the effectiveness of the RFC to thicken the sludge. For the settleability test, it shows that RFC is more significant compare to Ferric Chloride being used as coagulant. However, the settleability rate of Alum and Ferrous Sulphate when being used is as coagulants show no different as compare to RFC. Refer to Appendix H-1 for detail result.

4.5.3 Colour Removal

The colour of the supernatant after the thickening process at different dosages of the coagulants and RFC was plotted in Figure 10 and Figure 11 respectively. It was observed that the optimum dosage of the coagulant for sludge thickening was not necessarily the optimum for colour removal. The optimum coagulant dosages to obtain the minimum colour of the supernatant for each coagulant are tabulated in Figure 10 below.

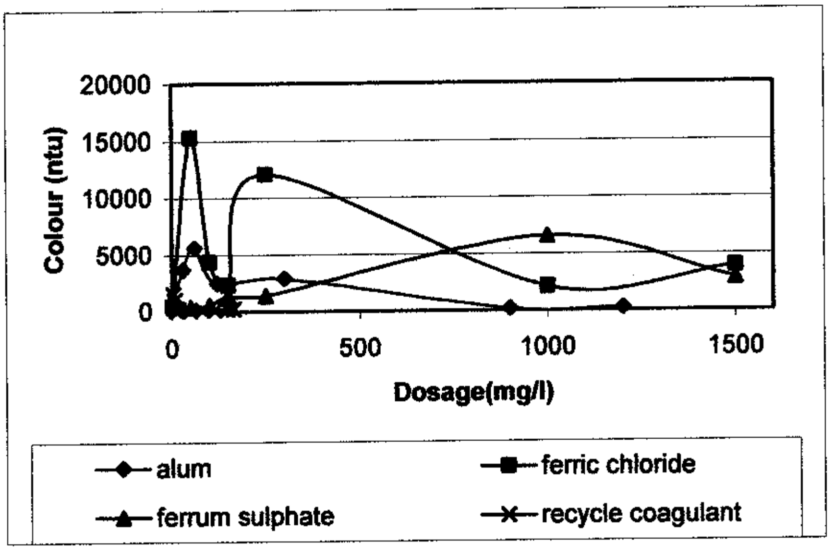


Figure 10: Colours (ntu) vs Dosage for each coagulant.

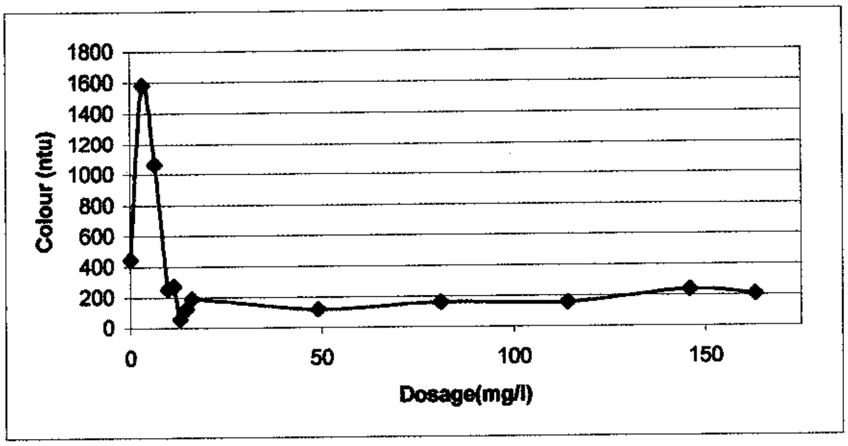


Figure 11: Colours vs dosage using recycle sludge as coagulant.

It can be observed from Table 3 that RFC gave the lowest supernatant colour compared to the other coagulants at the lowest dosage of 13 mg/L.

Table 3: Summary of Colour Removal of Various Coagulants

Coagulant	Optimum Dosage of Coagulant for Colour (mg/L)	Colour (NTU)
Alum	900	171
Ferric Chloride	1000	2077
Ferrous Sulphate	50	410
RFC	13	56

The RFC is significantly different from Alum and Ferric Chloride when is being used to remove the colour of the supernatant. Refer to Appendix H-1 for the detail result of the statistical analysis.

4.5.4 COD Removal

The COD of the supernatant were measured for each of the coagulant at different dosages. The COD of the supernatant at different dosages of the coagulant and RFC are plotted in Figure 12 and Figure 13, respectively. It was also observed that highest COD removals did not indicate highest settleability results. However, RFC gave the highest COD removal compared to other coagulants.

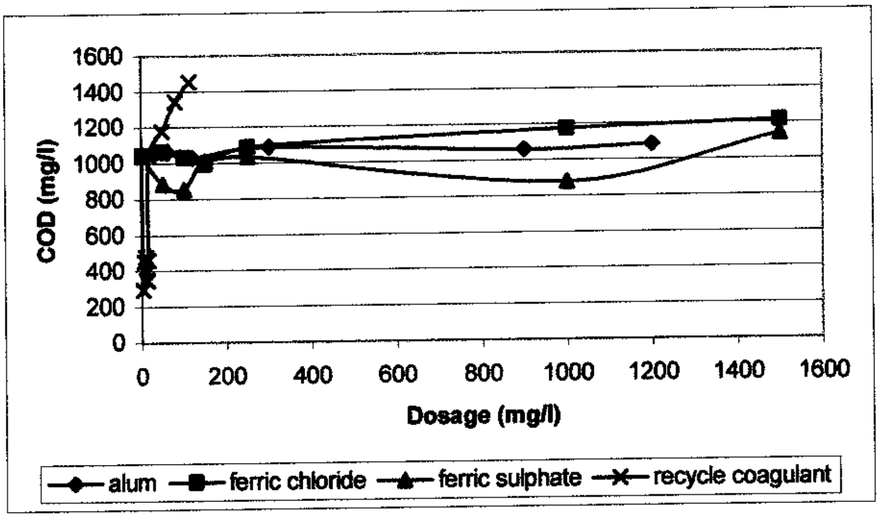


Figure 12: Cod vs Dosage for Different Coagulants

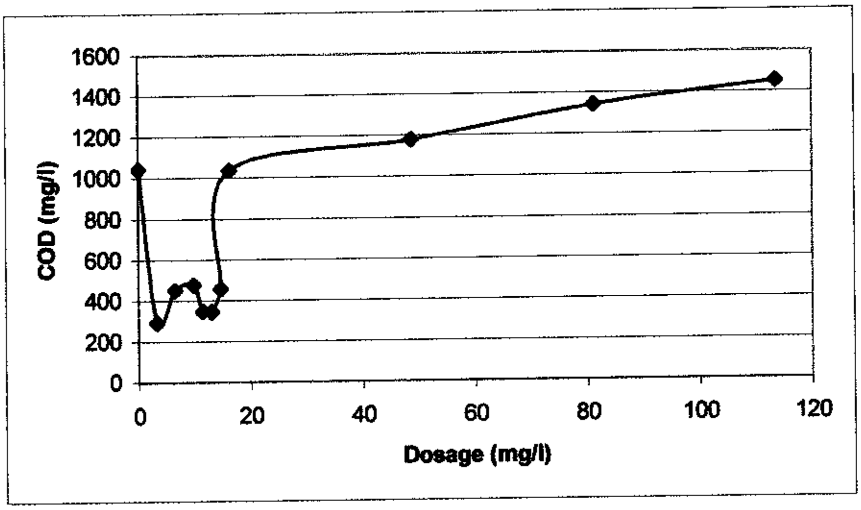


Figure 13: COD vs Dosage for the recycle sludge as a coagulant

The summary of supernatant COD are tabulated in Table 4. It can be observed that RFC gave the highest removal of COD of the supernatant compared to other coagulants where.

Table 4: Summary of COD Removal of Various Coagulants.

Coagulant	Optimum Dosage of Coagulant for COD (mg/L)	COD (mg/L)
Alum	120	1029
Ferric Chloride	150	996
Ferrous Sulphate	100	853
RFC	13	346

The COD removal of the samples shows that RFC is significantly different from all other coagulants since the $T_{statistic}$ of the test is larger than the $T_{critical}$ of the test. Refer to Appendix H-1 for the detail result of the statistical analysis.

4.5.5 Total Suspended Solid (TSS)

The TSS of the supernatant after the thickening process at different dosages of the coagulants and RFC were plotted in Figure 14 and Figure 15, respectively. The TSS results are tabulated in Table 5 below.

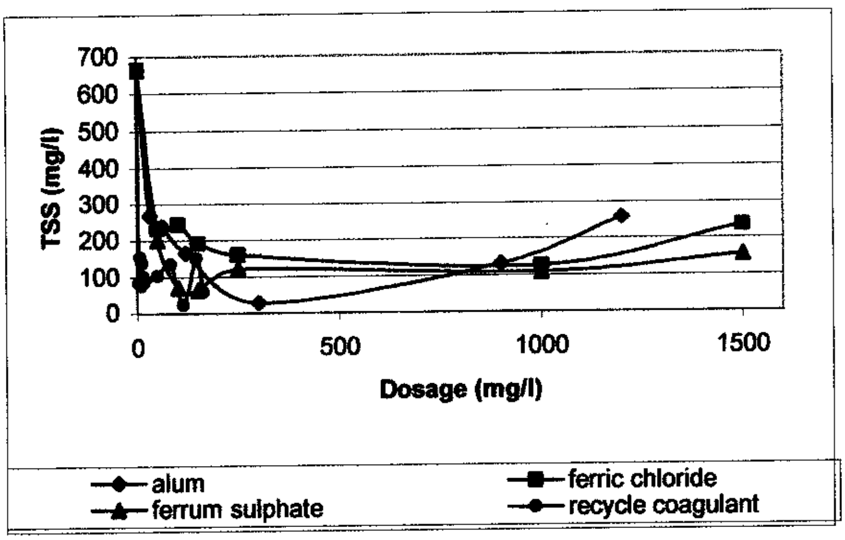


Figure 14: TSS vs Dosage graph for Each Coagulants

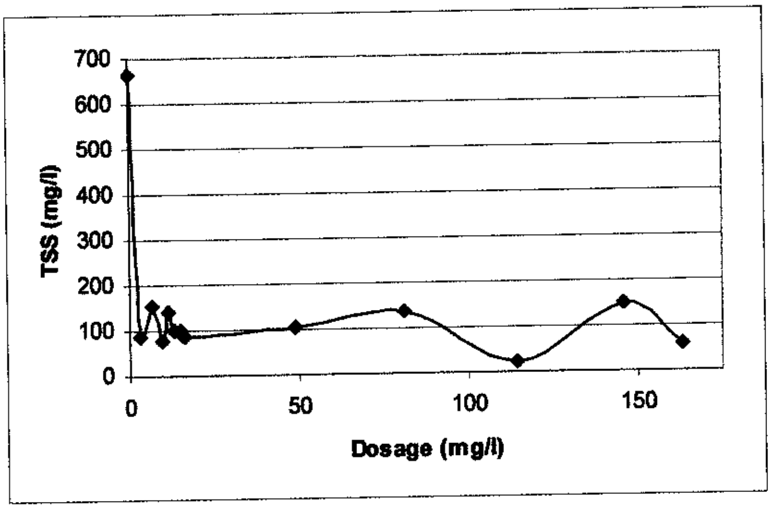


Figure 15: TSS vs Dosage for RFCs

It can be observed from Table 5 that the use of RFC as a coagulant gave higher TSS removals of the supernatant.

Table 5: Summary of TSS removal using Various Coagulants

Coagulant	Optimum Dosage of Coagulant for TSS (mg/L)	TSS (mg/L)
Alum	300	28
Ferric Chloride	1000	127
Ferrous Sulphate	100	72
RFC	114	24

The total suspended solid of the supernatant does not shows any differences in their removal since $T_{statistic}$ of the test is smaller than the $T_{critical}$ of the test. Refer to Appendix H-1 for the detail result of the statistical analysis.

4.6 Phase 2: Treating the Landfill Leachate

4.6.1 Raw Characteristic for Pulau Burung Landfill Leachate

The characteristic of the raw sample at Pulau Burung Landfill Site are as follow:

Parameter	Value
Soluble COD (mg/L)	3232
Total COD (mg/L)	4004
Total Suspended Solid (mg/L)	1987
Colour (PtCo)	3771
Total Organic Carbon	2058
Total Cooper (mg/L)	0
Total Zink (mg/L)	0
Total Nickel (mg/L)	0
Total Lead (mg/L)	0
Total Ferrum (mg/L)	7.74
Soluble Ferrum (mg/L)	5.54

4.6.2 Optimization of pH for RFC

The solubility of the coagulant is important in order the flocculation process to occur when the action of hydrolyzed metal ions (Metcalf et.al 2004). Thus the pH optimization needs to be conducted to determine the optimum pH for the destabilization and colloidal particle removal to achieve. Figure 16 Figure 17 and Figure 18 show the result of the COD, TSS and colour removal of various coagulants at various pH respectively. The standard dosage that had been used in this experiment was 1000mg/L for RFC while 600mg/L for Alum and Ferric Chloride.

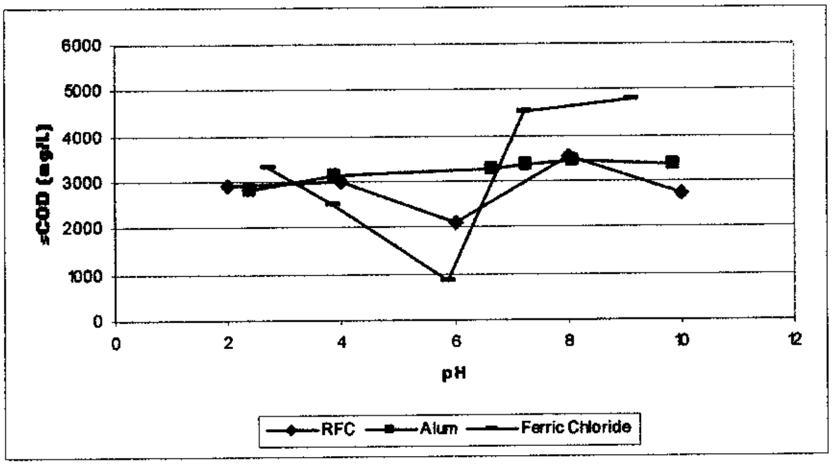


Figure 16: pH Optimization of Various Coagulants

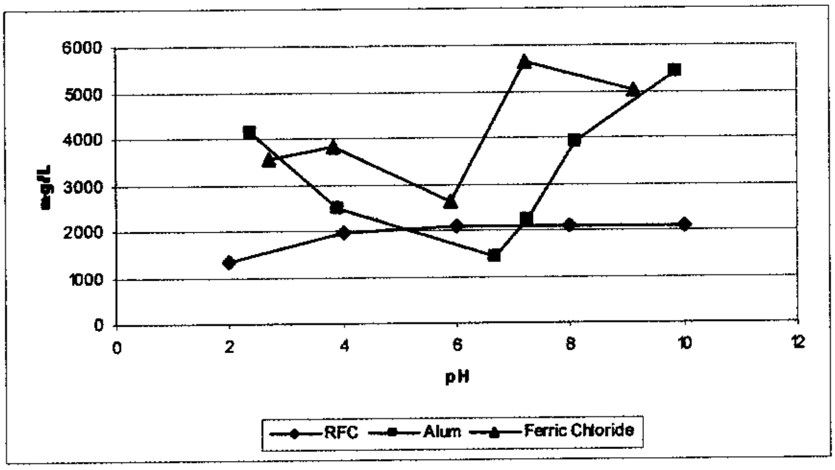


Figure 17: TSS Removal vs pH of Various Coagulants

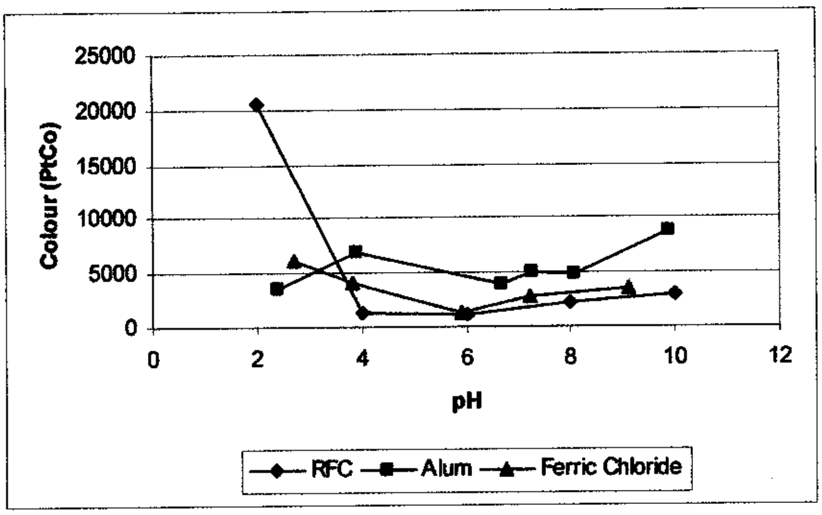


Figure 18: pH optimizations for Colour Removal using RFC

The graphs above show that all coagulants act the best approximately at pH6. Thus from this observation, it can be conclude that the flocculation and coagulation process of the samples work the best when the best at pH6.

