Use of Tannin from Mangrove (*Rhizophora Apiculata*) for Improving Thickening and Settleability of Sludge

by

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Dissertation submitted in partial fulfillment of
the requirements for
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CERTIFICATION OF APPROVAL

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Approved by,

____

(Assoc. Prof. Dr. Shamsul Rahman b. Mohamed Kutty)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2006

CERTIFICATION OF ORIGINALITY

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

MOHAMAD AZMI BIN YAAKOB

ABSTRACT

Tannin has been useful to humankind ever since it was found for its special ability in tanning hides as well as its medication benefits. However, the use of tannin from mangrove (*Rhizophora Apiculata*) in wastewater treatment still absent since mangrove only perceived as source for charcoal manufacturing. This research utilized the mangrove waste from charcoal factories to extract tannin and later being used for feasibility study on improving sludge settleability. Several natural waste products such as limestones powder, mangrove bark tannin and modified mangrove bark tannin were used in settling and thickening of sludge. This was compared with commercial coagulant such as alum. Dosages of the natural products were varied by jar test procedure and settleability of sludge of sludge was measured. The supernatant of the settling test will be tested on chemical oxygen demand (COD), pH, turbidity and total suspended solids (TSS). It was found that the results from the preliminary shown raw mangrove bark powder can act as coagulant and as competitive with a commercial coagulant. The best settling rate of alum as coagulant is 0.692 cm/min at dosage of 4500 mg/ L but raw mangrove powder has proved to get the best settling rate at 2.98 cm/min at dosage of 4000 mg/L. As for limestones, the best settling rate is only 0.259 cm/min. In the second phase of the research, for alum, the settling rate for zero dosage was the best at 0.436 cm/min. For tannin extract in the first trial, the best dosage in the test was 2400 mg/L of tannin with 4.833 cm/min. In the second trial of settling test using tannin extract, dosage of 2400 mg/L has the highest settling rate with 3.48 cm/ min and dosage of 180 mg/L has the lowest settling rate of 0.0833 cm/min. For modified tannin extract in first trial, the best dosage was 3600 mg/L with settling rate of 4.32 cm/min while in second trial the best settling rate was achieved at dosage of 2400 mg/L with settling rate of 1.75 cm/min. In COD removal, alum (1500 mg/L) has shown the best percentage removal by 98.3 percent followed by modified tannin at dosage 7200 mg/L with 84.5 percent removal. For tannin, it has achieved 76.7 percent of COD removal at settling rate of 1.29 cm/min. In conclusion, the results obtained were encouraging but further research will pave ways to explore this alternative coagulant, which should perform better and healthier than commercial coagulant without compromising the economic values.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Sludge dewatering has become much advantageous these days as to cut down the operational cost for sludge disposal. The removal of liquid content of sludge which is water has reduced the weight down to half of original weight. Prior to sludge dewatering, the sludge must be conditioned to improve its settleability. In common practice, the sludge will be conditioned with inorganic chemical to coagulate and flocculate the solid particles into flocs. For coagulation process, alum salts or ferric salts are the common chemicals being used for that purpose [1].

However, with the rise of health concerns over the use of alum in water and wastewater treatment systems, it has led to the discovery of natural chemicals as coagulants. Some has introduced the use of recycled waste from iron sludge and other natural-based chemicals as better alternatives for commercial coagulants [2-4].

As for tannin, there are several researches have been done on its feasibility for use in water and wastewater treatment process. Research on effectiveness of tannins obtained from Valonia as a coagulant aid for dewatering sludge has the closest profile to this research but differs in source of the tannin [5]. With this variation, the results may not be the same as produced by the abovementioned research.

1.2 PROBLEM STATEMENT

Sludge or fondly called as 'biosolids' is the end product of wastewater treatment plant regardless of its waste sources, domestic, industrial or chemical waste. This biosolids contains more than 80 percent of water which can cause a fortune if the sludge is going to be disposed straight away from the treatment plant. Therefore, a lot of dewatering techniques have emerged as results to this problem. To add more problems to this situation, the dewatering procedures also add more costs to handle the sludge treatment whereas the physical or mechanical treatment is insufficient. Then, a more comprehensive technique by employing chemicals as conditioner has been introduced to improve further the dewatering of sludge.

In Kuala Sepetang, the Larut-Matang charcoal factory produces 800 metric tons per annum of waste from the aforementioned industry. The generated waste is believed to contain a substantial amount of tannins which has good coagulation characteristics due to the polyphenol functional groups. This abundant source of non-toxic natural coagulants shall be exploited as to replace the use of inorganic chemicals that have shown some adverse effects towards environment especially in human's health i.e, Alzheimer's disease [6-8].

1.3 OBJECTIVES AND SCOPE OF STUDY

The primary objective of the study is to investigate the feasibility of using local waste products in facilitating the sludge settling process. The local waste products used in this study were limestones powder, mangrove bark powder, mangrove bark tannin and modified mangrove bark tannin.

Jar tests were conducted on municipal sludge using the natural waste products as coagulants. Parameters such as settling rate, pH, chemical oxygen demand (COD), total suspended solids (TSS), and turbidity were monitored throughout the tests. The conditioned sludge was tested for its filterability through using the capillary suction time (CST).

CHAPTER 2

LITERATURE REVIEW

2.1 SLUDGE CONDITIONING AND DEWATERING PROCESS

Sludge must be conditioned to improve its dewatering ability and characteristics. Conditioning can be accomplished either by chemical methods, where organic or inorganic coagulant or flocculants are used, or physical methods by using heat and freezing to change the characteristics of the sludge [9].

The main purpose of sludge conditioning process is to enhance the effectiveness of a solid-liquid separation process may it be thickening or dewatering of sludge. The sludge conditioning has been viewed as being similar to the coagulation and flocculation process that is employed in water treatment. The sludge is perceived as a concentrated suspension of colloidal materials which are held apart by the mutual repulsion of their like-charged. From this point of view, the concept of charge stabilization is introduced as the chemical conditioning for sludge [1].

As for alum, it has been used less commonly. The use of inorganic chemicals has been less satisfactory in some mechanical dewatering applications. Lime is undesirable when used prior to centrifuges due to its abrasive properties. Moreover, much higher doses of these inorganics are required than equivalent dewatering process based on polymer conditioning. The use of ferric chloride and lime can add more 20 to 40 percent to the original dry weight of the sludge. In contrast, the typical polymer dose adds only 1 percent [1].

However, those synthetic polymers have a major drawback as they show an acute toxicity to aquatic life if being discharged directly into surface water [1]. Although this situation is under control, the need for safe and high performance natural based coagulant like tannin is likely to be viable.

2.2 DEWATERING PARAMETERS AND SLUDGE FILTERABILITY

Wastewater is usually characterized by chemical, colloidal or biological parameters and not as much by physical parameters, but as for sludge; it is traditionally characterized by a number of methods to find the physical properties which are important in management of sludge [10].

The main two parameters in dewatering are the Initial Settling Rate (ISR) and Sludge Volume Index (SVI). These characteristics are assessed using batch tests in graduated cylinder with gravity acts as dewatering driving force. ISR characterize the settleability of the sludge by determining the slope of straight line portion of a sludge interface height vs. settling time. On the other hand, the SVI characterize the compactibility of the sludge by giving a ratio between the sludge volume after 30 minutes of settling and the sludge solids concentration.

Sludge filterability can be defined through two main parameters; Capillary Suction Time (CST) and Specific Resistance to Filtration (SRF). Both of parameters are characterizing the implication due to sludge filtering. The most popular technique is to use CST as the main parameter to determine the dewatering rate. CST is determined by the time for a wetting front in a filter paper to travel between fixed points. The driving force is the capillary suction of approximately 50 cm H_2O [10]. Although the CST is preferred for its speed and easy handling, the limitation caused by the fact that the sludge solids concentration not explicitly is taken into account and because there is a minimum apparatus resistance giving the minimum CST obtainable, which is virtually independent of sludge. The CST provides empirical measure of the resistance offered by the sludge to the withdrawal of water and a good indicator of dewatering rate. As the higher CST value, the slower of the dewatering rate and vice versa [11].

2.3 TANNIN CHEMISTRY

Etymologically, tannin is an ancient Celtic word for oak, a typical source of tannins for leather making. The ability for tannins to convert animal hides into leather is not surprising as it combines with the protein of animal skin to produce tough and durable leather. Tannins is secondary compounds found in plants where its role as support systems for the plants by providing toxicity to hormonal mimicry and protecting the plants from herbivores and disease [12].

As for mangrove, trees of the family *Rhizophoraceae*, especially those of the genera Rhizophora, Bruguiera, Avicennia and Ceriops, have rich content of tannins in the barks. The tannin content of mangrove barks varies widely, however, from less than 10 percent to more than 40 percent depending upon a number of factors, including the species, as well as the age, exposure to sun and air, location on the tree where the bark is removed, etc. Tannins are also found in the leaves, fruits, barks, roots and wood of trees [13].

Basically, tannins occur in two groups, the proanthocyanidins (or condensed tannins) and the gallic acid with its derivatives or hydrolysable tannins, which are often, esterified to polyols such glucose. The building blocks for condensed tannin are three-ring flavanols (refer Figure 1 on the terminology of extender units and terminal units). At least a dozen variations of these stereochemically active compounds are known to occur in condensed tannin. The most common linkages in condensed tannin are 4→8, whereas 4→6 linkages lead to branching (Figure 1). Condensed tannin with these linkages is often referred to proanthocyanidin (PA) due to formation of cyanidins or related compounds on acid depolymerisation [14]. The structural contrast between condensed and hydrolysable tannin has led different in functionality of the two polyphenols [15].

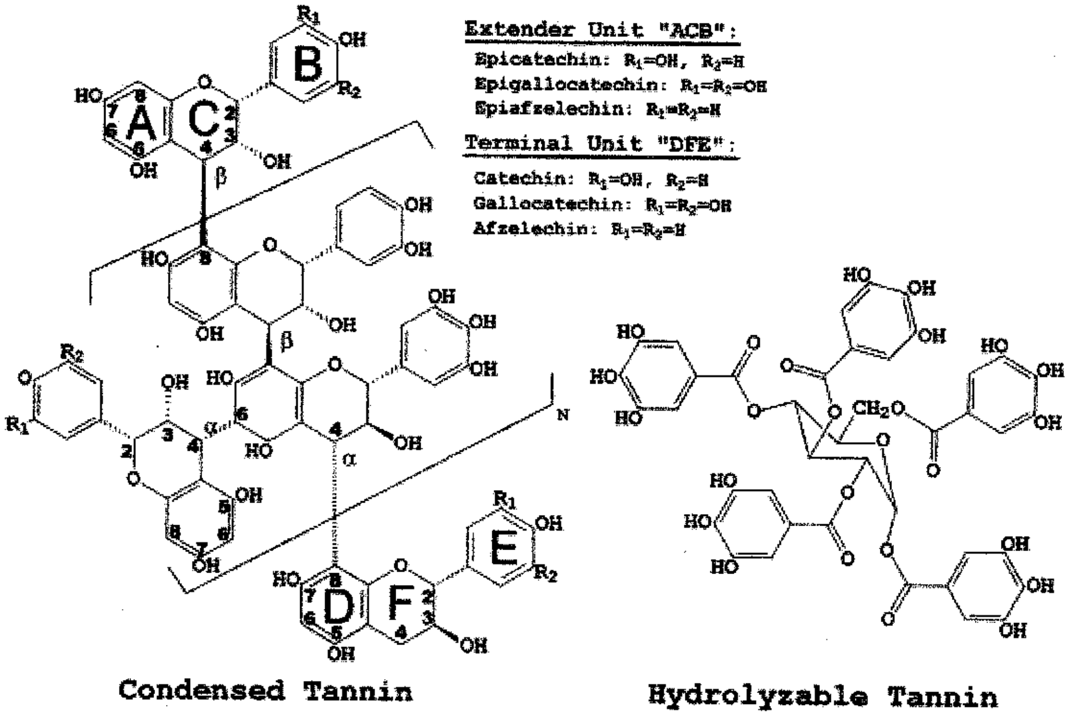

Figure 1: Structures of typical condensed and hydrolysable tannin

Complex polysaccharide tannin derivatives have been used extensively in potable water, wastewater and industrial effluent treatment applications [16]. The reaction of tannin with formaldehyde and aminoethanol produces a basic polymer that is more effective in removing turbidity and colour from river water [17]. The various studies conducted on water treatment using tannins as coagulant have revealed that effectiveness of tannins depends mainly on the chemical structure of tannins that have been extracted from that plant and its degree of modification [18-20].