4.6.3 Total COD Removal

The COD of the supernatant were measured for each of the coagulant at different dosages. The COD of the supernatant at different dosages of the coagulants and RFC are plotted in Figure 19.

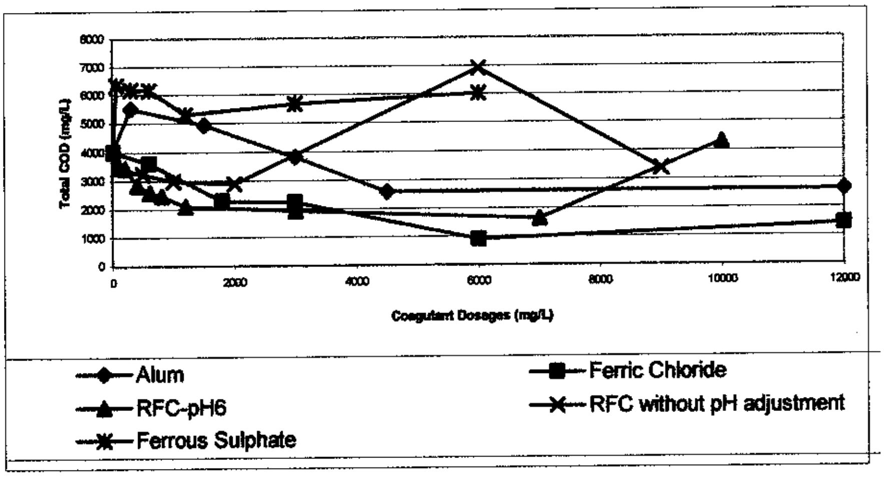


Figure 19: TSS vs Coagulant Dosages of Various Coagulants

The supernatant Total COD result is tabulated in Table 6. It can be observed that Ferric Chloride shows the best Total COD removal followed by the RFC and Alum. The amount of total COD removed is slightly lower when the leachate being treated using recycled coagulant without any pH adjustment. However, the amount of Total COD increased when Ferrous Sulphate had been used as a coagulant in treating the leachate.

Table 6: Summary of Total COD Removal

Coagulant	Optimum Dosage of Coagulant for COD (mg/L)	Total COD (mg/L)
Alum	4500	2676
Ferric Chloride	6000	909
Ferrous Sulphate	1200	5303
RFC at pH6	7000	1616
RFC without pH adjustment	2000	2882

From the t-test result conducted, the RFC is significantly different in treating landfill leachate comparing to ferrous sulphate. However alum and ferric chloride do not show any different in the experiment conducted based on the t-test result.

4.6.4 Soluble COD Removal

Figure 20 shows the soluble COD removal of the leachate after the treatment using four (4) different coagulants. Different dosages had been used to measure the COD.

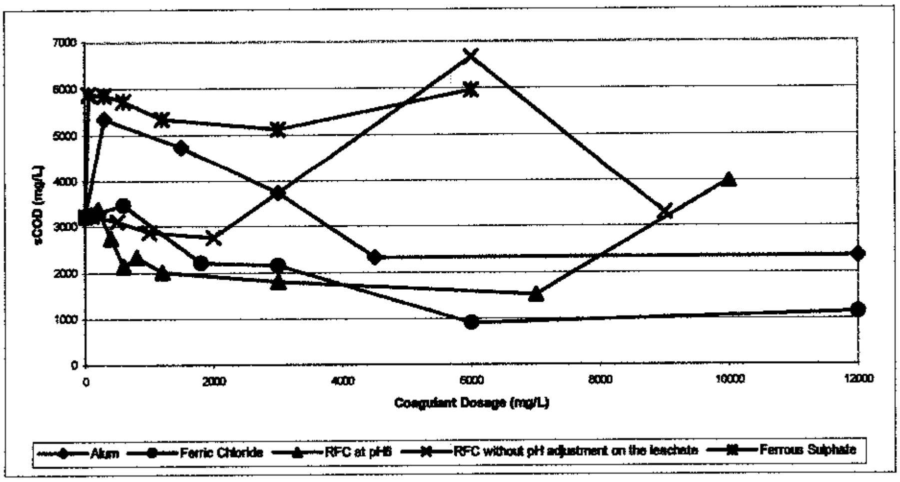


Figure 20: sCOD vs. Coagulant Dosages for Various Coagulants

Table 7 shows the summary of the sCOD removed for various coagulants. Ferric Chloride shows the best COD removal followed by the RFC after adjusting the leachate to pH=6. Alum shows only 28% of sCOD managed to be removed after the treatment process being conducted.

Table 7: Summary of sCOD Removal for Various Coagulants

Coagulant	Optimum Dosage of Coagulant for sCOD (mg/L)	Soluble COD (mg/L)
Alum	4500	2323
Ferric Chloride	6000	909
Ferrous Sulphate	3000	5117
RFC at pH6	7000	1520
RFC without pH adjustment	2000	2768

4.6.5 Measurement of Colour

The Supernatant Colour removed the best when RFC is used as coagulant but without pH adjustment on the leachate followed by alum and RFC with pH adjustment for the leachate.

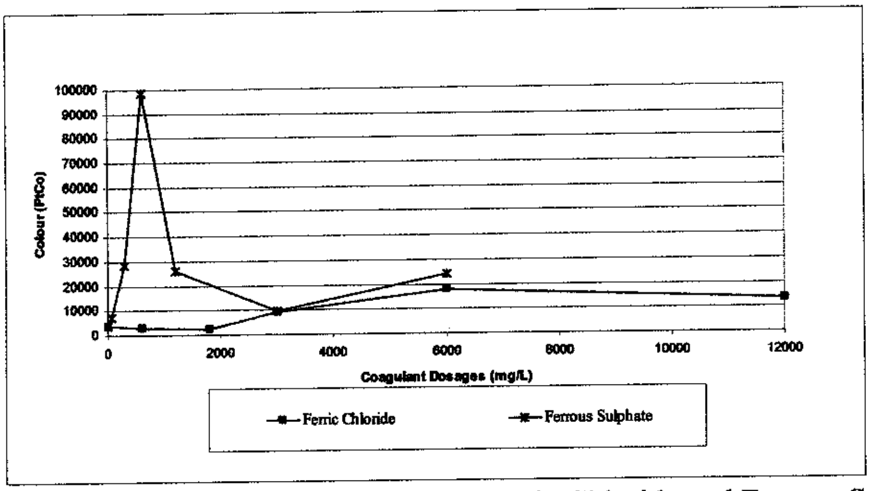


Figure 21: Colour vs Coagulant Dosage for Ferric Chloride and Ferrous Sulphate

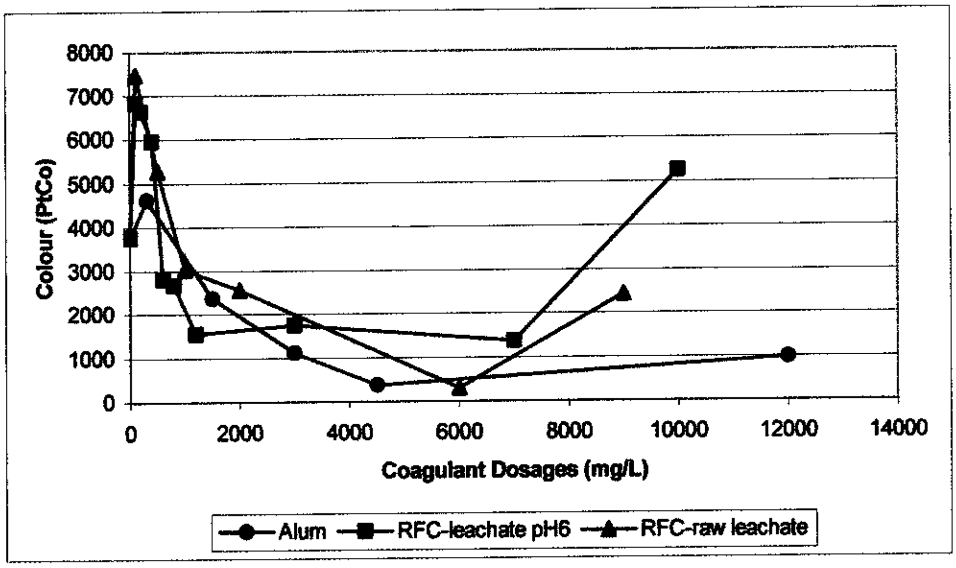


Figure 22: Colour vs Coagulant for RFC and Alum

Table 8 shows the summary of leachate colour removed using various coagulants. It can be observed that RFC gave the lowest supernatant colour when the leachate pH is 8. The optimum dosage to remove colour is 6000mg/L.

Table 8: Summary of Colour Removed for Various Coagulant

Coagulant	Optimum Dosage of Coagulant for Colour (PtCo)	Colour (PtCo)
Alum	3000	1111
Ferric Chloride	3000	9191
Ferrous Sulphate	60	7222
RFC at pH6	7000	1364
RFCwithout pH adjustment	6000	303

The statistical analysis conducted shows that the RFC is significantly different compare to ferrous sulphate. However the alum and ferric chloride do not show any different based on the t-test result.

4.6.6 TSS Removal

The TSS of the supernatant after the treatment process at different dosages of the coagulants and RFC were plotted in Figure 23. Table 9 shows the summary of TSS removal for various coagulants. The statistical analysis was conducted in this experiment to determine the efficiency of the RFC.

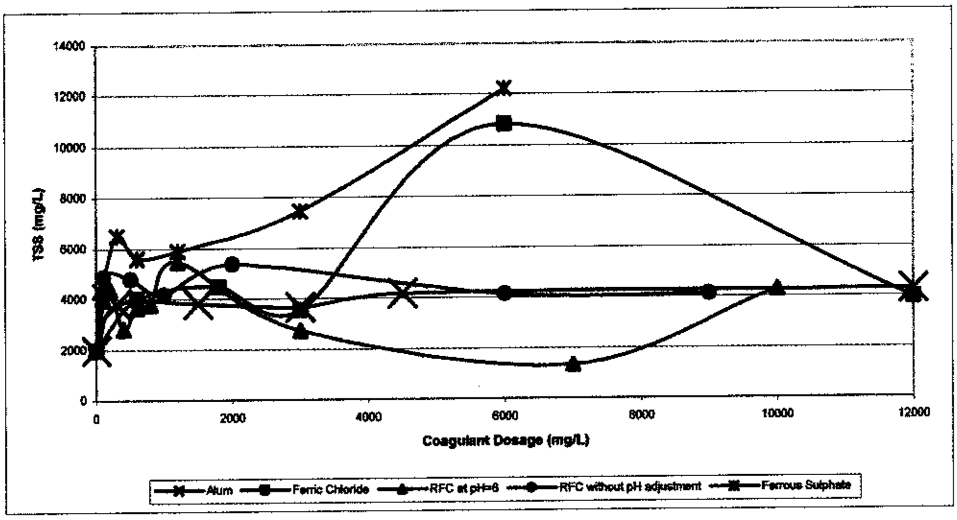


Figure 23: TSS vs Dosages of Various Coagulants

From the tabulated data, it shows that most of the coagulant failed to remove the suspended solid in the leachate in fact the amount of suspended solid are increasing. However, at pH 6, RFC managed to remove for 32%. Further research need to be done in order to improve the effectiveness of the coagulants in removing the suspended solid in the leachate.

Table 9: Summary of TSS Removal for Various Coagulants

Coagulant	Optimum Dosage of Coagulant for TSS (mg/L)	TSS (mg/L)
Alum	3000	3662
Ferric Chloride	3000	3552
Ferrous Sulphate	60	4332
RFC at pH6	7000	1346
RFC without pH adjustment	9000	4112

4.7 COST ESTIMATION

Shows the cost estimated based on the laboratory experiment.

Table 10: Summary of Cost Estimated for Various Coagulants for UTP Municipal Sludge Thickening Process.

Coagulant	Laboratory Cost/Liter (RM)	Lab Cost for 1000L (RM)
Alum	0.47	470
Ferric Chloride	0.09	90
Ferrous Sulphate	3.02	3020
RFC	0.027	27

Table 11: Summary of Cost Estimation for Various Coagulants for Pulau Burung Landfill Leachate Treatment Process.

Coagulant	Laboratory Cost/Liter (RM)	Lab Cost (RM) for 1000L
Alum	1.77	1770
Ferric Chloride	3.60	3600
Ferrous Sulphate	3.62	3620
RFC at pH6	1.50	1500

CHAPTER 5
CONCLUSION & RECOMENDATION

From the experiment being conducted, the result shows that RFC is effective to thicken the sludge and treating leachate. However from the result obtained, it shows that the RFC is more effective in thickening and treating the municipal sludge. From the study it can be concluded that RFC is effective in thickening of municipal sludge as well as colour, COD and TSS removals. Lower dosages of RFC were required compared to other commercial coagulants. RFC improved the settling rate by 88% and also removed colour, COD and TSS at 42%, 54% and 88%, respectively at the optimum settleability dosage.

For the second phase of the project, RFC removed 60% of the COD when leachate pH is 6 and 92% of the colour being removed if no pH adjustment was being done on the leachate before conducting the jar test. However, if the leachate pH is being adjusted to pH6; the colour removal is 64%. The RFC also managed to remove 32% of the suspended solid if the leachate pH is adjusted to pH6 before conducting the experiment.

Based on the X-Ray Fluorescent Test conducted, there are several chemical composition contained in the groundwater sludge. Thus, the present of several chemical compositions in the groundwater sludge may also influence the experiment result. The cost to treat the municipal sludge and leachate are also cheaper compare to other coagulants based on the lab cost estimation analysis conducted. Further research need to be done on it to enhance the usage of RFC and reduce the amount of groundwater treatment plant being disposed to the environment.

CHAPTER 6

REFERENCES

Accepta™ Water Treatment, 2007. Coagulant – Water & Wastewater Treatment. Product Information.

APHA – AWWA, 1992. Standard Methods for Water and Wastewater Examinations. 17th ed. American Public Health Association/American Water Works Association: Washington, DC.

BSP Corporation (Brisbane, CA), 1971. Dewatering of Sludge.

Canadian Council of Minister of the Environmental, February 2008. Municipal Wastewater Effluent.

Degremont, Water Treatment Handbook. Six Edition 1991.

Dr Amirhossein Malakahmad, Semester January 2008 – Universiti Teknologi Petronas. Lecture notes on Measuring Change.

Environmental Leverange Inc, June 2006. Sludge Dewatering.

ETSU for the DTI, Introduction to Household Waste Management, March 1998.

Gray, N. F. (2005)Water Technology: an introduction for environmental scientists and engineers. (2nd edition) Elsevier, Oxford

German D. S, PE, February 2004. Arsenic Removal Arsenal. Environmental Protection, Volume 15, No.2

Hamidi Abdul Aziz, Salina Alias, Mohd. Nordin Adlan, Faridah, A.H. Asaari, Mohd Shahrir Zahari (2007). Colour Removal from landfill leachate by coagulation and flocculation process. Bioresource Technology 98 (2007) p 218 – 220.

Henry Shephard, Alison Lee, Laura Stewart, Kisty Johnston, Katie Steen, Tania, Schmieder. Landfill and Waste Management.

Ishikawa S., N. Ueda, Y. Okumura, Y. Iida & K. Baba 2006. Recovery of coagulant from water supply plant sludge and its effect on clarification. Springer Japan 1438-4957 p 1611-8227

Jason Dow, Touria Hafsi November 1998. Wastewater Sludge – Quality Process Control. Engineering 801.

James D. Englehardt. Yang Deng, Jose Polar, Daniel E. Meeroff, Yves Legrenzi, Joel Mognol, January 2006. Option for Managing Municipal Landfill Leachate: Year 1 Development of Iron Mediated Treatment Processes.

*Juang, D. F. & Chiou L. J. January 2007. Microbial population structures in activated sludge before and after the application of synthetic polymer

Kargi, F., Pamukoglu, M.Y., 2004. Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation. Bioresource Technology 94, p 285–291.

L. Braul, A Leader, 18 March 2003. Praire Water News – Coagulation Beaker Test. Agriculture and Agri-Food Canada.

Manu, B., Chaudhari, S., 2002. Anaerobic decolorization of simulated textile wastewater containing azo dyes. Bioresource Technology 82, p 225–231.

Marco Guida, Marialuisa Mattei, Clauido Della Rocca, Giovanni Melluso, Süreyya Meriç, 2007. Optimization of alum-coagulation/flocculation for COD and TSS removal from five municipal wastewaters. Desalination 211 (2007) p 113 – 127.

MDC Sdn. Bhd., 1997. Laws of Malaysia—Environmental Quality Act 1974 and Regulations, 4th edition, Kuala Lumpur, Malaysia.

Metcalf & Eddy, Wastewater Engineering Treatment and Reuse. Mc Graw Hill, Fourth Edition, 2004.

Minessota Rural Water Association (MRWA) 2007. Coagulation and Flocculation Process.

Monroe, February 2001. Landfill Leachate Treatment: VSEP Offer a Revolutionary Solution.

MRWA – Coagulation and Flocculation process

National Water Research Institute (NWRI), July 2004. Municipal Waste Water. Waste water e-research.

Papa Secka, April 2002. The Study of Leachate Quality and Treatment of the Semi-aerobic Landfill at Ampang Jajar, Penang, Malaysia. Thesis for the degree of Master of Science.

Prof. H. N. Hsieh. Water and Wastewater Technology. New Jersey Institute Technology.

Rasit, Nazaitulshila (2006), Landfill Leachate Treatment using Subsurface Flow Constructed wetland enhanced with magnetic field. Master Thesis, Universiti Teknologi Malaysia.

Rebecca Renner, 2 August 2006, Lead in Water Linked to Coagulant. Science News – Environmental Science & Technology Online. ACS Publication.

Report No WSAA 41, May 1992. Assessment of Coagulants for Water Treatment.

Roy Bingham, January 2005. Sludge Processing. Water Industry News.

Rui A.R. B., A.A.S. Duarte & M. F. Almeida. Aluminum recovery from water treatment sludge. IV Internation Conference Water Supply and Water Quality Krakow Polland, September 11 – 13, 2000.

Sheree DiTerlizzi, Fall 1994. Introduction to Coagulation and Flocculation of Wastewater

Spalding R. F. & I. A. Khan February 7,2006. Process for remediating ground water containing one or more nitrogen compounds. United State Patern 6994793

United Nation Atlas of the Ocean: Disposal of waste from land: Municipal Wastewater (Sewage), March 2007.

United Nation Atlas of the Ocean: Disposal of waste from land: Management of The Municipal Wastewater, March 2007.

United States Environmental Protection Agency, September 2004. Primer for Wastewater Treatment System.

Vaezi F. & F Batebi.2001, Recovery of Iron Coagulants from Tehran Water-Treatment-Plant Sludge for Reusing in Textile Wastewater Treatment. Iranian J. Publ. Health, Vol. 30, Nos. 3-4, PP. 135-138, 2001.

Wang, Z.P., Zhang, Z., Lin, Y.J., Deng, N.S., Tao, T., Zhuo, K., 2002. Landfill leachate treatment by a coagulation–photooxidation process. Journal of Hazardous Materials B95, 153–159.

Water Environment Association of Ontario, 2008. Sludge Thickening.

Water Solve, LLC, 2008. Dewatering Process.

Z. Lu, Medicament of water treatment, Publishing Company of Chemical Industry, Beijing (2002) p. 100–102.

Zouboulis, A.I., Chai, X.-L., Katsoyiannis, I.A., 2004. The application of bioflocculant for the removal of humic acids from stabilized landfill leachates. Journal of Environmental Management 70, p 35–41.

APPENDICES

APPENDIX A – X-RAY FLUORESCENT TEST

inted by Eval on 17-Aug-2007 14:42:28
imple :Sludge0807
imple measured on 17-Aug-2007 10:15:16

MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO
5.9 KCps	53.7 KCps	134.0 KCps	10.7 KCps	1.2 KCps	1.2 KCps	1295.6 KCps
0.396 %	4.60 %	11.5 %	0.765 %	0.0496 %	0.0218 %	30.4 %

MnO	Fe2O3	SrO	BaO	Tb4O7	Re	Compton
18.5 KCps	1578.1 KCps	9.0 KCps	1.6 KCps	3.9 KCps	10.9 KCps	
0.374 %	23.3 %	0.0196 %	0.138 %	0.00439 %	0.200 %	1.51

Rayleigh	Norm.
1.57	100.00 %

22/8/07
3²⁵pm

rinted by Eval on 17-Aug-2007 14:42:56
ample :Sludge0807
ample measured on 17-Aug-2007 10:15:16

O	Mg	Al	Si	P	S	K
	5.9 KCps	53.7 KCps	134.0 KCps	10.7 KCps	1.2 KCps	1.2 KCps
45.2 %	0.239 %	2.43 %	5.37 %	0.334 %	0.0199 %	0.0181 %

Ca	Mn	Fe	Sr	Ba	Tb	Re
295.6 KCps	18.5 KCps	1578.1 KCps	9.0 KCps	1.6 KCps	3.9 KCps	10.9 KCps
21.7 %	0.290 %	16.3 %	0.0165 %	0.123 %	0.00373 %	0.200 %

Compton	Rayleigh	Norm.
1.51	1.57	100.00 %

APPENDIX B

B-1 FERRIC CHLORIDE COAGULANT PREPARATION CALCULATION

B-2 FERROUS SULPHATE COAGULANT PREPARATION CALCULATION

B-1 FERRIC CHLORIDE COAGULANT PREPARATION CALCULATION

To Obtain the Stock Solution of Coagulant

Coagulant $FeCl_3$

Make 250 mL coagulant $FeCl_3$

5% $FeCl_3$ = 50 g/L = 50.000 mg/L

2. Use 99% $FeCl_3$ to make coagulant $FeCl_3$ 50 g/L

Calculation

Tare $FeCl_3$

$$= 50gFeCl_3 \times \frac{250mL}{1000mL} \times \frac{100}{99}$$

= 12.6262 g $FeCl_3$

Dillute in 250 mL

Exact Value

Tare $FeCl_3$ = 24.06 g $FeCl_3$

$$[FeCl_3] = 24.06gFeCl_3 \times \frac{1000mL}{510mL} \times \frac{99}{100}$$

= 46.7047 g/L

Get 510 mL 46.7047 g/L $FeCl_3$

B-2FERROUS SULPHATE COAGULANT PREPARATION CALCULATION

Coagulant FeSO4

1. Make 250 mL coagulant FeSO4

5% FeSO4 = 50 g/L = 50.000 mg/L

2. Use FeSO4 . 7 H2O to make coagulant FeSO4 50 g/L

Calculation

M FeSO4 = 152

M FeSO4 .H2O = 278

3. Tare FeSO4 .H2O

$$= \frac{M\ FeSO_4.H_2O}{M\ FeSO_4} \times 50g \times \frac{250mL}{1000mL}$$

$$= \frac{278}{152} \times 50g \times \frac{250mL}{1000mL}$$

= 22.8618 g FeSO4 .H2O

4. Dillute in 250 mL

Exact Value

5. Tare FeSO4 .H2O

= 137.06 g FeSO4 .H2O

[FeSO4]

$$= \frac{Mr\ FeSO_4}{Mr\ FeSO_4.H_2O} \times 137.06g \times \frac{1000mL}{500mL}$$

$$= \frac{152}{278} \times 137.06g \times \frac{1000mL}{500mL}$$

= 149.8786 g/L

6. Get 500 mL 149,8786 g/L FeSO4

APPENDIX C

C-1 SETTLEABILITY RESULT FOR RAW SAMPLE

C-2 SETTLEABILTY RESULT USING ALUM AS COAGULANT AT VARIOUS DOSAGES

C-3 SETTLEABILITY RESULT USING FERRIC CHLORIDE AS COAGULANT AT VARIOUS DOSAGES

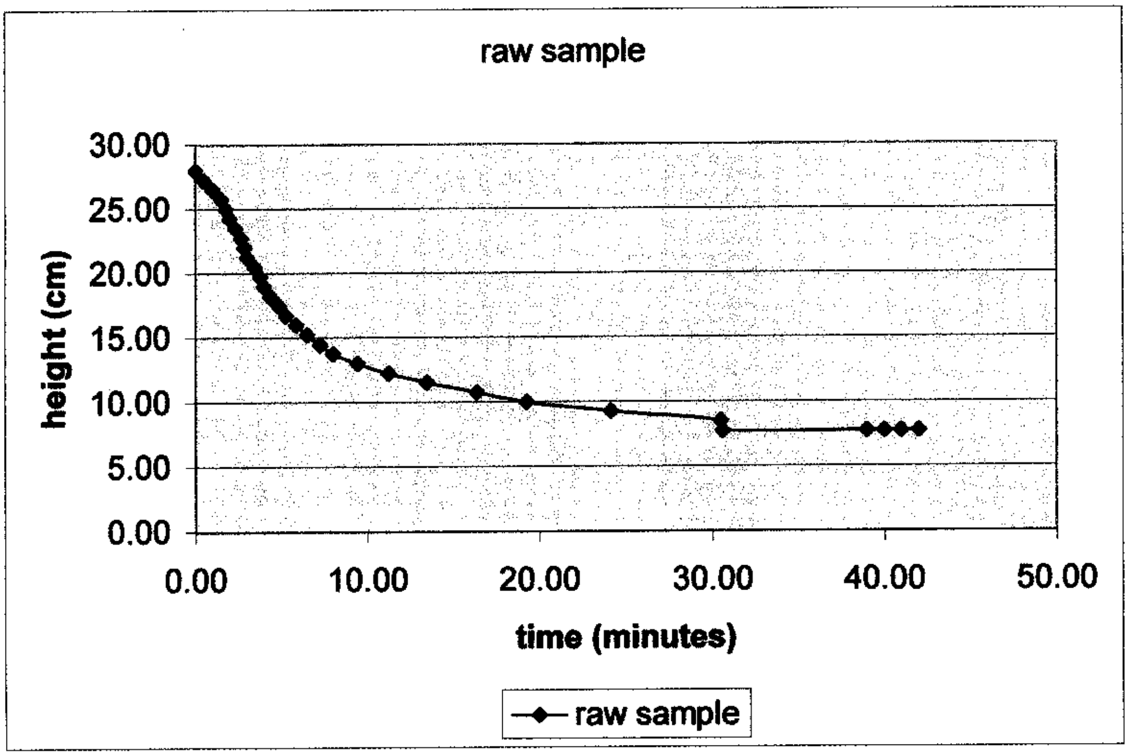
C-4 SETTLEABILITY RESULT USING FERROUS SULPHATE AS COAGULANT AT VARIOUS DOSAGES

C-5 SETTLEABILITY RESULT USING RFC AS COAGULANT AT VARIOUS DOSAGES

C-1 SETTLEABILITY RESULT FOR RAW SAMPLE

raw sample		raw sample	
time (min)	height (cm)	time (min)	height (cm)
0.00	28.00	5.85	16.00
0.50	27.25	6.50	15.25
1.00	26.50	7.25	14.50
1.50	25.75	8.00	13.75
1.75	25.00	9.43	13.00
2.00	24.25	11.25	12.25
2.33	23.50	13.45	11.50
2.67	22.75	16.33	10.75
2.87	22.00	19.25	10.00
3.00	21.25	24.13	9.25
3.47	20.50	30.50	8.50
3.75	19.75	30.63	7.75
4.00	19.00	39.00	7.75
4.35	18.25	40.00	7.75
4.83	17.50	41.00	7.75
5.25	16.75	42.00	7.75

Graph Height vs Time for Raw Sample



$$\text{Settling rate} = \frac{25.75 - 16.75}{1.5 - 5.25}$$

$$= -2.4\text{cm/min}$$

C-2 SETTLEABILTY RESULT USING ALUM AS COAGULANT AT VARIOUS DOSAGES

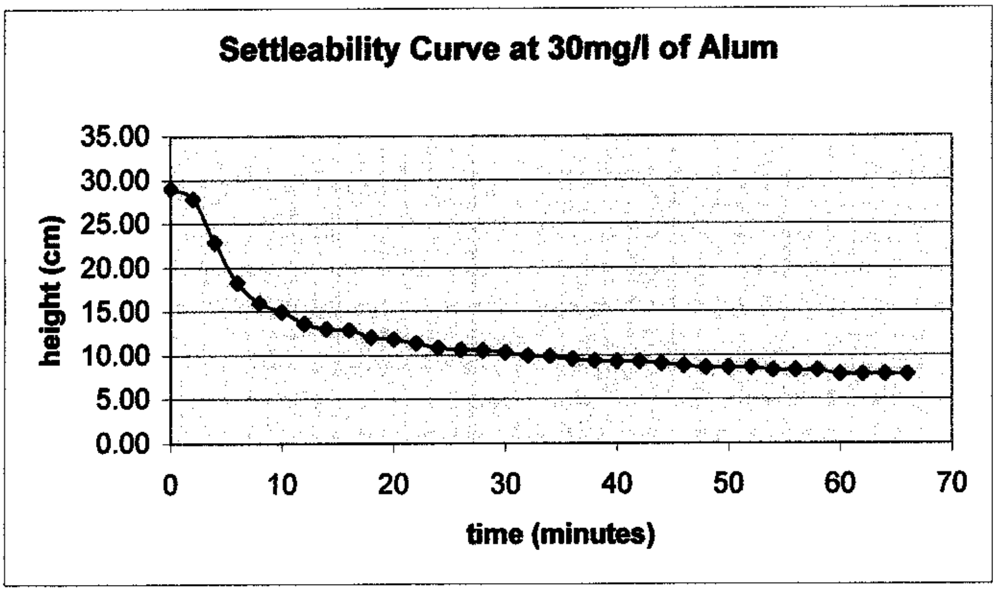
30mg/l		60mg/l		120mg/l	
time	height	time	height	time	height
0	29.10	0	28.90	0	30.00
2	27.90	1.25	27.25	2	23.00
4	22.90	1.83	26.55	4	17.50
6	18.30	2.33	25.90	6	14.50
8	16.00	2.75	25.15	8	13.20
10	15.00	3.16	24.40	10	12.30
12	13.70	3.55	23.70	12	11.30
14	13.10	4.15	23.00	14	10.80
16	12.90	4.5	22.30	16	10.10
18	12.10	4.83	21.55	18	9.60
20	11.90	5.23	20.85	20	9.50
22	11.40	5.63	20.15	22	9.00
24	10.90	6.13	19.40	24	8.70
26	10.70	6.6	18.75	26	8.50
28	10.60	7.27	18.05	28	8.00
30	10.40	8.05	17.35	30	8.00
32	10.00	9.07	16.65	32	7.90
34	9.90	9.98	15.90	34	7.90
36	9.60	11.13	15.20	36	7.70
38	9.40	12.15	14.50	38	7.60
40	9.30	14.32	13.80	40	7.60
42	9.30	16.43	13.05	42	7.50
44	9.10	19.03	12.35	44	7.30
46	8.90	22.32	11.60	46	7.30
48	8.60	26.2	10.90	48	7.30