However, studies on mangrove as coagulant in sludge settling process is a novelty research as none has pronounced the results of such studies. Therefore, with positive results in water treatment on use of tannins, will give better hope in improving wastewater treatment particularly in sludge settleability.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

For this research project, a set of works are prepared according two main phases namely, tannin extraction from mangrove barks and application of tannin in sludge settleability tests. In the first phase, this project was emphasized on tannin extraction process of the mangrove waste. An extraction process was carried out on basis of existing in-campus facilities and with help from other institutions whom may have certain laboratory equipments which are unavailable in-campus. The mangrove waste was taken from a charcoal factory in Kuala Sepetang in form of dried tree barks which is believed to contain tannins. The dried mangrove bark was later to be prepared for the extraction by some physical treatments and grinding process. The grinding turned the dried barks into mangrove powder and ready to be used for extraction process. In extraction process, several physical and chemical processes were carried out to extract the tannin from raw mangrove powder. Later, chemical assays were performed to the extracted tannin to quantify the amount of tannins found in the extracts.

For the second phase, the tannins extracts from the previous phase were utilized to examine the effectiveness in sludge settling process. Jar tests were conducted as to investigate the performance of tannins extract as compared to commercial coagulant e.g. aluminium sulphate (alum). Several parameters such as pH, chemical oxygen demand (COD), total suspended solids (TSS), and turbidity were tested on the supernatant after the jar test and settling test completed. The settling rate was also being analyzed based on the settling test after application of tannin through jar test. Afterwards, the research conclusion was prepared as according to the results and the discussion.

3.2 SLUDGE SAMPLE COLLECTION

Sludge sample collection is the field work activity for this research study. In this activity, the sludge was collected from clarifier of UTP's sewage treatment plant. Extreme precaution also was taken during this activity as the sludge was high in bacterial content. This bacterial content is a biohazard if splashed on human body either directly on skin or with clothes. Therefore, a proper planning of work was prepared before sludge sample collection was done. The planning consists of safety procedures, safety gears, proper container and proper transportation vehicle.

The sludge was collected using a grab sampler that can contain approximately two (2) liters of sludge. Upon arriving to the clarifier, the rope that tied to the grab sampler was tied to the railing of the clarifier as part of safety procedure. After that, the two lids of the grab sampler bottom were setup and the sampler was lowered down until it rested on the bottom of the clarifier. The trip mechanism was deployed by sending the messenger knob to close the sampler lids and the sludge was grabbed simultaneously. Then, the sampler was hauled back to the top of clarifier and filled inside the bucket. This activity concluded when enough amount of sludge was collected.

To provide protection while transporting the sample, a plastic cover was wrapped around the bucket or pail. This practice also improved handling process to load it onto the vehicle and to unload upon reaching the laboratory. It is also advised to undertake this activity with company to avoid any mishaps at the location.

3.3 TANNIN EXTRACTION

3.3.1 Sample Collection

The mangrove waste which is the mangrove barks were collected from Larut Matang charcoal factory in Kuala Sepetang. From that factory, about 20 kg of mangrove bark were collected in form dried barks and later being transported in gunny sacks to the laboratory for extraction process.

3.3.2 Sample Drying

The mangrove barks (Figure2) were dried in the oven with temperature in a range of 40°C – 60°C until constant weight ± 2g. In this range of temperature, oxidation of polyphenols could be avoided and overheating damage and polymerization would not occur [21].

Figure 2: Dried mangrove bark

3.3.3 Sample Grinding

FRITSCH cutting mill combination pulverisette (Figure 3) was used for grinding and collecting sample that passéd through 0.5 mm sieve for the extraction purposes. The powder-like sample was kept in the dessicator to avoid moisture infusion.

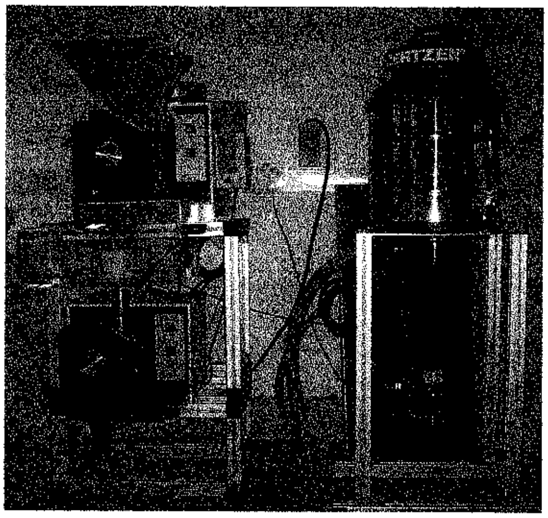

Figure 3: Cutting mill combination pulverisette (FRITSCH)

3.3.4 Extraction Process

The extraction process was commenced with immersion of mangrove barks powder in three cycle of filtration. A 250 mg of ground mangrove bark was immersed in solvent of 1000 ml (70% acetone and 30% water) in 2 liter beaker. The immersed barks were left stirred for 24 hours before first filtration. After first filtration, the same mangrove barks powder was reused for second immersion and left stirred for 24 hours and filtered for second time. This process was repeated for the third time and all filtered solution from the same sample was kept in the same container to represent a batch of extraction.

After the third cycle of filtration was done, the filtered solution was sent for acetone removal process. The acetone of the solution was removed using rotary vaporizer (BUCHI) (Figure 4) through distillation process.

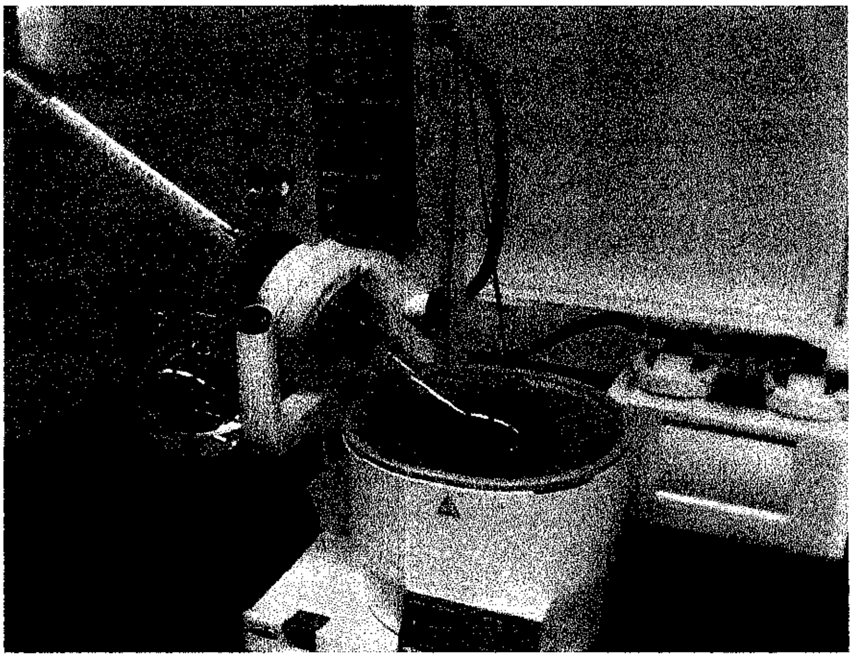

Figure 4: Rotary vaporizer machine (BUCHI)

A 200 ml of tannin extract that contains acetone was filled in the feeding flask of 300 ml and immersed in water bath. Water bath temperature was set to 56°C or 57°C according to the boiling point for acetone. As for the pressure in the distillation column, it was set to 354 mm bar. The condensation unit was turned on with setting of 10°C as the working temperature. The receiving flask was clamped at the end of distillation unit and the machine was turned on. After 5 minutes, all operating conditions were achieved, acetone was vaporized and distillated into the receiving flask. Finally, after the feed solution become viscous, the machine was turned off and another 200 ml of tannin extract was filled in the feed flask. The recovered acetone from the receiving flask also was transferred to a container for keep.

The tannin extract recovered after acetone removal was kept in their respective batch bottle and some amount was dried up to get tannin in powder form. To achieve this, the liquid tannin was poured into plastic dishes and left dried up in oven for 24 hours under temperature in range of 40°C to 60°C.

3.4 TANNIN CHARACTERISATIONS

3.4.1 Tannin and Lignin Test (Tyrosine Method [22])

A special kit from HACH for Tannin Lignin test was used with the DR 5000 spectrophotometer (HACH) (Figure 5)

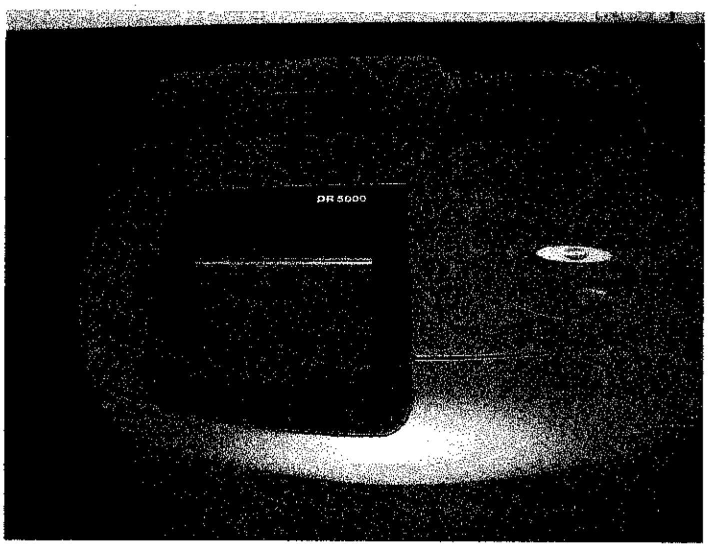

Figure 5: DR 5000 spectrophotometer (HACH)

Prior to the test, the samples of liquid tannin extract were prepared accordingly in dilution since this test only detects tannin concentration of 9.00 mg/L and below. The liquid tannin extract was diluted to 1:10000 and for the dried tannin sample, 1 mg of sample was diluted into 1000 ml of water to give concentration of 1 mg/L.

The spectrophotometer was switched on and program 720 for Tannin and Lignin was selected. A blank sample was prepared for every different type of samples. In every sample cell, 25 ml of prepared sample was filled and pipetted with 0.5 ml of TanniVer3 reagent. Then, 5.0 ml of Sodium Carbonate was added to every cell and swirled to mix well, and later, blue colour was developed to indicate any tannin or lignin compound in the sample. Timer of 25 minutes on the spectrophotometer was pressed for the reaction time before reading was done. After 25 minutes, the blank sample cell was placed in the cell holder first and followed by the prepared sample to read the value of tannin. The reading for every cell was recorded and analyzed to determine the content of tannin extract and tannin powder in terms of tannic acid.

3.5 SLUDGE SETTLEABILITY AND FILTERABILITY

In sludge settling process, there were three (3) tests conducted to investigate on the sludge characteristic before and after application of the coagulants namely, jar tests, settling tests, and the post-settling tests. The jar tests have a purpose to demonstrate the application of the coagulant of different types and dosages. In the meanwhile, the post-settling tests are governed by several parameters i.e. chemical oxygen demand (COD), pH, total suspended solids (TSS) and turbidity. Those parameters were tested on the supernatant from the settling test.

3.5.1 Jar Test Studies

The coagulation experiments were using six jars multiple stirrers machine (Figure 6). The dosages of the coagulant used such alum, mangrove bark powder and tannin extract were determined before the test started and the coagulants were prepared according to the dosage requirements. In every jar, 1000 ml of well mixed sludge was filled accordingly. The test was set to have two type of mixing. The first mixing, rapid mixing was conducted at 120 rpm in 1 minutes and the second mixing, slow mixing was conducted at 45 rpm for 15 minutes. Then, the coagulated sludge was used in settling test.