50	8.60	31.2	10.20	50	7.30
52	8.60	37.5	9.50		
54	8.30	47.33	8.75		
56	8.30	57.25	8.05		
58	8.30	72.83	7.35		
60	7.90	74.83	7.35		
62	7.90	76.83	7.35		
64	7.90	78.83	7.35		
66	7.90	80.83	7.35		

300mg/l		900mg/l		1200mg/l	
time	height	time	height	time	height
0	28.70	0	28.80	0	26.00
0.16	27.99	2	25.30	2	24.44
0.32	27.28	4	20.70	4	20.54
0.49	26.57	6	17.50	6	17.68
0.87	25.15	8	15.30	8	15.86
1.07	24.44	10	13.90	10	14.30
1.28	23.73	12	12.80	12	13.26
1.5	23.02	14	11.70	14	12.48
1.73	22.31	16	11.40	16	11.44
1.92	21.60	18	10.60	18	10.66
2.18	20.89	20	10.30	20	10.14
2.55	20.18	22	9.60	22	9.62
2.93	19.47	24	9.30	24	9.36
3.32	18.76	26	9.20	26	8.84
4.42	17.34	28	8.90	28	8.58
4.57	16.63	30	8.60	30	8.32

5.1	15.92	32	8.20	32	8.06
5.65	15.21	34	8.20	34	7.80
6.23	14.50	36	8.10	36	7.54
7.22	13.79	38	8.00	38	7.41
8.38	13.08	40	7.60	40	7.28
9.58	12.37	42	7.50	42	7.02
10.6	11.66	44	7.50	44	6.89
13.33	10.95	46	7.50	46	6.76
16.32	10.24	48	7.50	48	6.76
19.4	9.53	50	7.50	50	6.63
22.86	8.82			52	6.50
28.55	8.11			54	6.50
40.08	7.40			56	6.24
79.68	6.69			58	6.24
81.68	6.69			60	6.24
83.68	6.69			62	6.24
85.68	6.69			64	6.24
87.68	6.69				

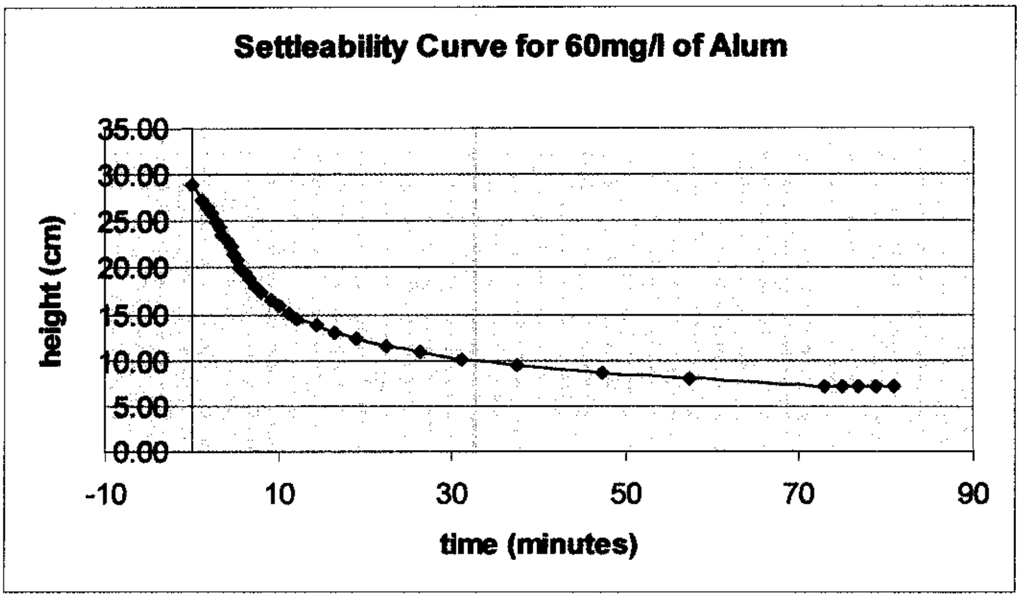
Graph Height vs Time for 30mg/L of Alum



Settling rate = $\frac{27.90 - 18.30}{2.0 - 6.0}$

= -2.4cm/min

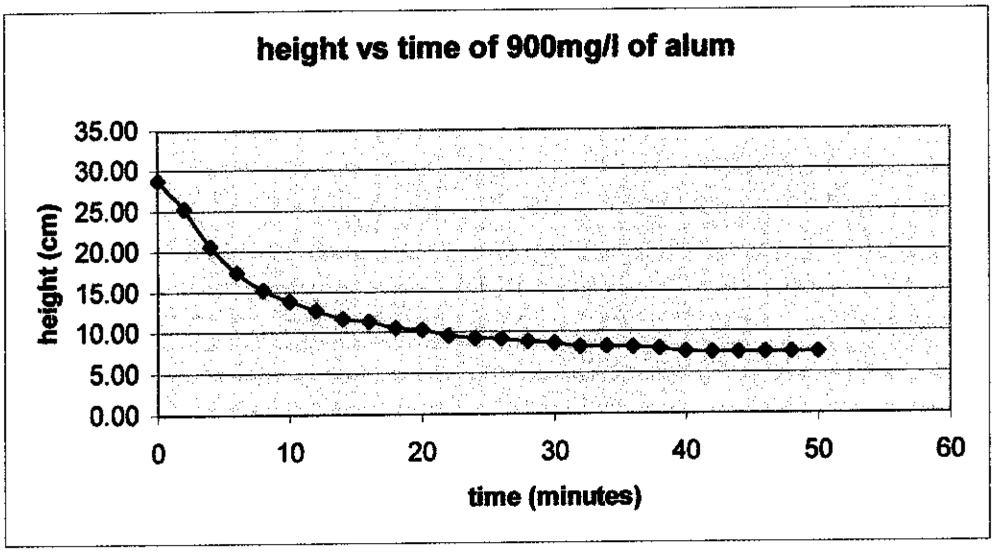
Graph Height vs Time for 60mg/L of Alum



Settling rate = $\frac{28.90 - 18.05}{0 - 7.27}$

= -1.492 cm/min

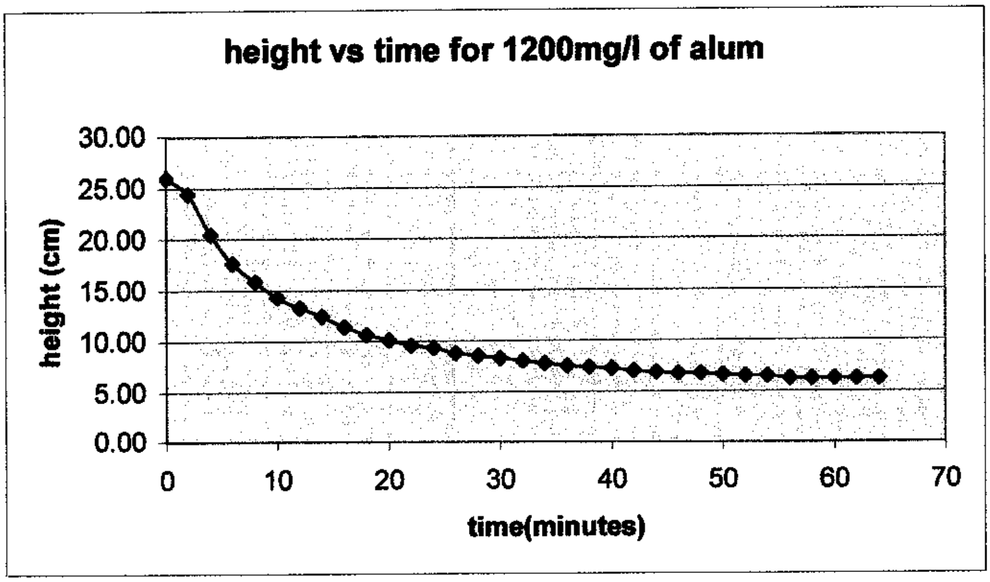
Graph Height vs Time for 900mg/L of Alum



Settling rate = $\frac{28.80 - 17.50}{0 - 6}$

= -1.883 cm/min

Graph Height vs Time for 1200mg/L of Alum



Settling rate = $\frac{26.00 - 15.86}{0 - 8}$

= -1.2675cm/min

C-3 SETTLEABILITY RESULT USING FERRIC CHLORIDE AS COAGULANT AT VARIOUS DOSAGES

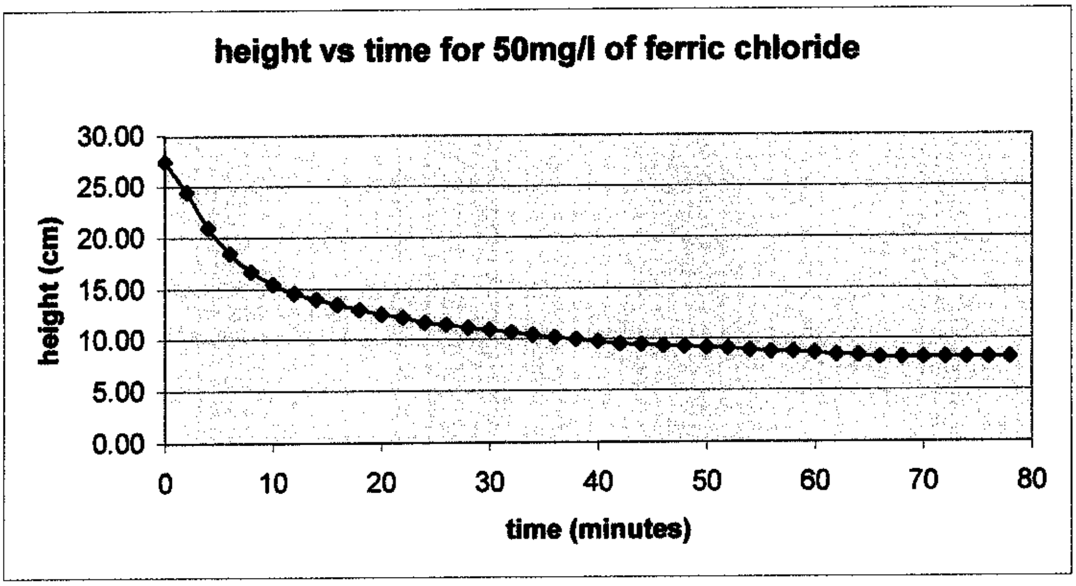
50mg/l		100mg/l		150mg/l	
time	height	time	height	time	height
0	27.50	0	28.50	0	28.8
2	24.50	0.72	27.28	1	28.57
4	21.00	1.65	26.55	2	27.41
6	18.50	2.08	26.55	3	26.55
8	16.70	2.33	25.83	4	24.53
10	15.50	2.92	24.38	5	24.24
12	14.60	3.28	23.65	6	23.37
14	14.00	3.73	22.93	7	22.22
16	13.50	4.15	22.20	8	21.07
18	13.00	4.65	21.48	9	20.20
20	12.50	5.32	20.75	10	19.62
22	12.20	5.92	20.03	11	18.47
24	11.70	6.38	19.30	12	17.60
26	11.50	7.12	18.58	13	17.03
28	11.20	8.05	17.85	14	16.45
30	11.00	8.9	17.13	15	15.87
32	10.70	9.88	16.40	16	15.00
34	10.50	11.17	15.68	17	14.72
36	10.20	12.48	14.95	18	14.14
38	10.00	14.2	14.23	19	13.85
40	9.80	15.78	13.50	20	13.56
42	9.60	18.05	12.78	21	13.27
44	9.50	20.33	12.05	22	12.70
46	9.40	23.9	11.33	23	12.41
48	9.30	27.75	10.60	24	12.12

50	9.20	32.9	9.88	25	11.83
52	9.10	40.2	9.15	26	11.54
54	8.90	49.2	8.43	27	11.25
56	8.80	63.83	7.40	28	11.11
58	8.80	65.83	7.40	29	10.97
60	8.70	67.83	7.30	30	10.68
62	8.50	69.83	7.20	31	10.53
64	8.40	71.83	7.20	32	10.39
66	8.20	73.83	7.10	33	10.24
68	8.20	75.83	7.05	34	10.10
70	8.20	77.83	7.00	35	9.81
72	8.20	79.83	7.00	36	9.67
74	8.20	81.83	7.00	37	9.52
76	8.20			38	9.38
78	8.20			39	9.23
				40	9.23

250mg/l		1000mg/l		1500mg/l	
time	height	time	height	time	height
0	27.50	0	28.90	0	25
2	27.20	0.33	28.18	2	19.50
4	23.70	0.7	27.46	4	16.80
6	21.20	1.13	26.74	6	15.00
8	18.10	1.43	26.03	8	13.70
10	17.10	2.12	24.59	10	12.40
12	15.40	2.42	23.87	12	11.50
14	14.35	2.72	23.10	14	10.70
16	13.30	3.05	22.38	16	10.10
18	12.60	3.4	21.67	18	9.70
20	12.00	3.73	20.95	20	9.30

22	11.70	4.22	20.23	22	8.90
24	10.80	4.5	19.51	24	8.60
26	10.00	4.93	18.79	26	8.20
28	9.70	5.65	18.07	28	8.00
30	9.50	6.22	17.35	30	7.90
32	9.40	7.88	15.91	32	7.60
34	9.00	8.75	15.19	34	7.50
36	8.80	9.85	14.47	36	7.20
38	8.70	11.28	13.75	38	7.20
40	8.60	12.48	13.03	40	7.10
42	8.50	14.67	12.31	42	7.00
44	8.40	16.87	11.59	44	6.90
46	8.20	19.57	10.87	46	6.90
48	8.20	22.93	10.15	48	6.80
50	8.20	27.83	9.43	50	6.80
52	7.90	34.2	8.71	52	6.60
54	7.90	48.12	7.99	54	6.60
56	7.90	61.08	7.70	56	6.60
58	7.90	64.55	7.70	58	6.60
60	7.90	66.55	7.70	60	6.40
62	7.60			62	6.40
64	7.60			64	6.40
66	7.60			66	6.40
68	7.60			68	6.40
70	7.60			70	6.40
72	7.60				
74	7.60				
76	7.60				

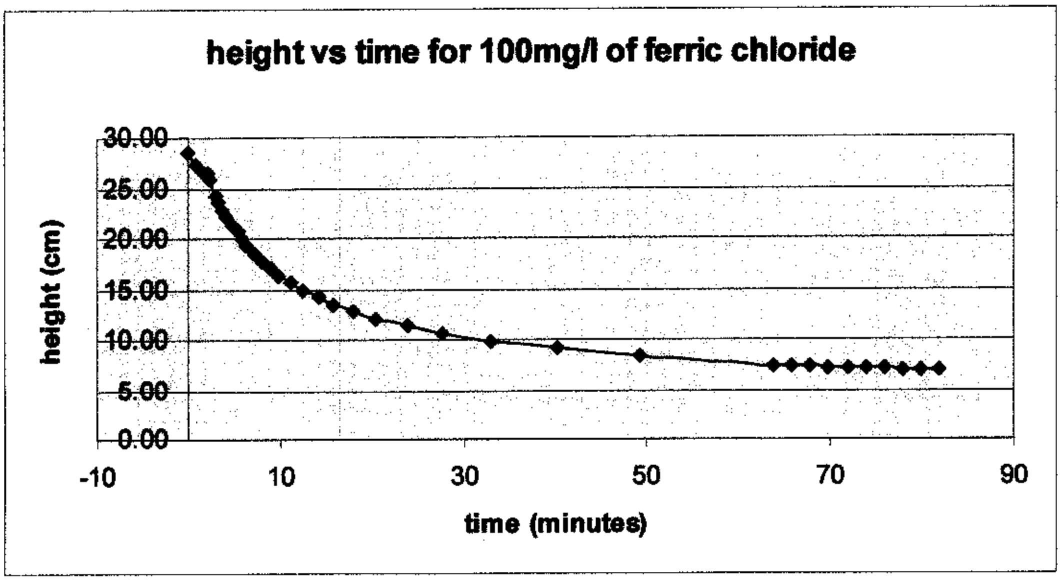
Graph Height vs Time for 50mg/L of Ferric Chloride



Settling rate = $\frac{27.50 - 18.50}{0 - 6}$

= -1.5cm/min

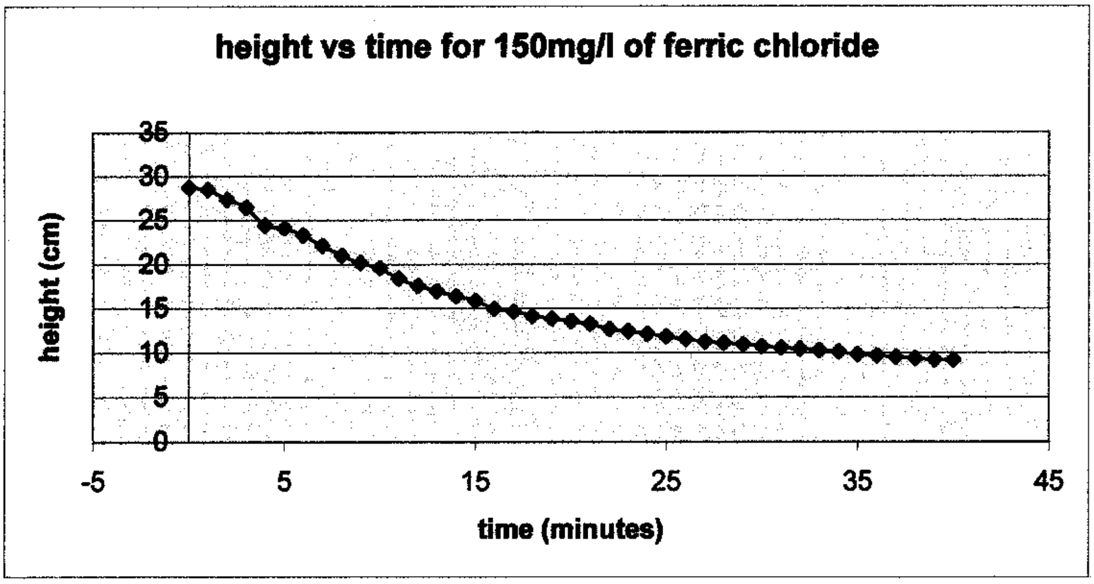
Graph Height vs Time for 100mg/L of Ferric Chloride



Settling rate = $\frac{28.50 - 17.13}{0 - 8.9}$

= -1.278cm/min

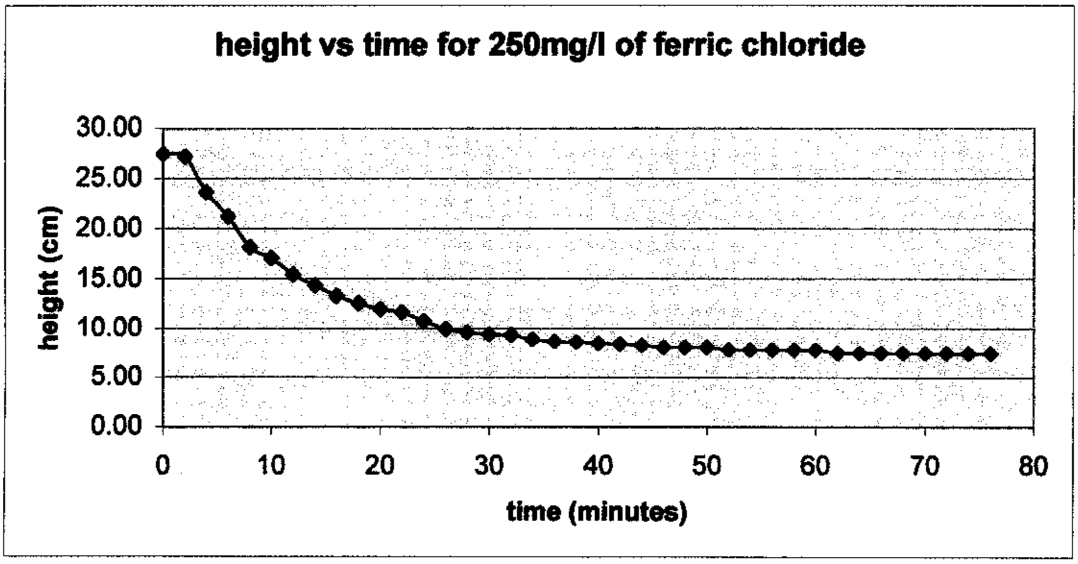
Graph Height vs Time for 150mg/L of Ferric Chloride



Settling rate = $\frac{28.80 - 17.60}{0 - 12}$

= -0.933cm/min

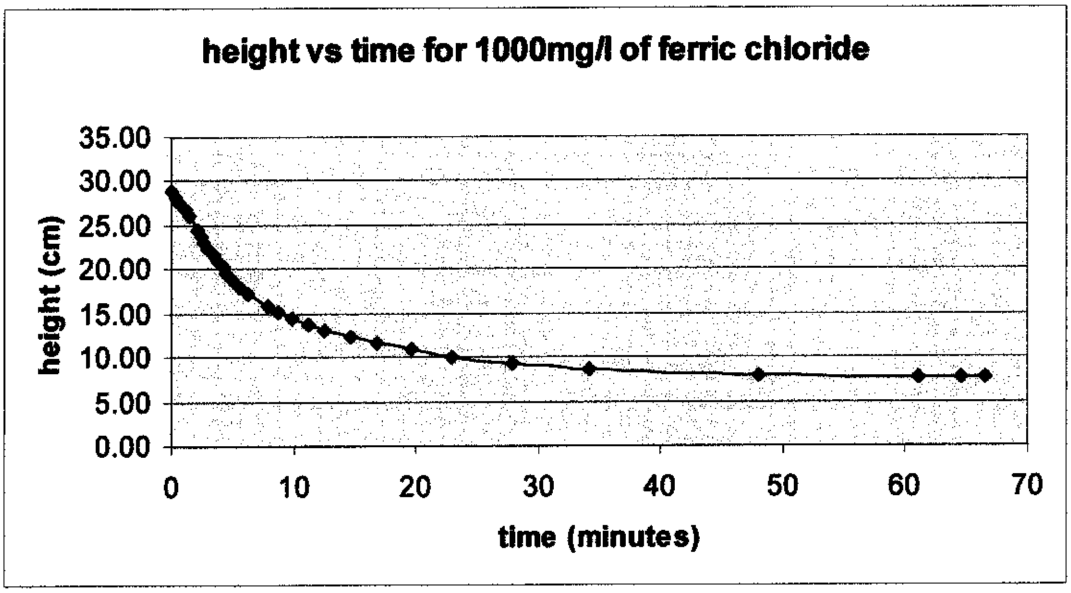
Graph Height vs Time for 250mg/L of Ferric Chloride



Settling rate = $\frac{27.50 - 18.10}{0 - 8}$

= -1.175cm/min

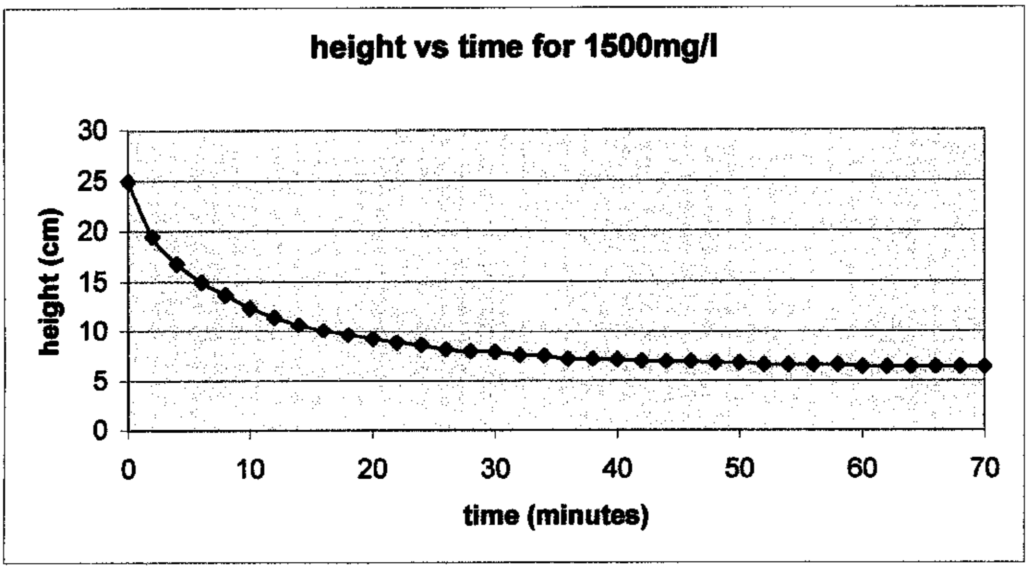
Graph Height vs Time for 1000mg/L of Ferric Chloride



$$\text{Settling rate} = \frac{28.90 - 17.35}{0 - 6.22}$$

$$= -1.857\text{cm/min}$$

Graph Height vs Time for 1500mg/L of Ferric Chloride



$$\text{Settling rate} = \frac{16.80 - 12.40}{4 - 10}$$

$$= -0.733\text{cm/min}$$

C-4 SETTLEABILITY RESULT USING FERROUS SULPHATE AS COAGULANT AT VARIOUS DOSAGES

50mg/l		100mg/l		150mg/l	
time	height	time	height	time	height
0	36.00	0	28.30	0	28.50
2	34.20	2	25.40	2	24.94
4	28.80	4	18.90	4	21.38
6	24.12	6	15.20	6	17.81
8	21.06	8	13.80	8	16.74
10	19.08	10	12.30	10	14.96
12	17.82	12	11.60	12	14.25
14	16.92	14	10.90	14	13.54
16	16.20	16	10.60	16	12.83
18	15.48	18	10.20	18	12.30
20	14.94	20	9.90	20	11.76
22	14.40	22	9.40	22	11.40
24	14.04	24	9.10	24	11.04
26	13.68	26	9.00	26	10.69
28	13.32	28	8.70	28	10.33
30	13.03	30	8.10	30	9.98
32	12.78	32	8.10	32	9.61
34	12.60	34	8.00	34	9.44
36	12.35	36	8.00	36	9.26
38	12.06	38	7.80	38	9.08
40	11.88	40	7.70	40	8.91
42	11.59	42	7.70	42	8.73
44	11.52	44	7.30	44	8.55
46	11.34	46	7.30	46	8.46
48	11.16	48	7.30	48	8.37

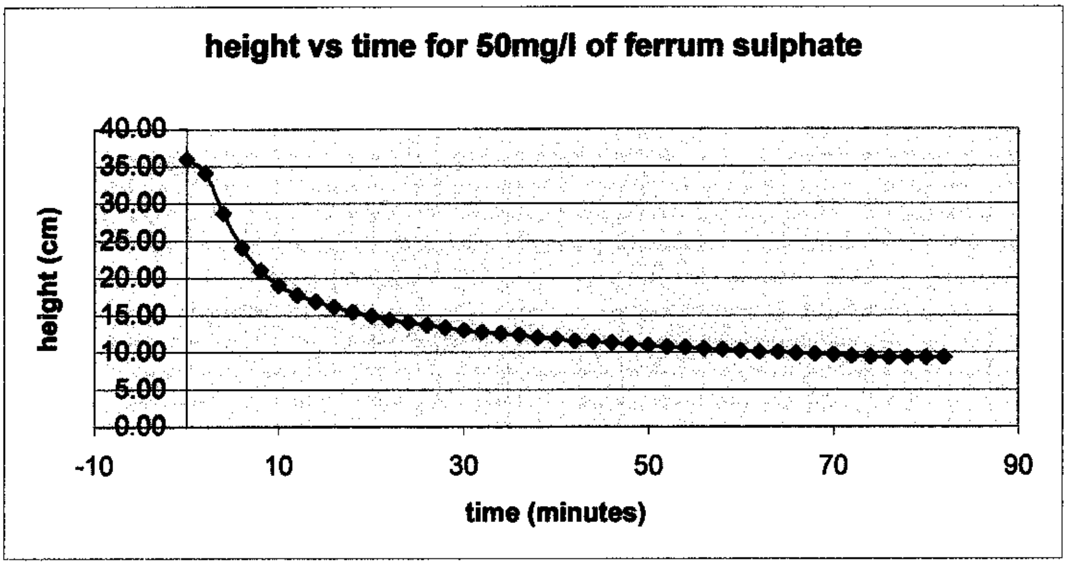
50	10.98	50	7.30	50	8.19
52	10.80	52	7.00	52	8.02
54	10.73	54	7.00	54	7.93
56	10.51	56	6.50	56	7.84
58	10.44	58	6.50	58	7.48
60	10.26	60	6.50	60	7.48
62	10.08			62	7.48
64	10.08			64	7.48
66	9.90			66	7.48
68	9.79			68	7.48
70	9.72			70	7.48
72	9.54			72	7.48
74	9.43			74	7.48
76	9.36			76	7.48
78	9.36			78	7.48
80	9.36				
82	9.36				

250mg/l		1000mg/l		1500mg/l	
time	height	time	height	time	height
0	28.50	0	28.50	0	29.00
2	25.94	2	23.50	2	26.10
4	20.66	4	18.50	4	20.10
6	17.24	6	16.00	6	16.50
8	15.39	8	14.50	8	14.60
10	14.25	10	13.11	10	13.60
12	13.54	12	11.97	12	12.50
14	12.83	14	11.40	14	12.10

16	12.11	16	11.12	16	11.50
18	11.40	18	10.69	18	10.80
20	11.12	20	9.97	20	10.60
22	10.69	22	9.70	22	10.30
24	10.55	24	9.41	24	10.00
26	10.26	26	9.26	26	9.80
28	9.98	28	9.12	28	9.50
30	9.69	30	8.98	30	9.20
32	9.26	32	8.55	32	8.90
34	9.26	34	8.50	34	8.80
36	9.12	36	8.41	36	8.60
38	8.84	38	7.98	38	8.50
40	8.69	40	7.84	40	8.30
42	8.55	42	7.80	42	8.20
44	8.55	44	7.70	44	8.00
46	8.27	46	7.65	46	7.90
48	7.98	48	7.50	48	7.80
50	7.98	50	7.50	50	7.70
52	7.84	52	7.41	52	7.60
54	7.84	54	7.13	54	7.50
56	7.41	56	7.13	56	7.50
58	7.41	58	7.12	58	7.40
60	7.41	60	6.84	60	7.20
62	7.41	62	6.84	62	7.20
64	7.13	64	6.55	64	7.10
66	7.13	66	6.55	66	7.10
68	7.13	68	6.55	68	7.00
70	7.13	70	6.55	70	6.90
72	7.13	72	6.55	72	6.90
74	7.13	74	6.55	74	6.90

76	7.13	76	6.55	76	6.90
		78	6.55		
		80	6.55		
		82	6.55		

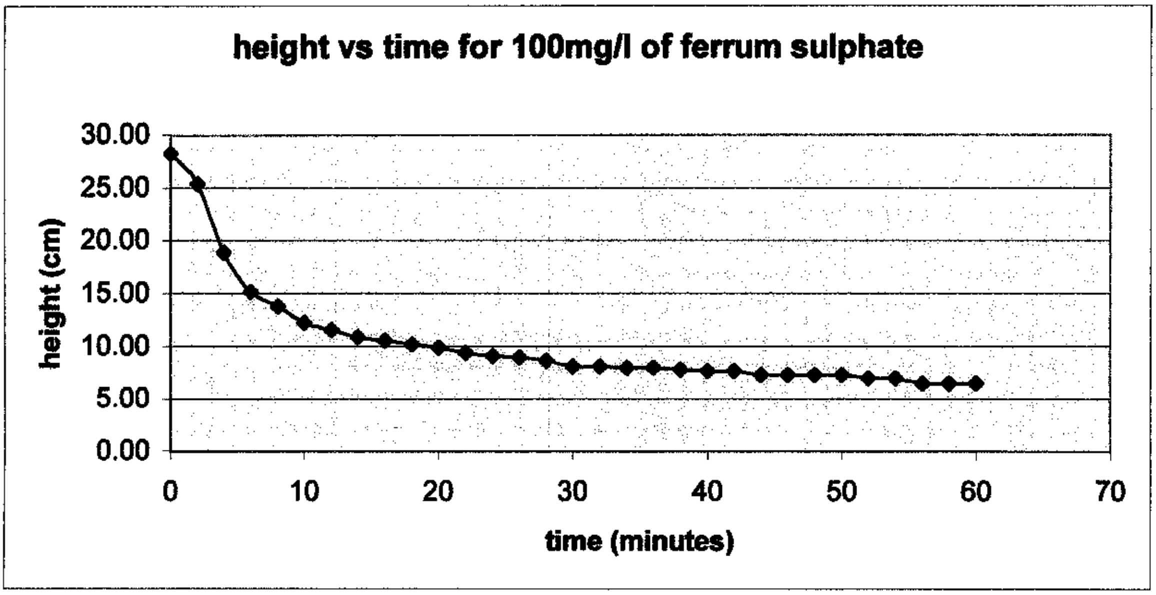
Graph Height vs Time for 50mg/L of Ferrous Sulphate