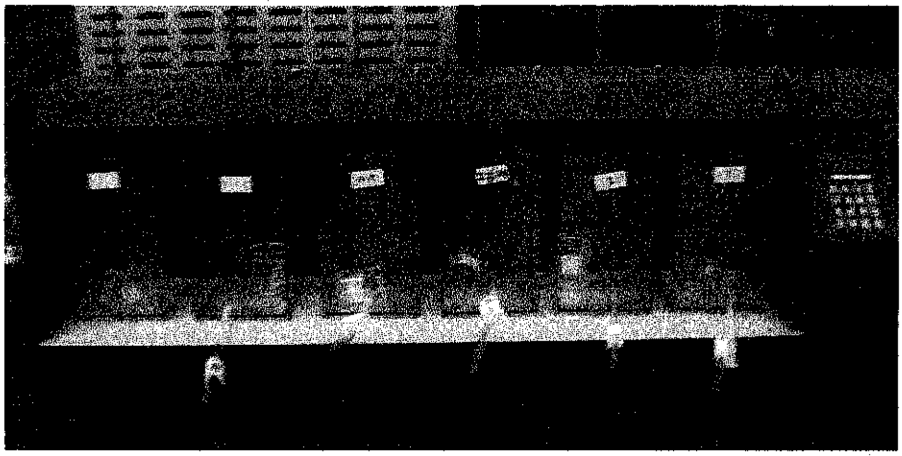

Figure 6: Jar test machine

3.5.2 Settling Test

The coagulated sludge from the jar test was poured into a 100- ml cylinder to conduct the settling test. The test was set to run for 1 hour and for every 2 minutes, the height of sludge settled was recorded. To ease the data recording, the graduations of the cylinder were used as reference for settling height. Afterwards, the height of the cylinder's graduations was measured to enable conversion from volume to height. The height of sludge settling was plotted against time for every cylinder to produce settleability curve.

3.5.3 Chemical oxygen demand (COD) Determination

Supernatant from cylinders in settling test were collected in a 100 ml beaker. The heating blocks (Figure 7) were turned on and setup for COD test with 150°C. The test vials for COD high range (HACH) were filled with 2 ml of supernatant and blanks using pipette and shaken well. After the heating block was ready, the sample and blank vials were placed in the block heater and left for 2 hours incubation. After the 2 hours duration was over, the vials were left cooled to ambient temperature, and the COD values were read on DR 5000 spectrophotometer (HACH).

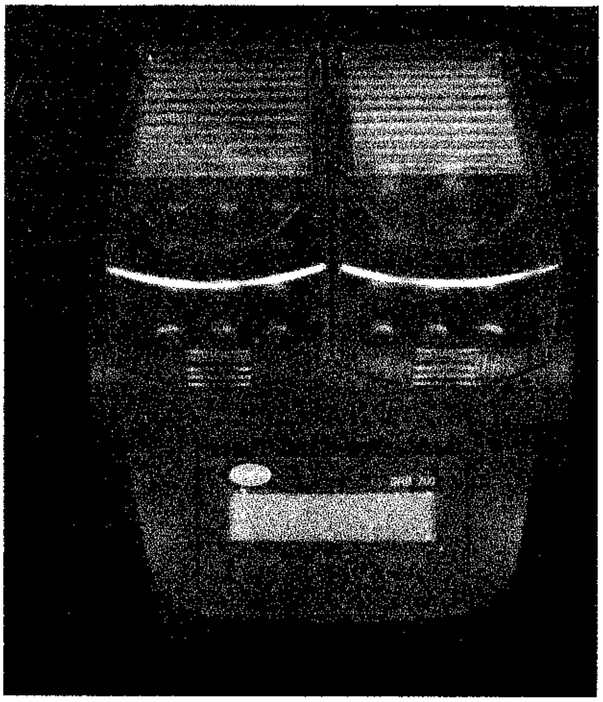

Figure 7: Heating block (HACH)

3.5.4 Total Suspended Solid (TSS) Determination

The remaining supernatant from settling test was used for the total suspended solid test. Whatman filter papers were demoisturised by oven drying before usage. After oven-dried, the initial weight of the filter paper with aluminium dish was recorded. A vacuum filtering machine (Figure 8) was used as means to separate solid and liquid of the sample. The filter paper was clamped between orifice and the vacuum flask. For every sample, 200 ml of supernatant was filled in the orifice and the vacuum machine was turned on. The trace of supernatant was cleaned by rinsing with distilled water. After that, the filter paper was removed carefully using scalpel and put into its respective aluminium dish, and oven-dried for an hour at 103° to 105°C. The oven-dried filter paper was weighed again and recorded as the final weight. The total suspended solids (TSS) values were calculated by subtracting the final weight of the filter paper with the initial weight.

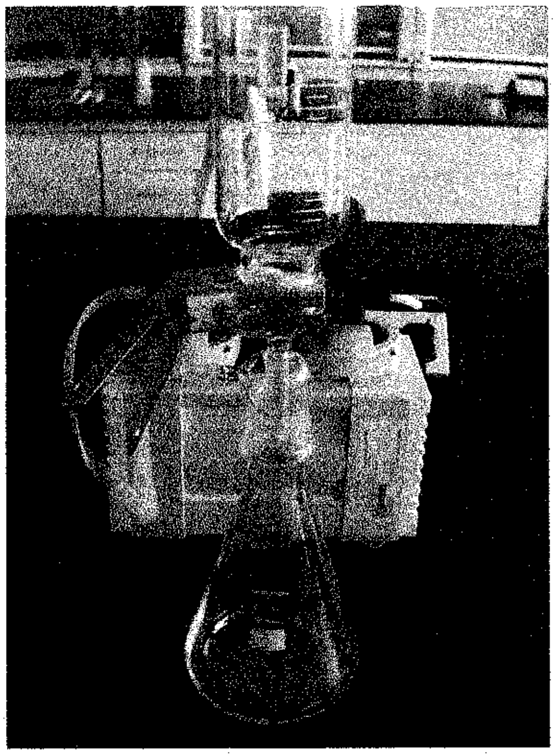

Figure 8: Vacuum filter machine

3.5.5 Turbidity and pH determination

For turbidity test, supernatant of the sludge settling process was filled into the turbidity test vials and the turbidity value was obtained using the turbidimeter. The unit used for turbidity is called NTU or nephelometric turbidity unit or its other name, FTU (formazin turbidity unit). For pH, the pH meter (Mettler-Toledo) was used by immersing the probe into the supernatant and the values were recorded straight away.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 TANNIN EXTRACTION YIELD

In the acetone removal, the rate of removal was calculated for every batch. As five batches have completed the production phase, the average rate of acetone removal was 19.2 ml/min. As for percentage of acetone removal, the first batch has 45 percent acetone removed from total amount of filtered bark solution. The second, third, fourth and fifth has percentage of acetone removal of 42.1 percent, 43.2 percent, 44.8 percent and 37.7 percent respectively. With consumption of 11.25 liter of acetone in the immersion during extraction process, 4.7 liter acetone recovered which was 41.6 percent.

In terms of tannin extraction yield (refer Table 1), the average percentage of tannin extract obtained was 58.26 percent or 6.35 liter. The fifth batch was having less acetone removal thus giving a slightly higher percentage of yields while others were almost the same to the average percentage. However, the tannin extract still has water content which needs to be removed in order to find the total dry weight of tannin extracted. The average percentage of yields is 58.26 percent.

Batch	Total Solution (ml)	Tannin extract obtained (ml)	Acetone recovered (ml)	Percentage of yields (%)
1	2000	1100	900	55
2	2150	1270	880	59.1
3	2350	1355	995	57.7
4	2160	1230	930	56.9
5	2200	1390	810	63.2
Total	**10860**	**6345**	**4515**	**58.26 (average)**

Table 1: Tannin extraction yield

4.2 TANNIN CHARACTERISATION

4.2.1 Tannin Content

A test on tannin characterization was carried out to determine the concentration of the tannin in the extracted solution. Based on result in Table 2, the actual concentration of the tannin extract was determined as 20g/L or 20000 mg/L. As for dried tannin, the amount of tannin is only half or 0.5 mg/L as equivalent to commercial tannin or commercial tannic acid. The results on commercial tannin and tannic acid as standard concentration have verified the accuracy on content of tannin extract in previous tests.

Sample	Concentration (mg/L)	Reading equivalent to 1 mg/L of Tannin (mg/L)
Tannin extract from extraction	-	21000
	-	22000
	-	19000
Average		20000
Dried Tannin	1 mg/L	0.5
	1 mg/L	0.5
	1 mg/L	0.5
Average		0.5
Commercial Tannin	1 mg/L	1.1
	1 mg/L	1.1
	1 mg/L	1.0
Average		1.0
Commercial Tannic Acid	1 mg/L	1.1
	1 mg/L	1.0
	1 mg/L	1.1
Average		1.1

Table 2: Tannin and Lignin Test Results

4.3 SETTLEABILITY CURVES

A set of jar tests was conducted for three (3) different coagulants namely, aluminium sulphate (alum), limestones powder, and raw mangrove powder as preliminary tests in the first phase of this research. Then, in second phase, another set of jar tests also was conducted using tannin extract, alum and modified tannin extract. Later, settleability tests have been conducted directly after jar tests are completed. The results for the settleability curves and other tests are explained in the following parts.

4.3.1 Settleability curve using alum as coagulant

Figure 9 and 10 show the dosage of 4500 mg/L of alum was the best settling rate of 0.692 cm/min based on the gradient of its curve in early of the test. It was followed by dosage of 12000 mg/L (0.660 cm/min) and 30000 mg/L (0.301 cm/min). However, the 30000 mg/L dosage gave a straight line rather a curve due to lack of data collected during the laboratory experiment. This linear pattern also occurred to other dosages such as 300 mg/L (0.157 cm/min) and 12000 mg/L. Several dosages were also showing sudden drop of settling rate after staying constant at the first half of the testing time. This can be observed for dosage of 24000 mg/L (0.255 cm/min) and 15000 mg/L (0.217 cm/min). For dosages like 600 mg/L (0.253 cm/min), 3000 mg/L (0.301 cm/min) and 6000 mg/L (0.350 cm/min), the curves are almost identical.

In the end of the test, dosage of 300 mg/L has given the lowest sludge settling height followed by 24000 mg/L. Dosage of 1500 mg/L has the highest final sludge settling height and several others having the same final sludge settling height. If both early settling rate and final sludge settling height is taken into consideration, the dosage of 300 mg/L has the best result but the dosage of 4500 mg/L also having competitive efficiency with high early settling rate.

The linear curve observed was slightly deviated from the actual settling pattern that shall be adopted during settling process. The dosage variability showed nothing significant and perhaps the results were slightly mixed up with unreliable values which have been taken during experimentation.