Settling rate = $\frac{36.0 - 21.06}{0 - 8}$

= -1.868cm/min

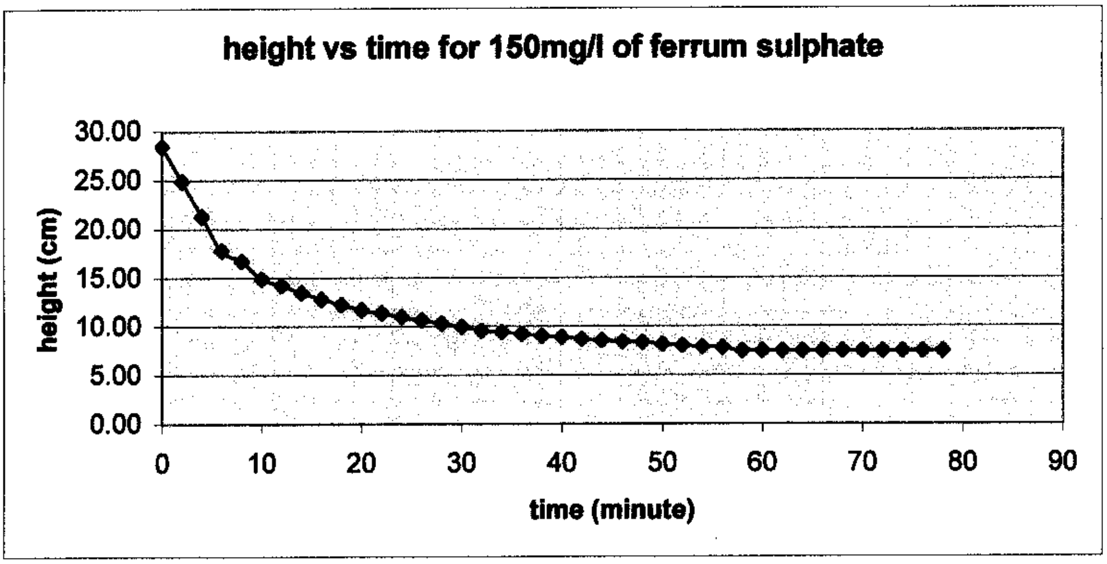
Graph Height vs Time for 100mg/L of Ferrous Sulphate



Settling rate = $\frac{28.3 - 15.20}{0 - 6}$

= -2.183cm/min

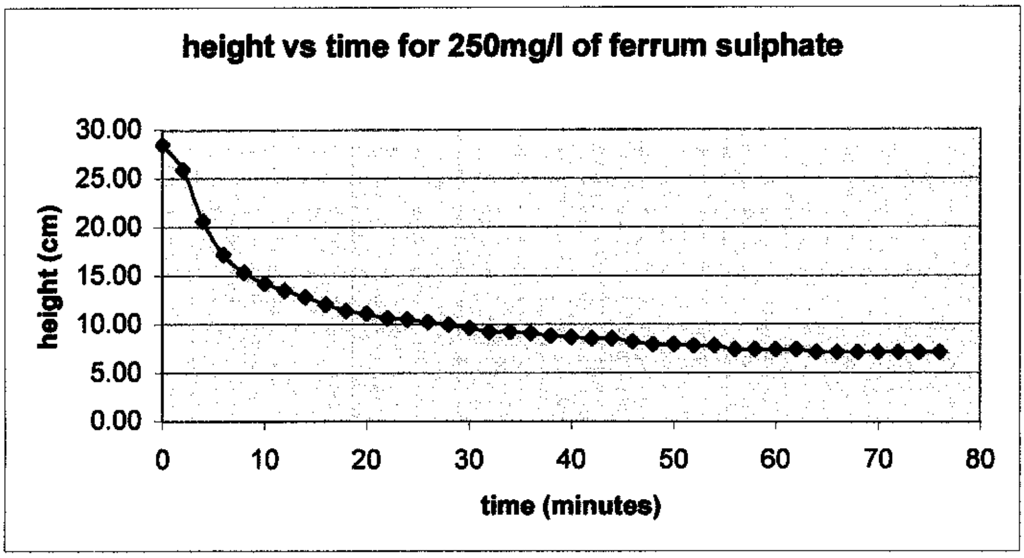
Graph Height vs Time for 150mg/L of Ferrous Sulphate



$$\text{Settling rate} = \frac{28.50 - 17.81}{0 - 6}$$

$$= -1.782\text{cm/min}$$

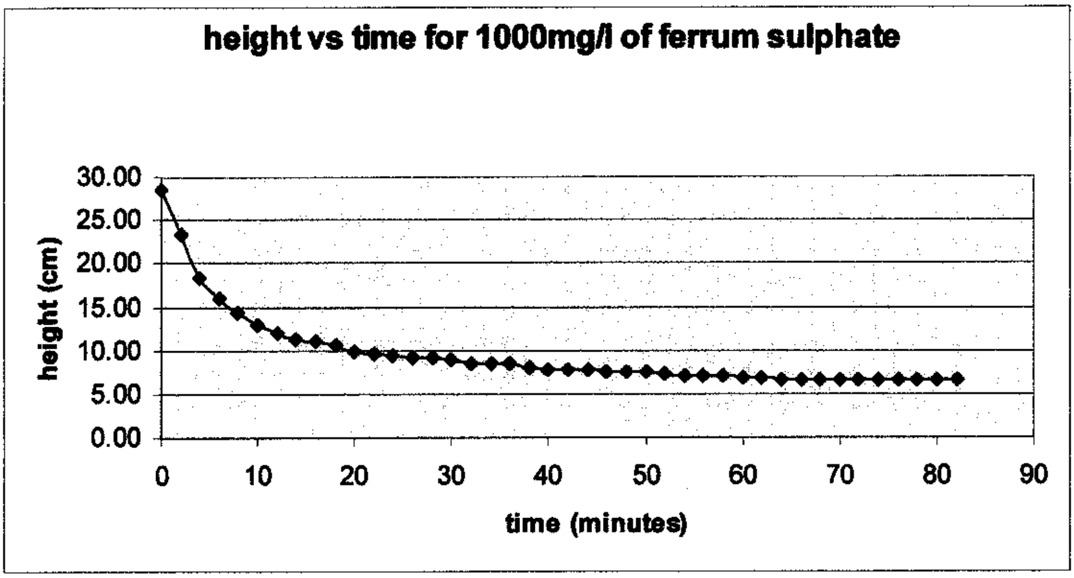
Graph Height vs Time for 250mg/L of Ferrous Sulphate



$$\text{Settling rate} = \frac{28.50 - 17.24}{0 - 6}$$

$$= -1.782\text{cm/min}$$

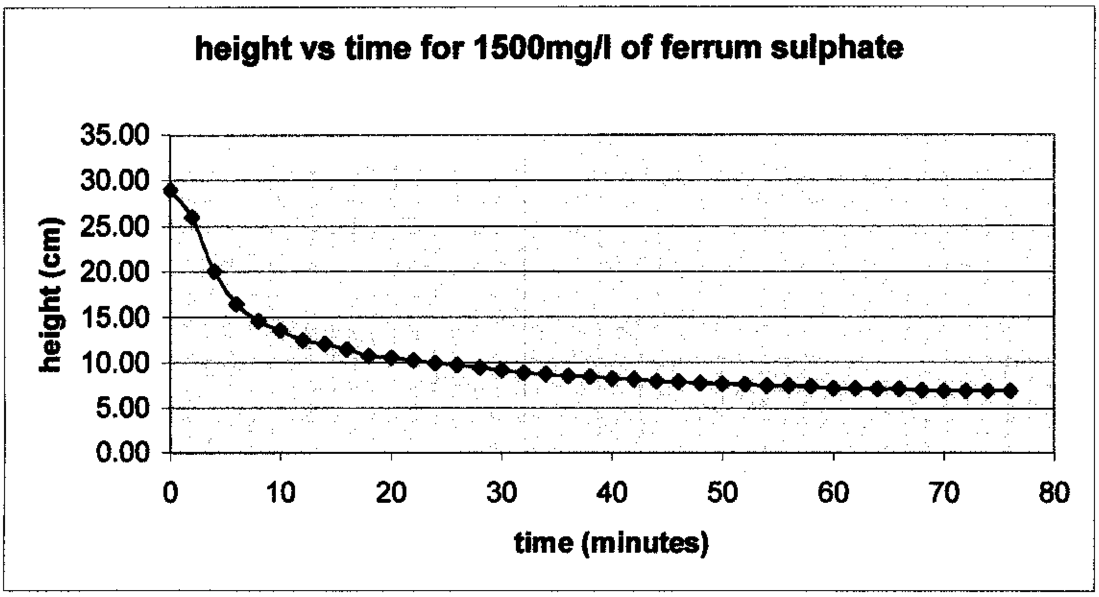
Graph Height vs Time for 1000mg/L of Ferrous Sulphate



$$\text{Settling rate} = \frac{28.50 - 18.50}{0 - 4}$$

$$= -2.5\text{cm/min}$$

Graph Height vs Time for 1500mg/L of Ferrous Sulphate



$$\text{Settling rate} = \frac{29.00 - 16.50}{0 - 4}$$

$$= -2.083\text{cm/min}$$

C-5 SETTLEABILITY RESULT USING RFC AS COAGULANT AT VARIOUS DOSAGES

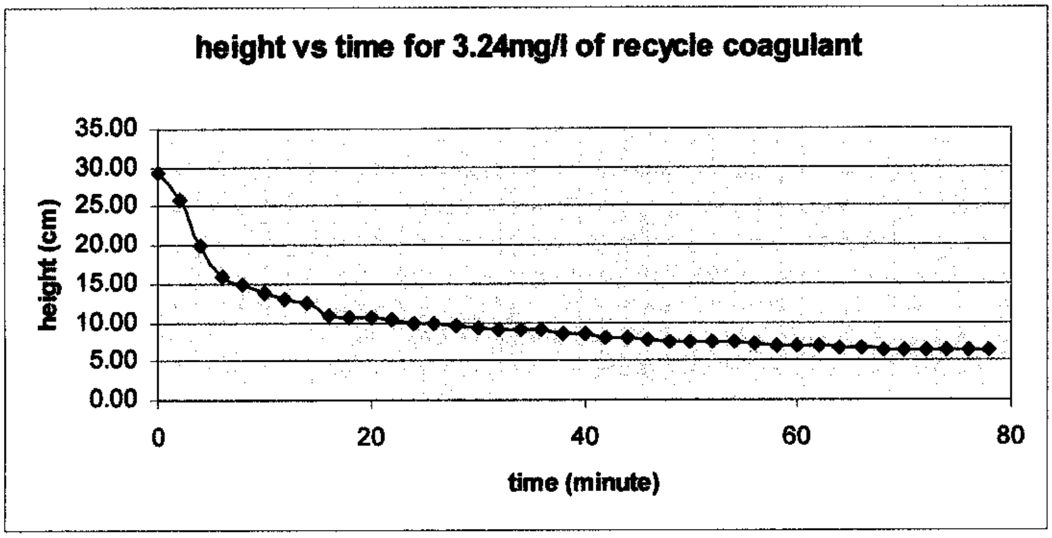
3.24mg/l		6.49mg/l		9.73mg/l	
time	height	time	height	time	height
0	29.50	0	28.50	0	29.00
2	26.00	2	20.00	2	20.00
4	20.00	4	16.00	4	16.50
6	16.00	6	13.50	6	14.50
8	15.00	8	12.50	8	13.00
10	14.00	10	11.00	10	12.50
12	13.00	12	10.50	12	11.50
14	12.50	14	10.30	14	9.80
16	11.00	16	9.90	16	9.50
18	10.80	18	8.50	18	9.00
20	10.70	20	8.40	20	8.00
22	10.40	22	8.30	22	8.00
24	10.00	24	8.20	24	8.00
26	10.00	26	8.10	26	7.50
28	9.50	28	8.00	28	7.50
30	9.30	30	7.50	30	7.50
32	9.00	32	7.50	32	7.00
34	9.00	34	7.00	34	7.00
36	9.00	36	7.00	36	7.00
38	8.50	38	7.00	38	7.00
40	8.50	40	6.80	40	7.00
42	8.00	42	6.50	42	6.50
44	8.00	44	6.50	44	6.50
46	7.80	46	6.50	46	6.50
48	7.50	48	6.00	48	6.50

50	7.50	50	6.00	50	6.50
52	7.40	52	6.00	52	6.50
54	7.40	54	6.00		
56	7.30	56	6.00		
58	7.00	58	6.00		
60	7.00	60	6.00		
62	7.00				
64	6.80				
66	6.80				
68	6.50				
70	6.50				
72	6.50				
74	6.50				
76	6.50				
78	6.50				

11.35mg/l		12.98mg/l		14.60mg/l	
time	height	time	height	time	height
0	30.00	0	30.20	0	28.80
2	22.00	2	23.00	2	22.80
4	17.00	4	18.00	4	17.00
6	15.00	6	15.70	6	14.30
8	13.00	8	13.80	8	12.20
10	12.50	10	12.70	10	11.80
12	11.50	12	12.20	12	11.00
14	11.00	14	11.20	14	10.50
16	10.50	16	10.40	16	10.00
18	9.50	18	10.00	18	9.50
20	9.50	20	9.50	20	9.00
22	9.00	22	9.00	22	8.50

24	8.70	24	8.50	24	8.00
26	8.50	26	8.50	26	8.00
28	8.00	28	8.20	28	7.50
30	8.00	30	8.00	30	7.50
32	7.50	32	7.90	32	7.50
34	7.50	34	7.50	34	7.50
36	7.40	36	7.50	36	7.00
38	7.00	38	7.40	38	7.00
40	7.00	40	7.00	40	7.00
42	7.00	42	7.00	42	7.00
44	6.80	44	6.80	44	6.80
46	6.50	46	6.80	46	6.50
48	6.50	48	6.50	48	6.50
50	6.50	50	6.50	50	6.50
52	6.30	52	6.50	52	6.00
54	6.00	54	6.50	54	6.00
56	6.00	56	6.50	56	6.00
58	6.00			58	6.00
60	6.00			60	6.00
62	6.00				

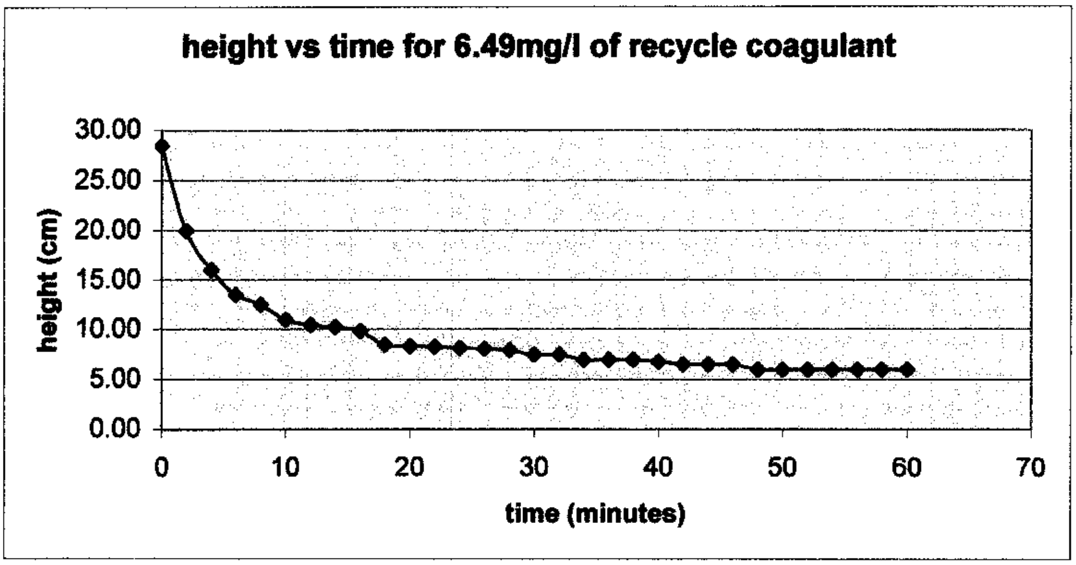
Graph Height vs Time for 3.24mg/L of RFC



$$\textbf{Settling rate} = \frac{29.50 - 16.00}{0 - 6}$$

$$= -2.25\text{cm/min}$$

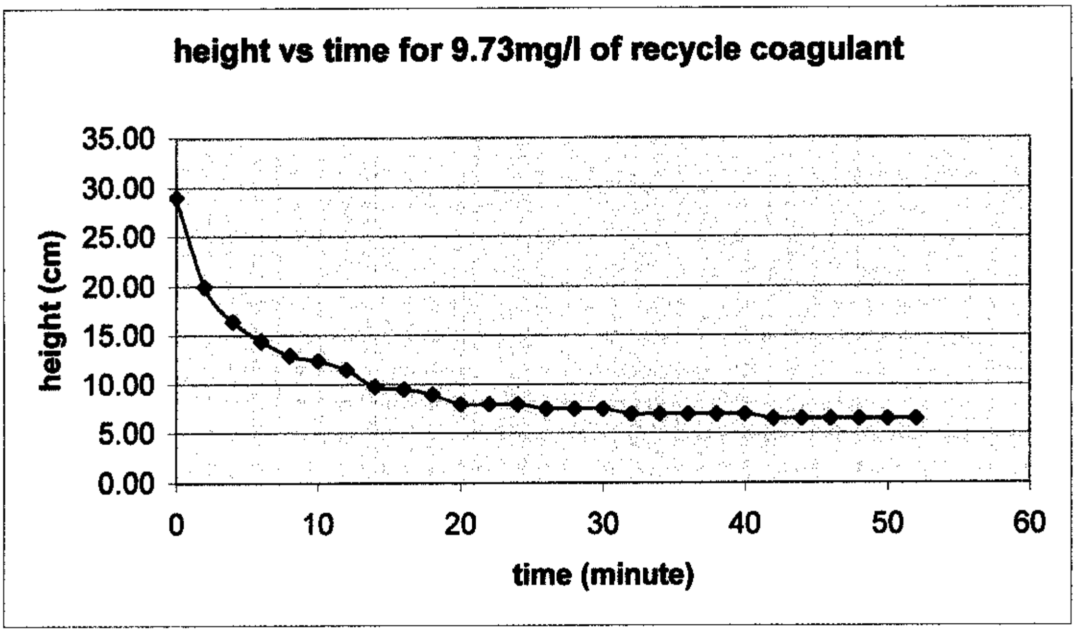
Graph Height vs Time for 6.49mg/L of RFC



$$\textbf{Settling rate} = \frac{28.50 - 20.00}{0 - 2}$$

$$= -4.25\text{cm/min}$$

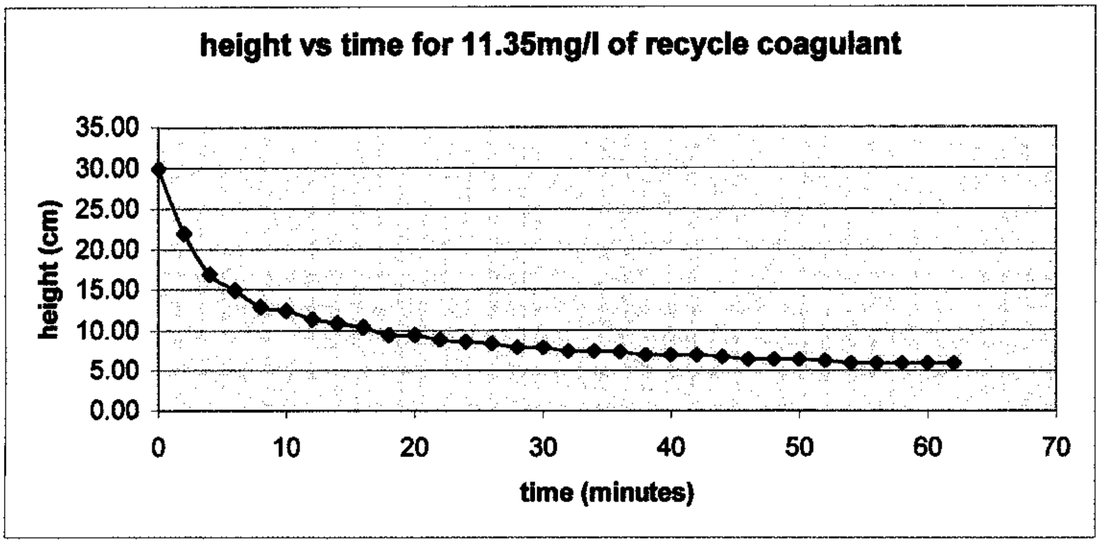
Graph Height vs Time for 9.73mg/L of RFC



$$\text{Settling rate} = \frac{29.00 - 20.00}{0 - 2}$$

$$= -4.50\text{cm/min}$$

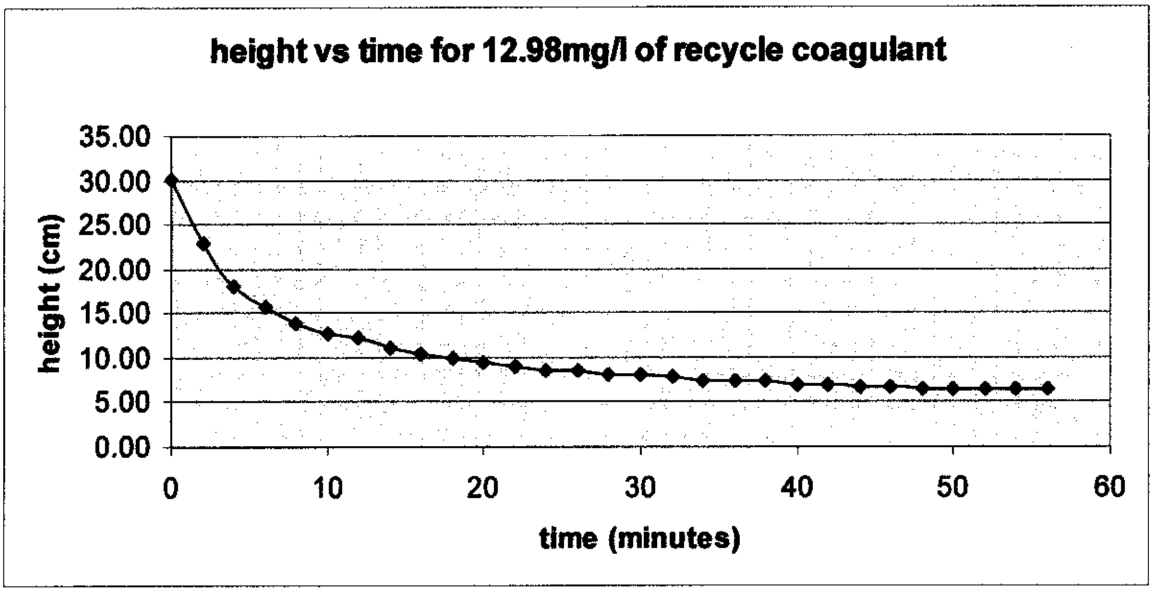
Graph Height vs Time for 11.35mg/L of RFC



$$\text{Settling rate} = \frac{30.00 - 17.00}{0 - 4}$$

$$= -3.25\text{cm/min}$$

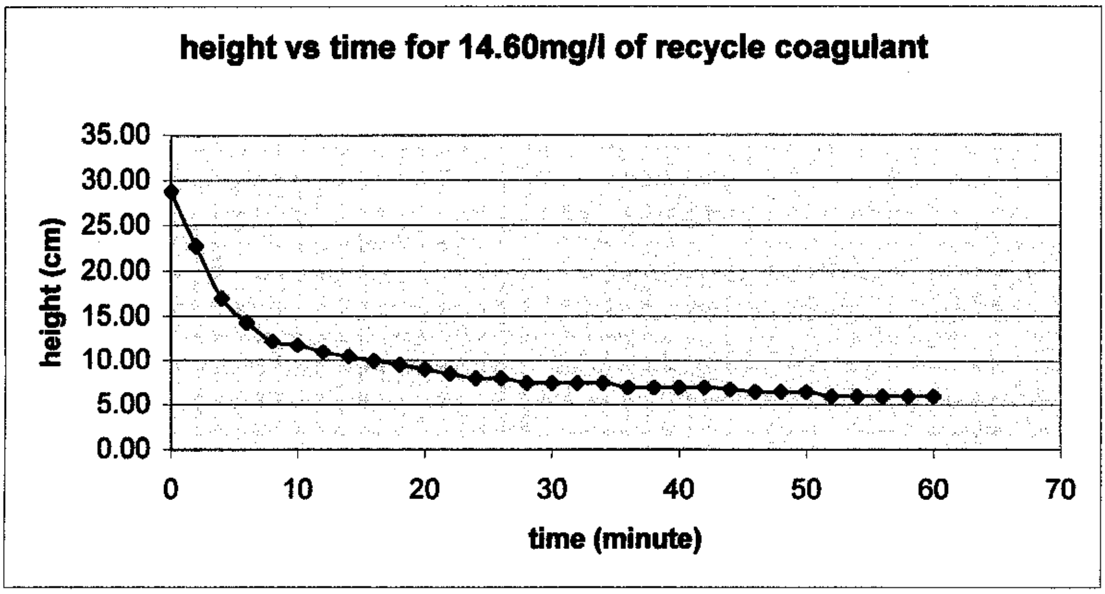
Graph Height vs Time for 12.98mg/L of RFC



$$\text{Settling rate} = \frac{30.20 - 18.00}{0 - 4}$$

$$= -3.05\text{cm/min}$$

Graph Height vs Time for 14.60mg/L of RFC



$$\text{Settling rate} = \frac{28.80 - 17.00}{0 - 4}$$

$$= -2.95\text{cm/min}$$

APPENDIX D – COLOUR TEST RESULT

Sample	Dosage (mg/l)	colour (ntu)
raw	0	444
alum	30	3719
	60	5628
	120	2513
	300	2881
	900	171
	1200	244
raw	0	444
ferric chloride	50	15343
	100	4322
	150	2312
	250	12060
	1000	2077
	1500	3886
raw	0	444
ferrum sulphate	50	410
	100	603
	150	1340
	250	1407
	1000	6533
	1500	2814
raw	0	444
RFC2	3.24	1583
	6.49	1067
	9.73	256

	11.35	273
	12.98	56
	14.6	124
RFC1	16	192
	49	119
	81	161
	114	157
	146	238
	163	210

APPENDIX E – CHEMICAL OXYGEN DEMAND (COD) RESULT

sample	dosage (mg/l)	COD (mg/l)			
		i	ii	iii	average
raw	0	1074	1100	957	1044
alum	30	1055	1055	1086	1065
	60	1028	1076	1081	1062
	120	1039	983	1064	1029
	300	1090	1078	1091	1086
	900	1125	1061	985	1057
	1200	1102	1024	1126	1084
raw	0	1074	1100	957	1044
ferric chloride	50	1064	1097	1035	1065
	100	1078	1016	1001	1032
	150	991	909	1088	996
	250	1086	1086	1082	1085
	1000	1104	1225	1189	1173
	1500	1284	1122	1240	1215
raw	0	1074	1100	957	1044
ferrum sulphate	50	868	931	851	883
	100	828	881	850	853
	150	969	1030	1032	1010
	250	886	1037	1187	1037
	1000	930	887	819	879
	1500	996	1318	1107	1140
raw	0	1074	1100	957	1044
RFC	3.24	290	298	326	294
	6.49	440	464	314	452

	9.73	346	494	458	476
	11.35	356	338	404	347
	12.98	348	345	344	346
	14.6	458	457	457	457
	16.22	1055	997	1060	1037
	48.66	1173	1227	1136	1179
	81.1	1216	1469	[redacted]	1343
	113.54	1610	1400	1349	1453
	145.98	**2690**	**1737**	**2941**	-In valid-
	162.62	**4013**	**3582**	**1240**	-In valid-

APPENDIX F – TOTAL SUSPENDED SOLID (TSS) RESULT

Sample	Dosage (mg/l)	weight (mg/l)
raw	0	665.2
alum	30	268
	60	238.8
	120	164.4
	300	27.6
	900	132.1
	1200	258.4
raw	0	665.2
ferric chloride	50	232.4
	100	244
	150	191.8
	250	160.2
	1000	126.5
	1500	234.4
raw	0	665.2
ferrum sulphate	50	200.2
	100	71.8
	150	64.5
	250	120.2
	1000	107.5
	1500	154.3

Sample	Dosage (mg/l)	weight (mg/l)
raw	0	665.2
RFC	3.24	85.6
	6.49	154.3
	9.73	76.2
	11.35	138.7
	12.98	98
	14.6	100.8
	16	84.6
	49	103.4
	81	135.6
	114	23.7
	146	151
	163	58.6

APPENDIX G – COST ESTIMATION CALCULATION

- Alum

RM 29.50 for 250ml of 30% concentration of alum

- Ferric Chloride

RM 45.00 for 500g of 99% concentration of ferric chloride

- Ferrous Sulphate

RM 55.00 for 500g of $FeSO_4 \cdot 7H_2O$

- Hydrochloric Acid

RM68.00 for 2.5liter of 70% concentration of acid.