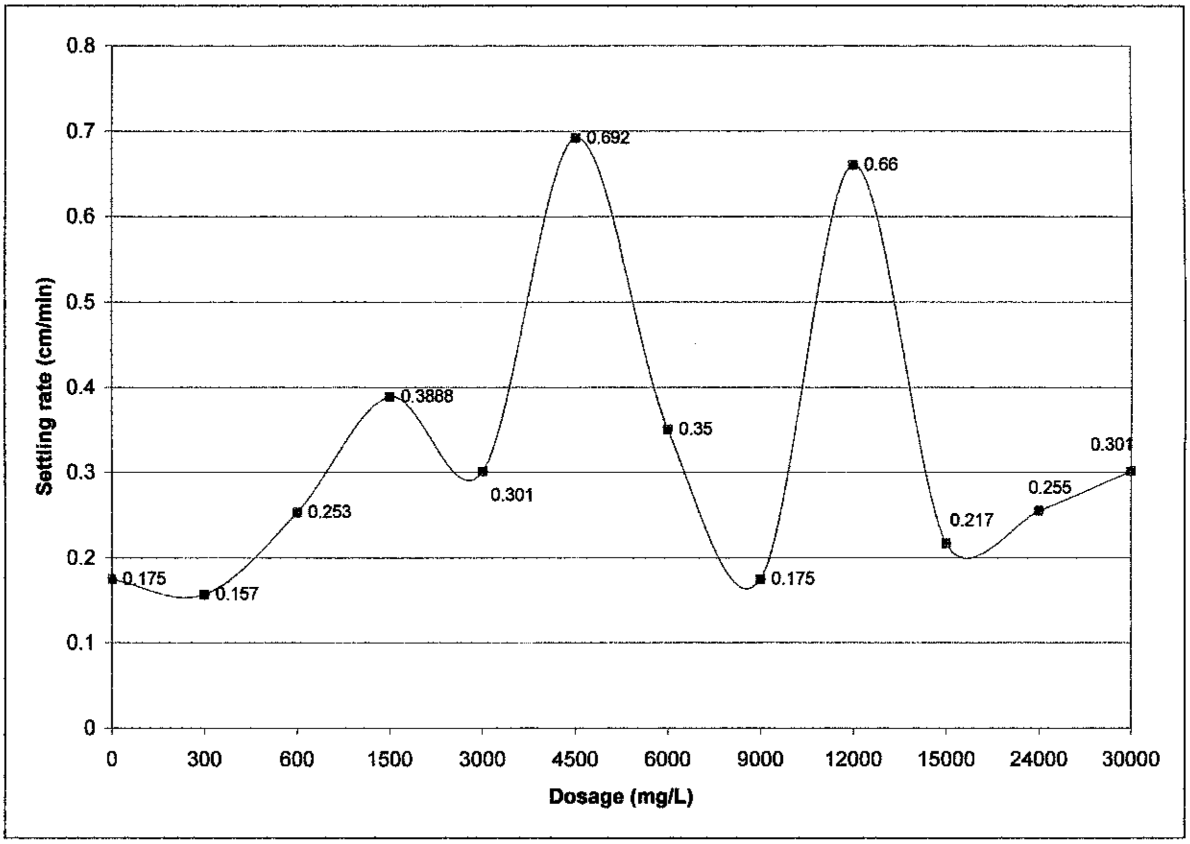

Figure 9: Settling rate vs. Alum Dosage

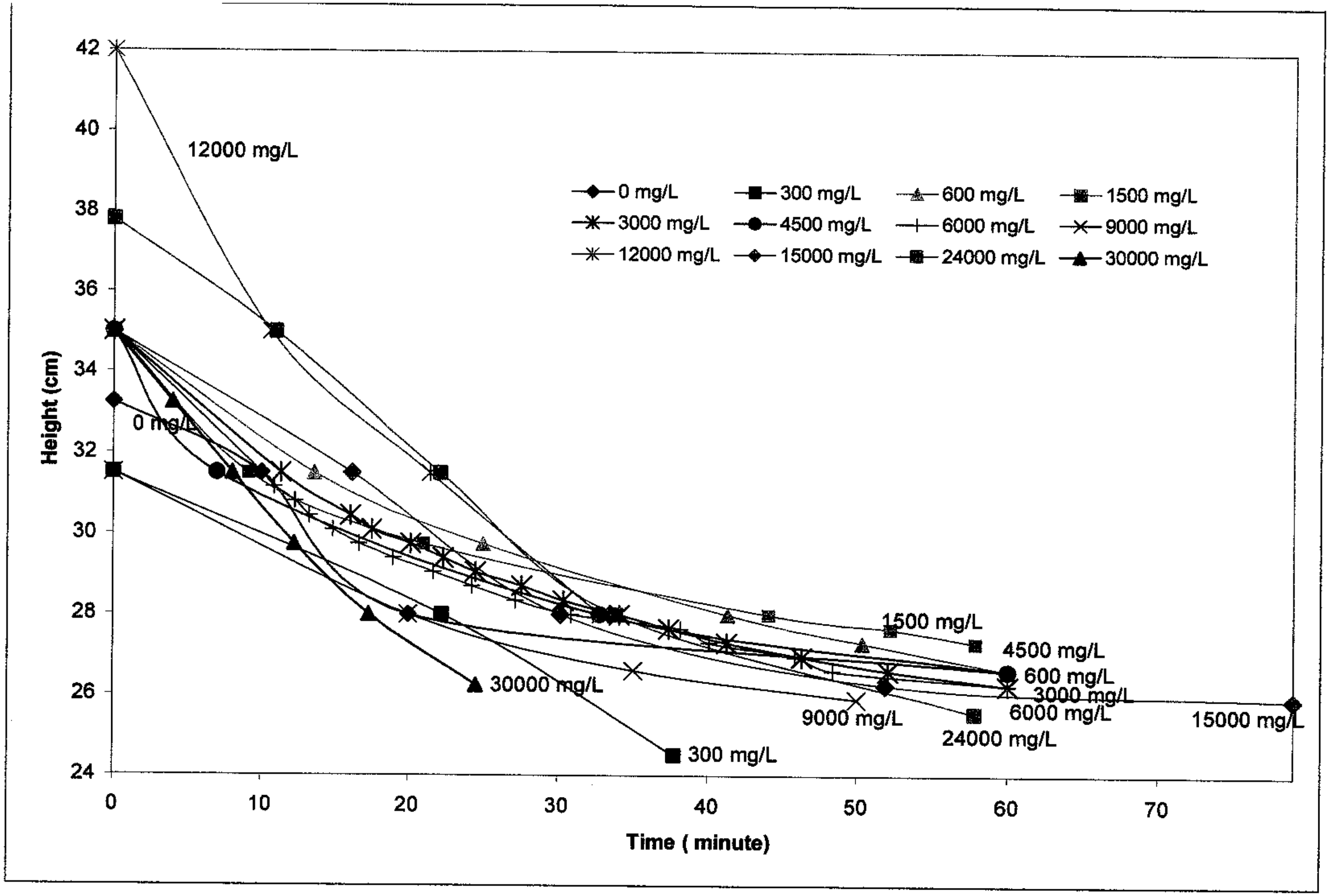

Figure 10: Settleability curve using alum as coagulant

4.3.2 Settleability curve using limestones powder as coagulant

The settleability curve for limestones as coagulant in sludge settling was largely different as compared with a commercial coagulant. Based on Figure 11 and 12, the best settling rate was achieved with dosage of 1000 mg/L of limestones at 0.259 cm/min. However, lack of data for that dosage gave a shortcoming in comparing this result with other dosages. In general, most of the curves were having linear patter which was unusual to commercial coagulant settleability curve i.e. alum.

Dosage of 400 mg/L (0.086 cm/min) has a slight curvature in the middle of its line despite of having low gradient earlier in the settling test. The same pattern also observed for dosage of 150 mg/L (0.157 cm/min) where drop of settling height is quite substantial at 30 minutes. For dosage of 1500 mg/L (0.038 cm/min), the sudden drop settling height in the end of 40 minutes was unusual but insignificant.