- Sulphuric Acid

RM65.00 for 2.5liter of 99% concentration of acid

APPENDIX H – STATISTICAL ANALYSIS

APPENDIX H-1 – PHASE 1 RESULT

APPENDIX H-2 – PHASE 2 RESULT

APPENDIX H-1 – PHASE 1 RESULT

Statistical Analysis for Settleability Rate

samples	Settleability Rate					
	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	0.00	0.00	0.00	0.00	0.00	0.00
1	2.25	2.40	2.25	1.50	2.25	1.87
2	4.25	1.49	4.25	1.28	4.25	2.18
3	4.50	3.13	4.50	0.93	4.50	1.78
4	3.25	3.13	3.25	1.18	3.25	1.78
5	3.05	1.88	3.05	1.86	3.05	2.50
6	2.95	1.27	2.95	0.73	2.95	2.08

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	2.892857	1.898929
Variance	2.227024	1.238009
Observations	7	7
Pooled Variance	1.732516	
Hypothesized Mean Difference	0	
df	12	
t Stat	1.412702	
P(T<=t) one-tail	0.091575	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.183151	
t Critical two-tail	2.178813	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	*y*
Mean	2.892857	1.068
Variance	2.227024	0.355961
Observations	7	7

Pooled Variance	1.291493
Hypothesized Mean Difference	0
df	12
t Stat	3.004118
P(T<=t) one-tail	0.005491
t Critical one-tail	1.782288
P(T<=t) two-tail	0.010982
t Critical two-tail	2.178813

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	y
Mean	2.892857	1.742571
Variance	2.227024	0.656494
Observations	7	7
Pooled Variance	1.441759	
Hypothesized Mean Difference	0	
df	12	
t Stat	1.792229	
P(T<=t) one-tail	0.049162	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.098325	
t Critical two-tail	2.178813	

Statistical Analysis for COD Removal

COD						
samples	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	1044	1044	1044	1044	1044	1044
1	294	1065	294	1065	294	883
2	452	1062	452	1032	452	853
3	476	1029	476	996	476	1010
4	347	1086	347	1085	347	1037
5	346	1057	346	1173	346	879
6	457	1084	457	1215	457	1140

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	487.952381	1060.952
Variance	64820.27513	425.3122
Observations	7	7
Pooled Variance	32622.79365	
Hypothesized Mean Difference	0	
df	12	
t Stat	-5.935100394	
P(T<=t) one-tail	3.43486E-05	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	6.86972E-05	
t Critical two-tail	2.178812827	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	*y*
Mean	487.952381	1087.048
Variance	64820.27513	6250.608
Observations	7	7
Pooled Variance	35535.4418	
Hypothesized Mean Difference	0	
df	12	
t Stat	-5.945645756	
P(T<=t) one-tail	3.37943E-05	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	6.75886E-05	
t Critical two-tail	2.178812827	

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	*y*
Mean	487.952381	978
Variance	64820.27513	11600.89
Observations	7	7
Pooled Variance	38210.58201	

Hypothesized Mean Difference	0
df	12
t Stat	-4.690082469
P(T<=t) one-tail	0.000261566
t Critical one-tail	1.782287548
P(T<=t) two-tail	0.000523132
t Critical two-tail	2.178812827

Statistical Analysis for Measurement of Colour

colour						
samples	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	444	444	444	444	444	444
1	192	3719	192	15343	192	410
2	119	5628	119	4322	119	603
3	161	2513	161	2312	161	1340
4	157	2881	157	12060	157	1407
5	238	171	238	2077	238	6533
6	210	244	210	3886	210	2814

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	217.2857	2228.571
Variance	11497.24	4273479
Observations	7	7
Pooled Variance	2142488	
Hypothesized Mean Difference	0	
df	12	
t Stat	-2.57068	
P(T<=t) one-tail	0.012257	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.024515	
t Critical two-tail	2.178813	

t Critical one-tail	1.782288
P(T<=t) two-tail	0.024515
t Critical two-tail	2.178813

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	y
Mean	217.2857	5777.714
Variance	11497.24	31802410
Observations	7	7
Pooled Variance	15906954	
Hypothesized Mean Difference	0	
df	12	
t Stat	-2.60825	
P(T<=t) one-tail	0.011438	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.022875	
t Critical two-tail	2.178813	

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	y
Mean	217.2857	1935.857
Variance	11497.24	4811663
Observations	7	7
Pooled Variance	2411580	
Hypothesized Mean Difference	0	
df	12	
t Stat	-2.07038	
P(T<=t) one-tail	0.030323	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.060647	
t Critical two-tail	2.178813	

Statistical Analysis for Total Suspended Solid Removal

TSS						
samples	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	665	665	665	665	665	665
1	86	268	86	232	86	200
2	154	239	154	244	154	72
3	76	164	76	192	76	65
4	139	28	139	160	139	120
5	98	132	98	127	98	108
6	101	258	101	234	101	154

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	188.4	250.6429
Variance	44995.62333	40599.61
Observations	7	7
Pooled Variance	42797.6181	
Hypothesized Mean Difference	0	
df	12	
t Stat	-0.56287731	
P(T<=t) one-tail	0.291940978	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	0.583881956	
t Critical two-tail	2.178812827	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	*y*
Mean	188.4	264.9286
Variance	44995.62333	33020.61
Observations	7	7
Pooled Variance	39008.11619	
Hypothesized Mean Difference	0	
df	12	

t Stat	-0.724903405
P(T<=t) one-tail	0.241203859
t Critical one-tail	1.782287548
P(T<=t) two-tail	0.482407718
t Critical two-tail	2.178812827

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	*y*
Mean	188.4	197.6714
Variance	44995.62333	44696.9
Observations	7	7
Pooled Variance	44846.26119	
Hypothesized Mean Difference	0	
df	12	
t Stat	-0.081906347	
P(T<=t) one-tail	0.468035752	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	0.936071503	
t Critical two-tail	2.178812827	

APPENDIX H-2 – PHASE 2 RESULT

Statistical Analysis for Total COD Removal

samples	total COD					
	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	4004	4004	4004	4004	4004	4004
1	3476	5521	3476	3602	3476	6363
2	3436	4949	3436	2273	3436	6195
3	2831	3804	2831	2222	2831	6161
4	2578	2576	2578	909	2578	5303
5	2449	2626	2449	1422	2449	5690
6	2094		2094		2094	6026
7	1919		1919		1919	
8	1616		1616		1616	
9	4293		4293		4293	

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	2869.45	3913.361
Variance	815583.4	1425079
Observations	10	6
Pooled Variance	1033260	
Hypothesized Mean Difference	0	
df	14	
t Stat	-1.98872	
P(T<=t) one-tail	0.033321	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.066643	
t Critical two-tail	2.144787	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	y
Mean	2869.45	2405.361
Variance	815583.4	1449020
Observations	10	6
Pooled Variance	1041811	
Hypothesized Mean Difference	0	
df	14	
t Stat	0.880486	
P(T<=t) one-tail	0.19673	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.39346	
t Critical two-tail	2.144787	

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	y
Mean	2869.45	5677.31
Variance	815583.4	672367.3
Observations	10	7
Pooled Variance	758297	
Hypothesized Mean Difference	0	
df	15	
t Stat	-6.54305	
P(T<=t) one-tail	4.65E-06	
t Critical one-tail	1.75305	
P(T<=t) two-tail	9.31E-06	
t Critical two-tail	2.13145	

Statistical Analysis for sCOD

samples	sCOD					
	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	3232	3232	3232	3232	3232	3232
1	3278	5353	3278	3468	3278	5892
2	3392	4747	3392	2222	3392	5858
3	2754	3737	2754	2155	2754	5723
4	2145	2323	2145	909	2145	5353
5	2343	2357	2343	1145	2343	5117
6	2024		2024		2024	5959
7	1813		1813		1813	
8	1520		1520		1520	
9	3991		3991		3991	

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	2649.1333	3624.778
Variance	645484.99	1543147
Observations	10	6
Pooled Variance	966078.51	
Hypothesized Mean Difference	0	
df	14	
t Stat	-1.9222107	
P(T<=t) one-tail	0.0375841	
t Critical one-tail	1.7613101	
P(T<=t) two-tail	0.0751683	
t Critical two-tail	2.1447867	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	*y*
Mean	2649.1333	2188.333
Variance	645484.99	1090827
Observations	10	6

Pooled Variance	804535.69
Hypothesized Mean Difference	0
df	14
t Stat	0.9948451
P(T<=t) one-tail	0.1683482
t Critical one-tail	1.7613101
P(T<=t) two-tail	0.3366963
t Critical two-tail	2.1447867

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	*y*
Mean	2649.1333	5304.905
Variance	645484.99	931259.5
Observations	10	7
Pooled Variance	759794.81	
Hypothesized Mean Difference	0	
df	15	
t Stat	-6.1825422	
P(T<=t) one-tail	8.767E-06	
t Critical one-tail	1.7530503	
P(T<=t) two-tail	1.753E-05	
t Critical two-tail	2.1314495	

Statistical Analysis for Measurement of Colour

colour						
samples	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	3771	3771	3771	3771	3771	3771
1	6834	4612	6834	2929	6834	7222
2	6632	2357	6632	2458	6632	28718
3	5959	1111	5959	9191	5959	98745
4	2794	370	2794	17810	2794	25890
5	2660	976	2660	13534	2660	9831
6	1549		1549		1549	24307
7	1751		1751		1751	

8	1364		1364		1364	
9	5252		5252		5252	

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	*y*
Mean	3856.55	2199.611
Variance	4609362.7	2868580
Observations	10	6
Pooled Variance	3987654.5	
Hypothesized Mean Difference	0	
df	14	
t Stat	1.6068057	
P(T<=t) one-tail	0.0652047	
t Critical one-tail	1.7613101	
P(T<=t) two-tail	0.1304093	
t Critical two-tail	2.1447867	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	*y*
Mean	3856.55	8282.056
Variance	4609362.7	40422561
Observations	10	6
Pooled Variance	17399791	
Hypothesized Mean Difference	0	
df	14	
	-	
t Stat	2.0545017	
P(T<=t) one-tail	0.0295443	
t Critical one-tail	1.7613101	
P(T<=t) two-tail	0.0590886	
t Critical two-tail	2.1447867	

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	*y*
Mean	3856.55	28354.74
Variance	4609362.7	1.06E+09
Observations	10	7
Pooled Variance	427535006	
Hypothesized Mean Difference	0	
df	15	
t Stat	- 2.4042116	
P(T<=t) one-tail	0.0147902	
t Critical one-tail	1.7530503	
P(T<=t) two-tail	0.0295804	
t Critical two-tail	2.1314495	

Statistical Analysis for TSS Removal

TSS						
samples	RFC	Alum	RFC	FeCl	RFC	$FeSO_4$
	x	y	x	y	x	y
raw	1987	1987	1987	1987	1987	1987
1	3991	3815	3991	4013	3991	4332
2	4384	3811	4384	4472	4384	6486
3	2833	3662	2833	3552	2833	5595
4	3661	4192	3661	10824	3661	5898
5	3781	4285	3781	3961	3781	7468
6	5460		5460		5460	12226
7	2747		2747		2747	
8	1346		1346		1346	
9	4294		4294		4294	

t-Test: Two-Sample Assuming Equal Variances for RFC and Alum

	x	y
Mean	3448.37	3625.45
Variance	1501594	702774.1
Observations	10	6
Pooled Variance	1216301	
Hypothesized Mean Difference	0	
df	14	
t Stat	-0.31093	
P(T<=t) one-tail	0.380217	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.760434	
t Critical two-tail	2.144787	

t-Test: Two-Sample Assuming Equal Variances for RFC and FeCl

	x	y
Mean	3354.411	4801.45
Variance	1589976	9438327
Observations	9	6
Pooled Variance	4608572	
Hypothesized Mean Difference	0	
df	13	
t Stat	-1.27893	
P(T<=t) one-tail	0.11164	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.223279	
t Critical two-tail	2.160369	

t-Test: Two-Sample Assuming Equal Variances for RFC and $FeSO_4$

	x	*y*
Mean	3448.37	6284.619
Variance	1501594	9942035
Observations	10	7
Pooled Variance	4877771	
Hypothesized Mean Difference	0	
df	15	
t Stat	-2.6059	
P(T<=t) one-tail	0.009932	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.019864	
t Critical two-tail	2.13145	

APPENDIX I – RAW DATA FOR LEACHATE TREATMENT

G-1 Jar Test Result for Pulau Burung Landfill Leachate

[redacted] 300000

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Soluble COD (mg/L)				Total COD (mg/L)				TSS (mg/L)				Colour (PtCo) - 465nm			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1.00	30	0.10	6.00	6.52	5050	5353	5252	5218	5151	5252	5555	5319	3838	4218	[redacted]	4028	3939	4848	4242	4343
2.00	300	1.00	6.00	6.45	5252	5656	5151	5353	6262	4949	5353	5521	3524	3862	4060	3815	5151	4545	4141	4612
3.00	1500	5.00	6.00	6.24	4747	4949	4545	4747	4646	5151	5050	4949	3864	3362	4208	3811	2929	2626	1515	2357
4.00	3000	10.00	6.00	5.98	3434	3838	3939	3737	3535	4141	3737	3804	3614	4002	3370	3662	1212	1212	909	1111
5.00	4500	15.00	6.00	5.81	2525	2121	2323	2323	2323	2828	[redacted]	2576	4232	4152	[redacted]	4192	202	404	505	370
6.00	12000	40.00	6.00	4.30	2727	2020	2323	2357	2424	2424	3030	2626	4124	4282	4450	4285	909	909	1111	976

[redacted] 20000 (Raw Leachate-without adjusting pH)

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Soluble COD (mg/L)				Total COD (mg/L)				TSS (mg/L) - final weight				Colour (PtCo) - 465nm			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1.00	10	0.50	8.50	8.36	3630	3465	3377	3491	3454	3652	3520	3542	4424	4064	4802	4430	7373	6565	7070	7003
2.00	100	5.00	8.50	8.21	3300	3179	3245	3241	3399	3410	3388	3399	4772	4742	5106	4873	7171	7777	7474	7474
3.00	500	25.00	8.50	7.55	3025	3080	3245	3117	3146	3355	3190	3230	3690	4868	4692	4780	5151	5454	5252	5286
4.00	1000	50.00	8.50	7.02	2860	2882	2904	2882	2926	3025	2970	2974	4376	4038	4288	4163	3131	3030	2929	3030
5.00	2000	100.00	8.50	6.48	2805	2739	2761	2768	2794	2992	2860	2882	5114	4886	5864	5375	2626	2626	2424	2559
6.00	6000	300.00	8.50	4.61	6600	6622	6765	6662	6666	7128	6930	6908	2698	3072	5214	4143	505	101	303	303
6.00	9000	450.00	8.50	2.57	3410	3278	3234	3307	3232	3333	3535	3367	4414	5112	3112	4112	2414	2464	2444	2441

Ferrous Sulphate 3% 30000

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Soluble COD (mg/L)				Total COD (mg/L)				TSS (mg/L)				Colour (PtCo)			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	60	1.00	5.93	6.00	6060	5858	5757	5892	6969	6161	5959	6363	**2954**	4872	5170	4332	6868	7676	6767	7222
2	300	5.00	5.92	6.00	5757	5959	5858	5858	6060	6161	6363	6195	**8016**	4956	4092	6486	28381	28583	29189	28718
3	600	10.00	6.08	6.15	5757	5757	5656	5723	6363	5353	6767	6161	4264	6926	**9824**	5595	23735	23028	249473	98745
4	1200	20.00	6.17	6.20	5353	5252	5454	5353	5555	5050	**6868**	5824	5368	6428	5982	5898	25856	25755	26058	25890
5	3000	50.00	6.10	6.40	5252	5151	4949	5117	5353	5656	6060	5690	7270	7666	**4884**	7468	10201	9696	9595	9831
6	6000	100.00	6.10	6.61	6060	5959	5858	5959	5757	6161	6161	5959	11236	12543	12900	12226	29694	30502	12726	24307

[redacted] 300000

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Soluble COD (mg/L)				Total COD (mg/L)				TSS (mg/L)				Colour (PtCo) - 465nm			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1.00	30	0.05	6.00	7.07	4343	5252	4040	4545	5151	4646	[redacted]	4899	3466	3906	4406	3926	5050	5555	4949	5185
2.00	600	1.00	6.00	6.74	3333	3535	3535	3468	3434	3636	3737	3602	3802	4198	4040	4013	[redacted]	2929	2929	2929
3.00	1800	3.00	6.00	6.05	2020	2121	2525	2222	2222	2323	[redacted]	2273	4472	4472	[redacted]	4472	1919	2424	3030	2458
4.00	3000	5.00	6.00	2.94	2020	2323	2121	2155	1919	2525	[redacted]	2222	3838	3372	3446	3552	8484	9696	9393	9191
5.00	6000	10.00	6.00	2.42	1212	707	808	909	1010	808	909	909	8754	12894	[redacted]	10824	17372	18483	17574	17810
6.00	12000	20.00	6.00	2.33	1313	1111	1010	1145	2008	1004	1255	1422	3934	3826	4122	3961	10807	14645	15150	13534

[redacted] 20000

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Soluble COD (mg/L)				Total COD (mg/L)				TSS (mg/L)				Colour (PtCo)			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	100	5.00	5.99	6.05	3245	3267	3322	3278	3520	3487	3421	3476	4560	3480	3932	3991	6666	6969	6868	6834
2	200	10.00	6.33	6.38	3476	3465	3234	3392	3421	3432	3454	3436	4672	4096	**3192**	4384	6565	6969	6363	6632
3	400	20.00	6.35	6.13	2816	2695	2750	2754	2772	2860	2860	2831	2748	2918	**5648**	2833	5858	6060	5959	5959
4	600	30.00	6.12	5.41	2145	2123	2167	2145	2640	2530	2563	2578	3684	3638	**5486**	3661	2828	2727	2828	2794
5	800	40.00	6.38	5.88	2266	2376	2387	2343	2354	2464	2530	2449	3990	3832	3522	3781	2727	2626	2626	2660
6	1200	60.00	6.37	5.24	2068	2079	1925	2024	1958	2123	2200	2094	5252	5668	**3434**	5460	1818	1818	1010	1549