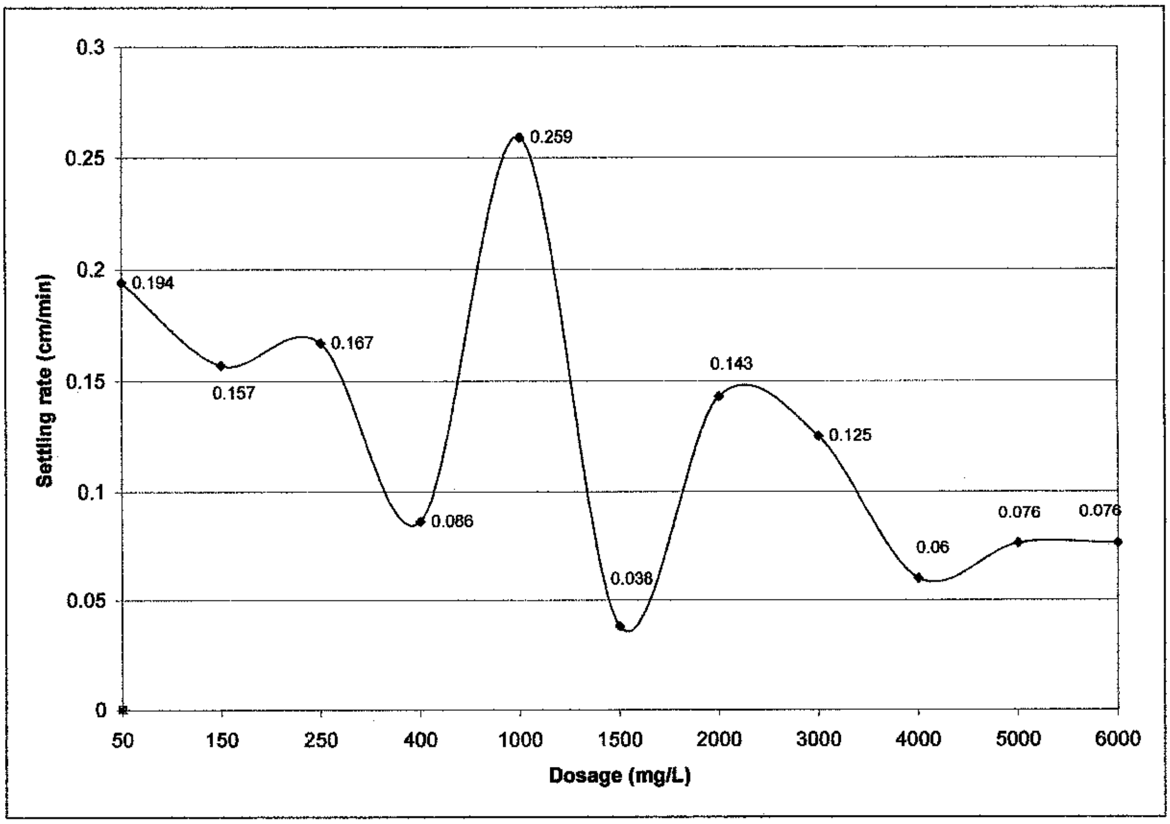

Figure 11: Settling rate vs Limestones powder Dosage

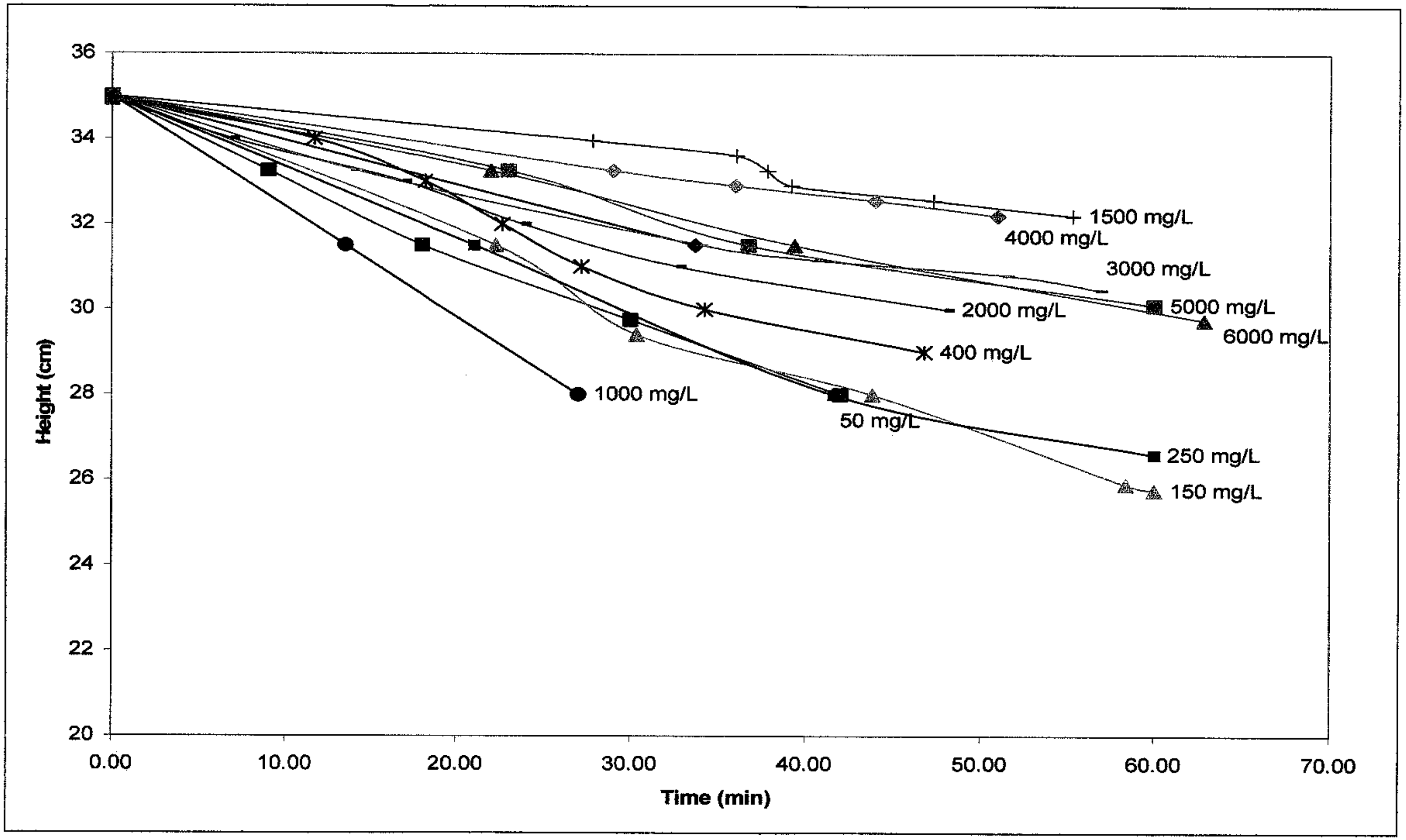

Figure 12: Settleability curve using limestones powder as coagulant

4.3.3 Settleability curve using mangrove powder as coagulant

The settleability curve of the mangrove powder as coagulant was the most consistent of all. In Figure 13 and 14, mangrove powder has shown its capability to improve settling rate of sludge. The highest settling rate was achieved with dosage of 4000 mg/L of raw mangrove powder of 2.98 cm/min. In the early stage of the settling process, the cylinder without coagulant has higher settling rate than other dosages except 4000 mg/L. This situation is less favourable as if the raw mangrove powder produced the same results even without coagulant.

However, as time progress, some dosage has beaten up the zero dosage's settling rate. This could be observed after 20 minutes of the test. As for final sludge settling height, the dosage of 4000 mg/L was ultimately the best with a lot of difference. The dosage of 50 mg/L, 150 mg/L, 400 mg/L and 500 mg/L have lower final sludge settling height as compared to zero dosage leaving other dosages with higher final sludge settling height than zero dosage's.

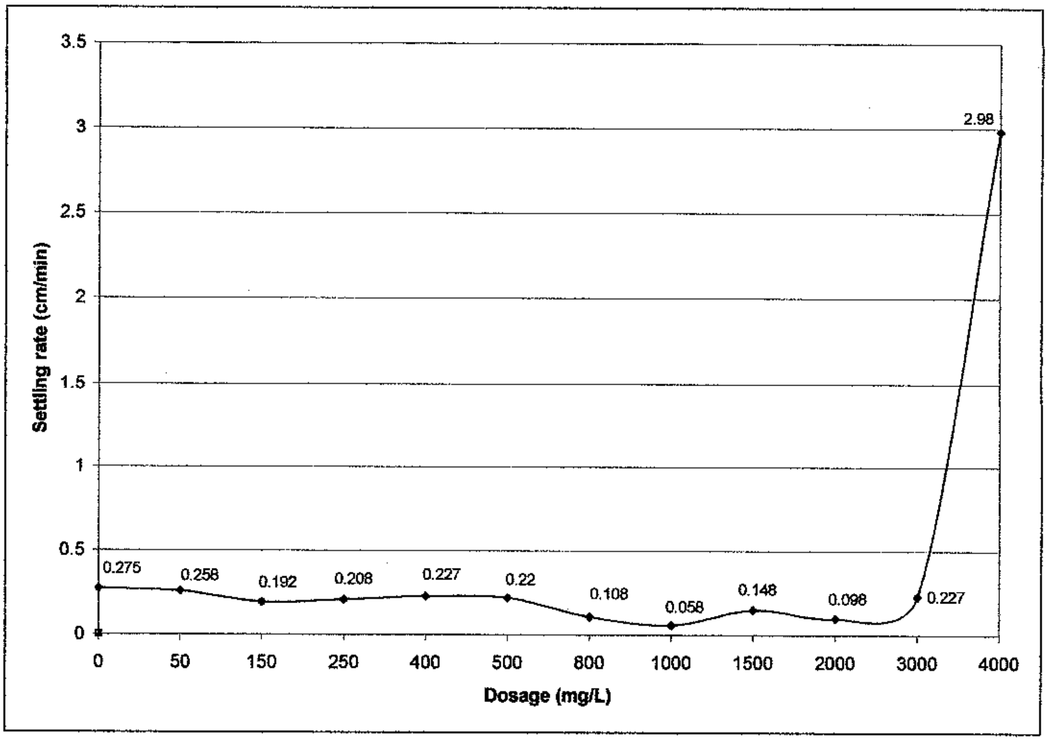

Figure 13: Settling rate vs Mangrove powder dosage

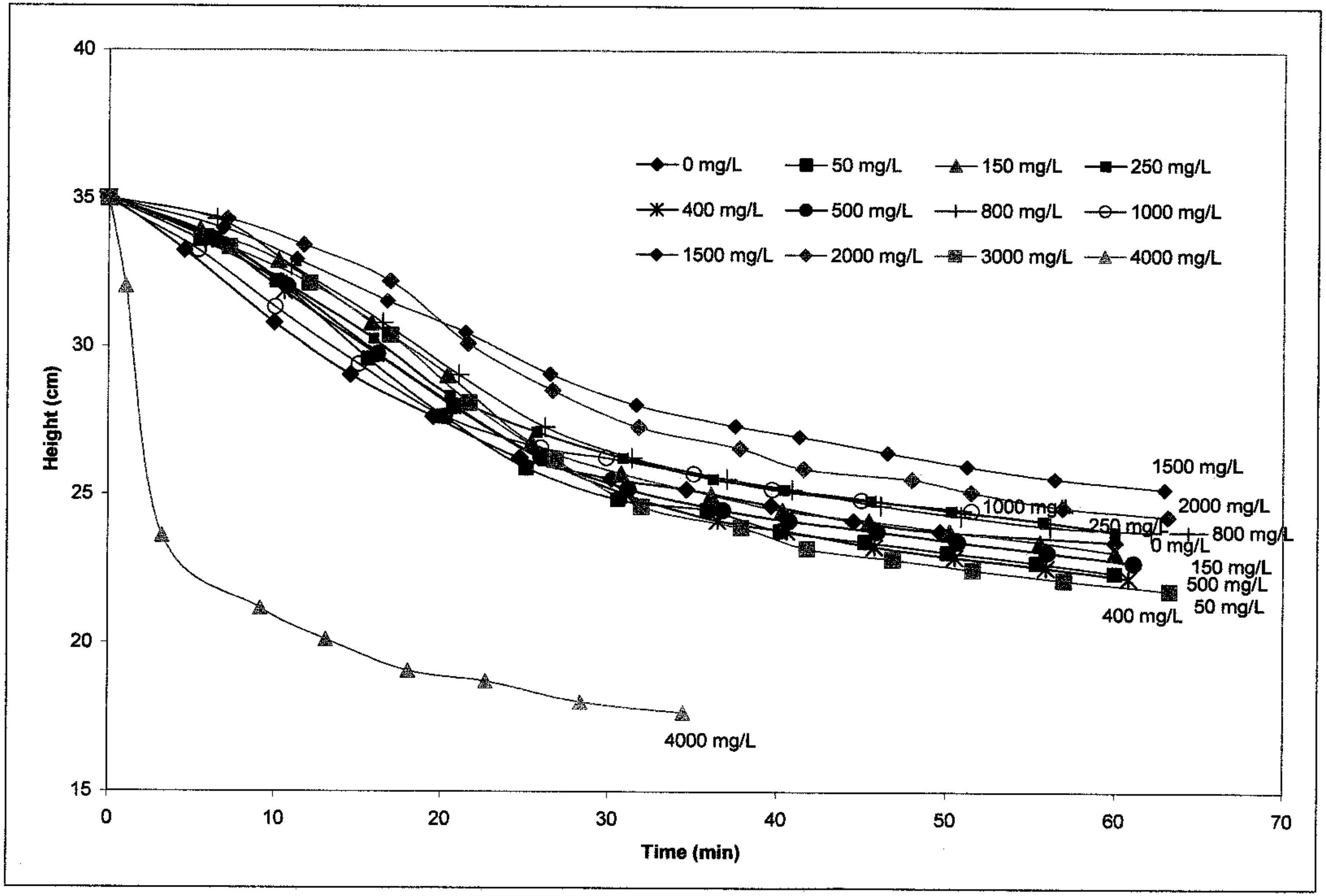

Figure 14: Settleability curve using mangrove powder as coagulant

4.3.4 Settleability curve using alum as coagulant (Phase 2)

Based on Figure 15 below, the result for settling test using alum in the second phase indicated negative pattern as the settling rates were depressing as more dosage of alum was added. The rate of settling for zero dosage was the highest followed closely by dosage of 300 mg/L of alum. The settling rate for zero dosage was 0.436 cm/min and followed by 300 mg/L dosage with 0.398 cm/min. The worst settling rate was observed by the highest dosage that was 1500 mg/L with 0.190 cm/min.

Such situation is most likely being influenced by the characteristics of the sludge that was used during the test, which has affected the performance of alum. Therefore, the use of alum in sludge dewatering process would be impractical if this situation persists. The pattern shown in Figure 16 implied a non-uniform settling for different dosage and the curves were smooth with fluctuation at the end of the test.

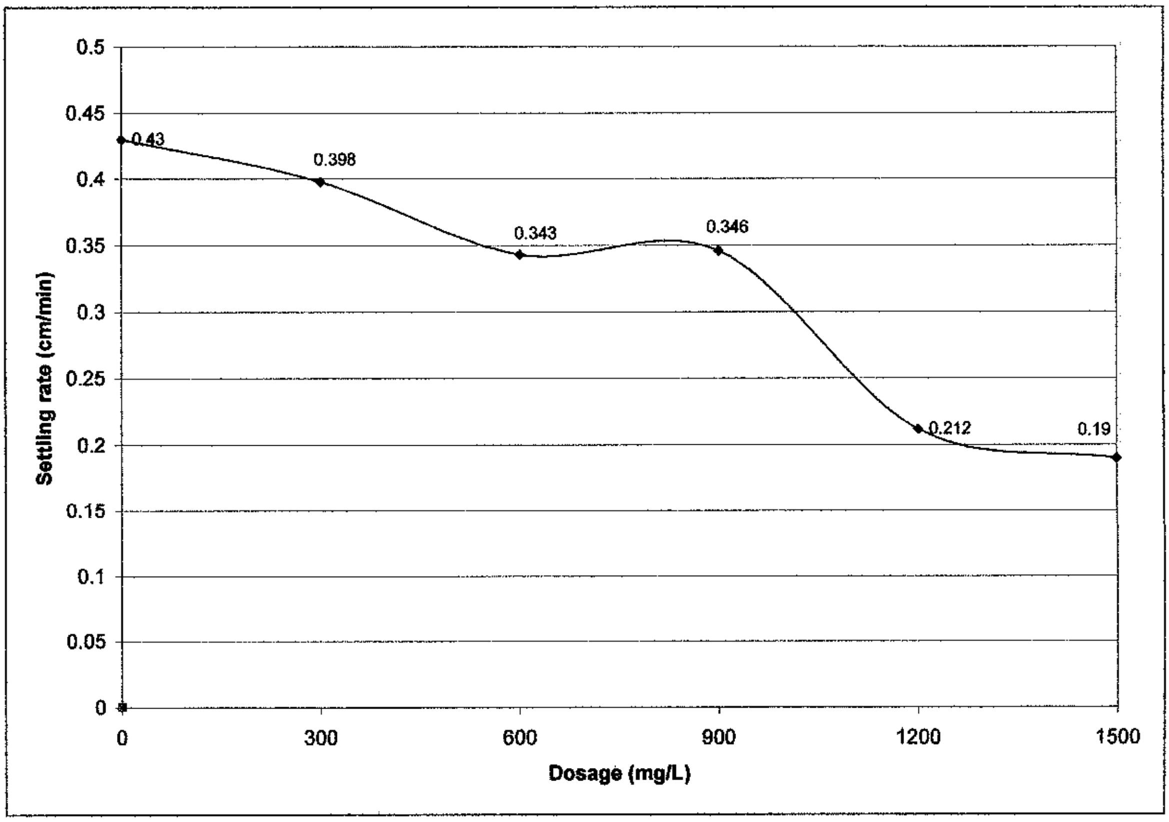

Figure 15: Settling rate vs alum dosage (Second Phase)

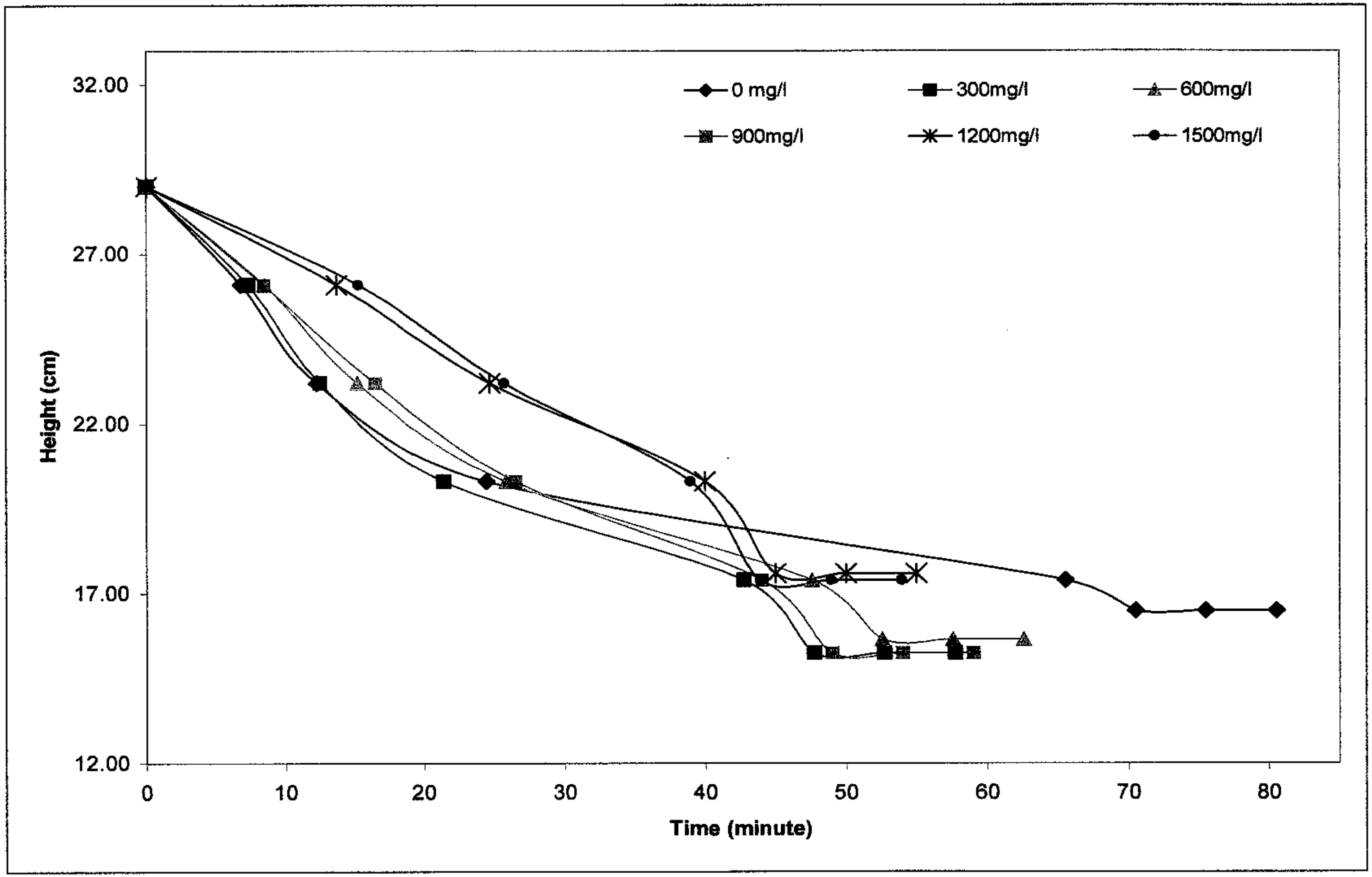

Figure 16: Settleability curve using alum as coagulant (Second Phase)

4.3.5 Settleability curve using tannin extract as coagulant (first trial)

The settleability curve (Figure 18) that obtained from settling test by using tannin during the first trial has uniform pattern in settling. However, the settling rate fluctuated in between high and low dosages. Based on Figure 17, the best dosage in the test was 2400 mg/L of tannin with 4.833 cm/min. The dosage of 3600 mg/L was the second best with 3.70 cm/min followed by 1200 mg/L and 300 mg/L which were having around 3.00 cm/min. The lowest settling rate was observed by dosage of 4800 mg/L with settling rate of 0.529 cm/min.

Basically, the range between 1200 mg/L to 3600 mg/L showed strong results in providing good settling rate during the test. The sudden change of the settling rate for dosage of 4800 mg/L was unexpected but non-homogeneity of sludge sample could have affected that reading. As for other curves, the settling rates dropped after the twentieth minute.

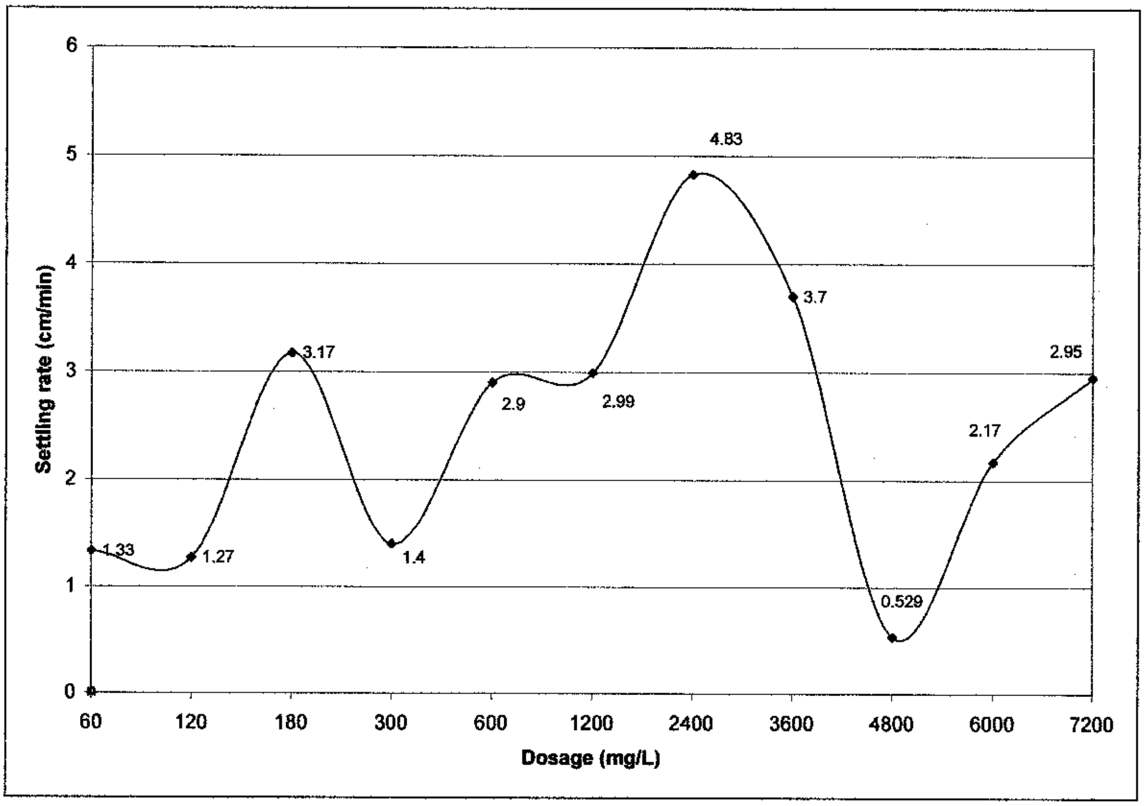

Figure 17: Settling rate vs Tannin extract dosage (first trial)

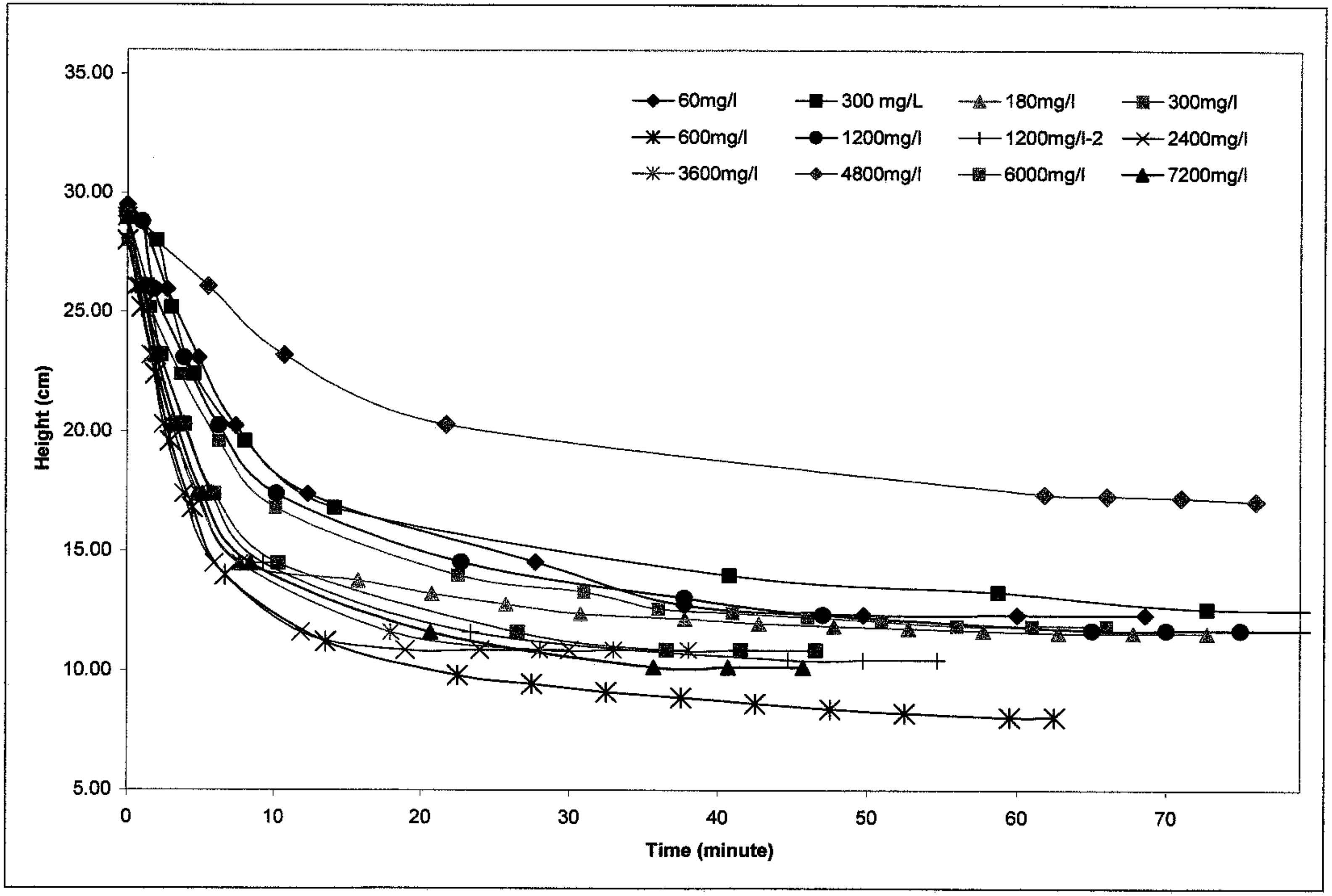

Figure 18: Settleability curve using tannin extract as coagulant (first trial)

4.3.6 Settleability curve using tannin extract as coagulant (second trial)

In the second trial of settling test using tannin extract, the results were changed tremendously with the lower dosages have low settling rate as compared to higher dosages. Based on Figure 19, Dosage of 2400 mg/L has the highest settling rate with 3.48 cm/ min and dosage of 180 mg/L produced the lowest settling rate of 0.0833 cm/min.

Curves of dosages from 60 mg/L to 720 mg/L were clustered together at the top of the graph whilst other curves were clustered at the bottom. In Figure 20, these two groups of curves seemed to have a uniform pattern and averaging the same settling rate.

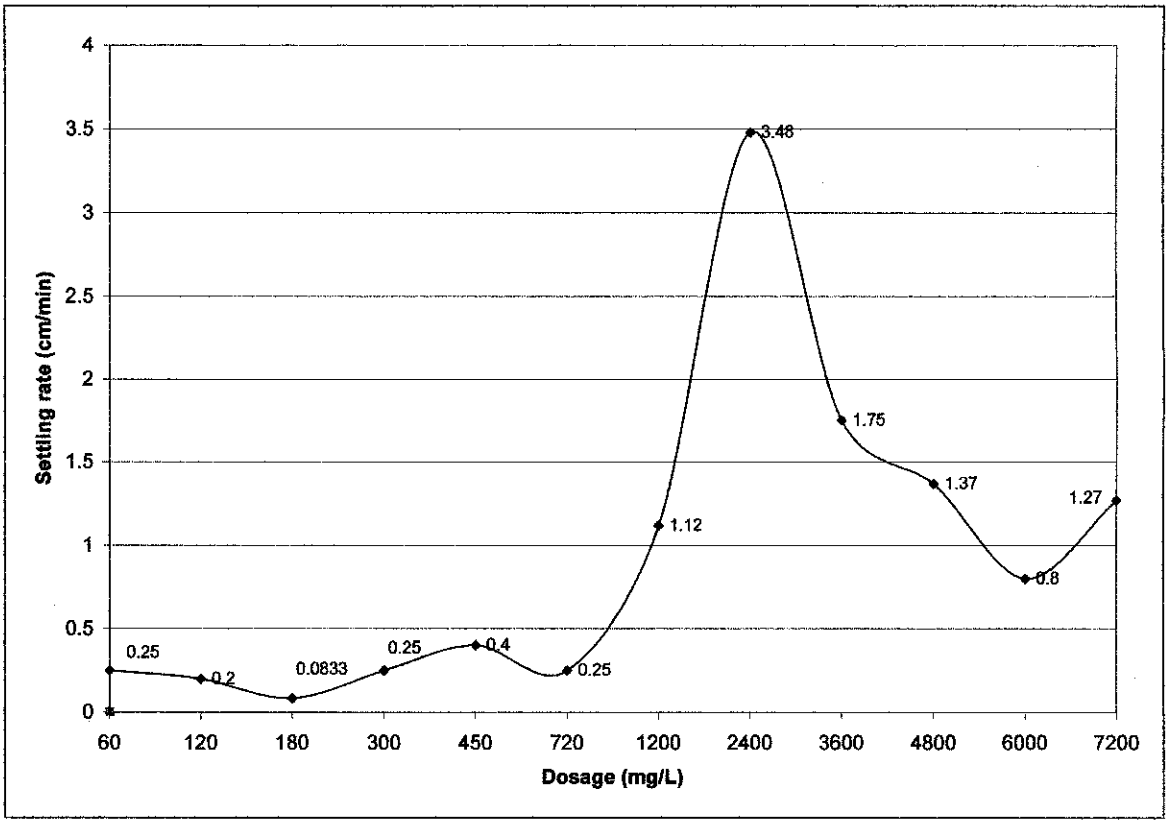

Figure 19: Settling rate vs Dosage of tannin extract (second trial)

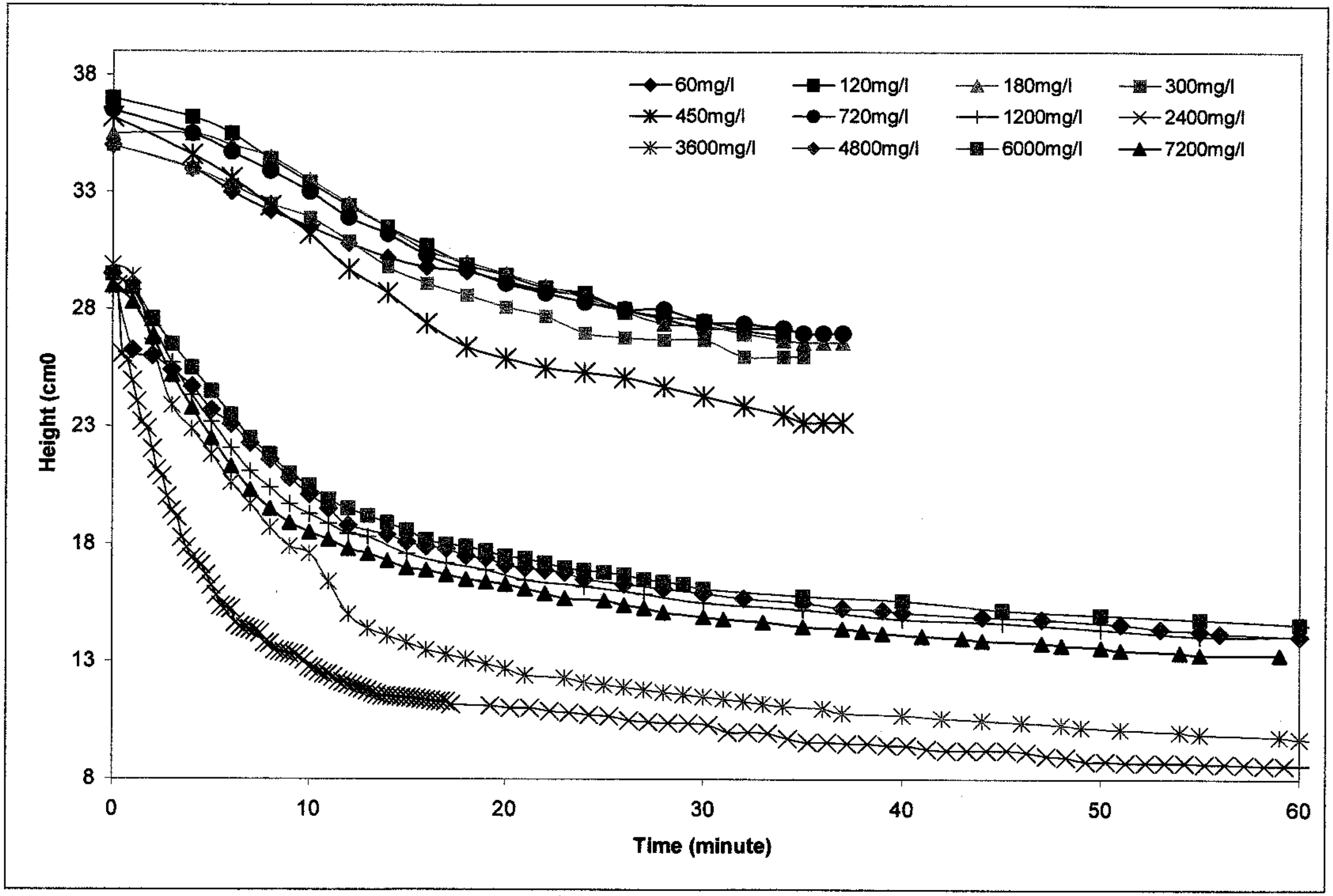

Figure 20: Settleability curve using tannin extract as coagulant (second trial)

4.3.7 Settleability curve using modified tannin extract as coagulant (first trial)

For modified tannin extract, the best dosage was 3600 mg/L with settling rate of 4.32 cm/min and the second best was dosage of 1200 mg/L which gave settling rate of 3.33 cm/min. The lowest settling rate was produced by 6000 mg/L dosage with settling rate of 0.982 cm/min. Based on Figure 21, the values of settling rate were fluctuating a lot at larger dosages whilst smaller dosages have only small differences. For an example, dosage 120 mg/L and dosage 180 mg/L were having settling rate at 2.102 and 2.108 cm/min respectively.

With reference to Figure 22, the settleability curves were scattered and did not have any uniform pattern after 5 minutes of settling test. The changing pattern could be caused by the reaction by the modified tannin which has less leaching properties as compared to original tannin extract. Dosage 1200 mg/L has shown an early cease in settling after 2 minutes and stayed constant.

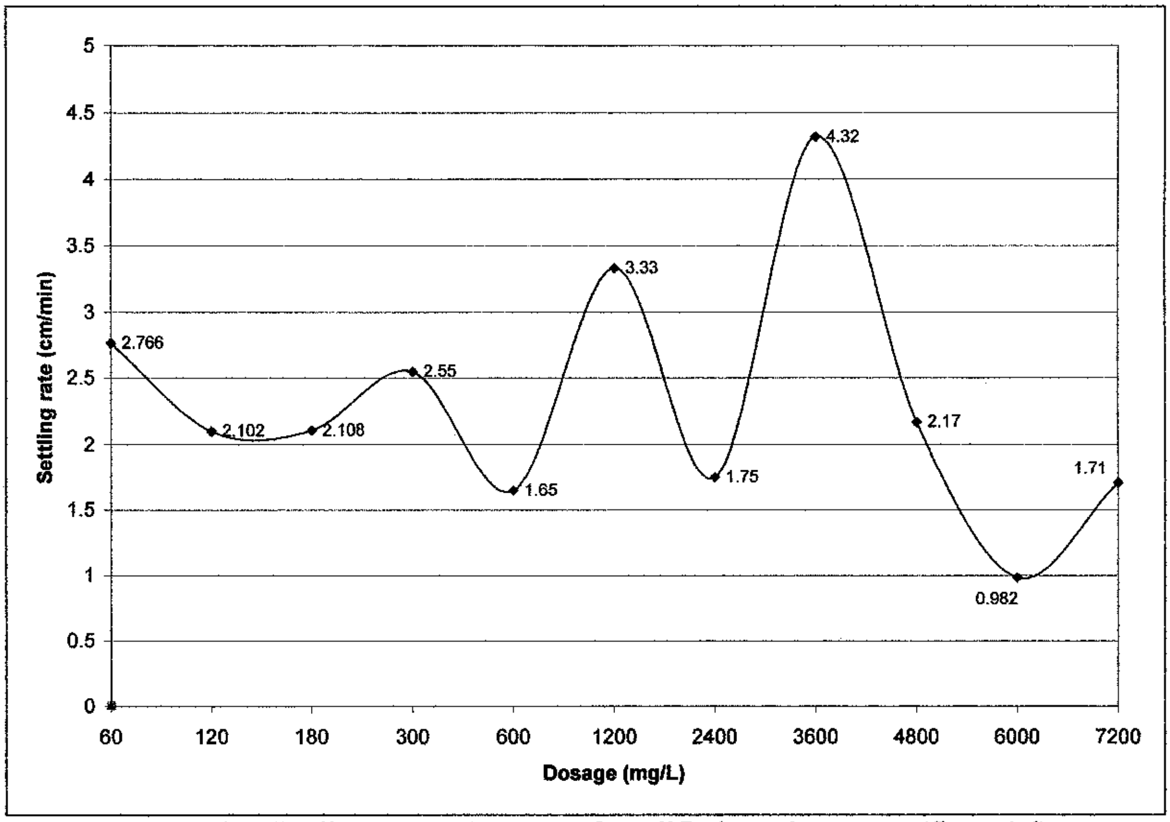

Figure 21: Settling rate vs Dosage of modified tannin extract (first trial)

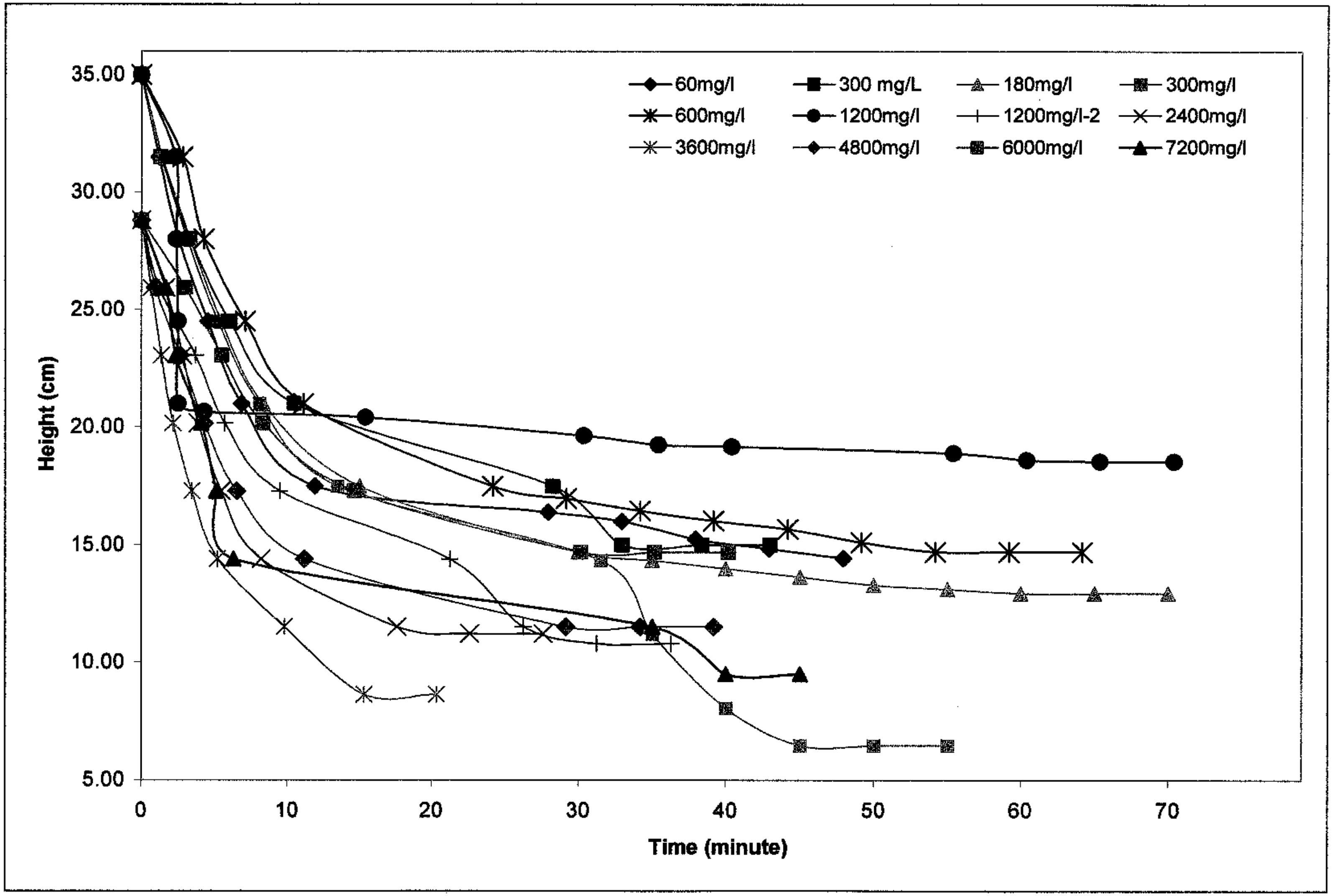

Figure 22: Settleability curve using modified tannin extract as coagulant (first trial)

4.3.8 Settleability curve using modified tannin extract as coagulant (second trial)

In the second trial of settling test using the modified tannin extract as coagulant, the best settling rate was achieved at dosage of 2400 mg/L with settling rate of 1.75 cm/min. The lower dosages also indicated low settling rate with dosage of 120 mg/L produced the lowest settling rate. Based on Figure 23, the first five dosages gave settling rate between 0.083 cm/min and 0.333 cm/min. Both dosages of 1200 mg/L and 7200 mg/L were following closely to best dosage with settling rate of 1.4 cm/min and 1.625 cm/min respectively.

Figure 24 also displayed clustering of the curves according to the group of higher dosage and lower dosage. Both groups were having distinctive pattern which reflected in the settling rate values as above. Dosage of 7200 mg/L showed further depression in terms of the height of solids despite being second in terms of rate settling.

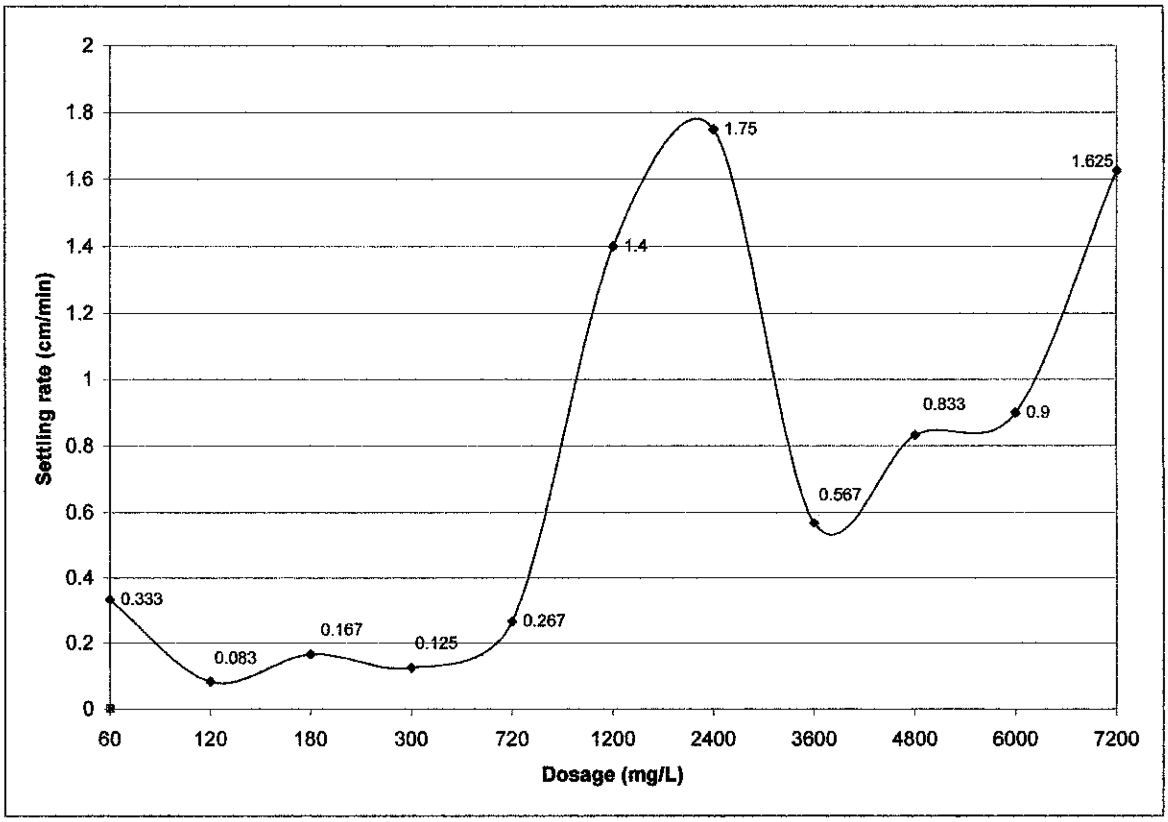

Figure 23: Settling rate vs Dosage of modified tannin extract (second trial)

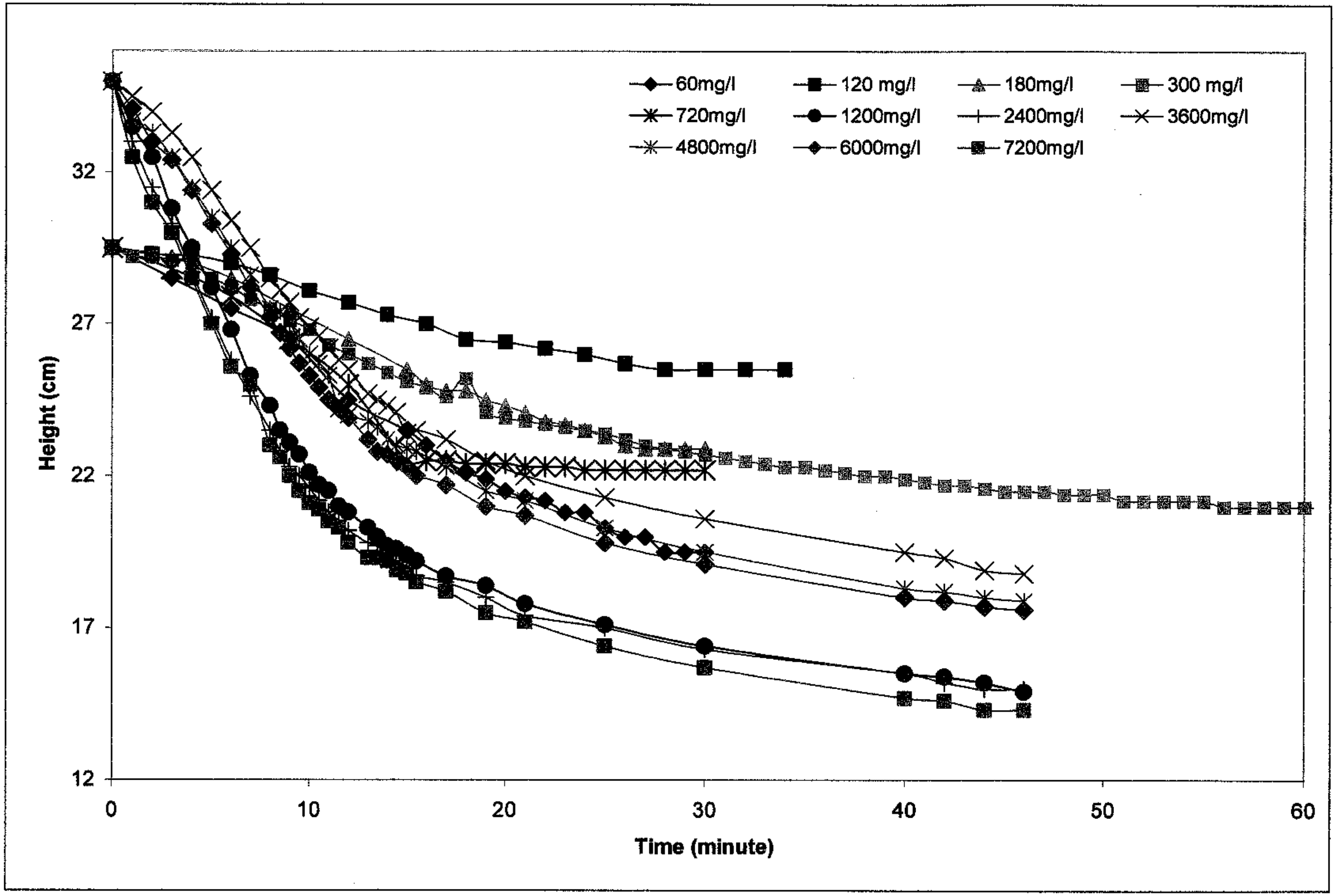

Figure 24: Settleability curve using modified tannin extract as coagulant (second trial)

4.3.9 Settleability comparison of different coagulants

In Figure 25, the three coagulants were tested in the first phase of the research and compared to see which coagulant performing the best and have the lowest final sludge settling height. Obviously, limestones settling curve was the worst and has a constant settling rate over time. The alum settling curve (0.692 cm/min) was only slightly better than limestones' settling curve (0.259 cm/min) but not as good as mangrove powder. The mangrove powder has a very high settling rate (2.98 cm/min) at the beginning of its test. As for final sludge height, the raw mangrove powder has the lowest of the three which means it is the best coagulant based on those jar tests and settling tests. In terms of dosage, lesser amount of raw mangrove was used than to alum and, limestones has the lowest dosage in this comparison.

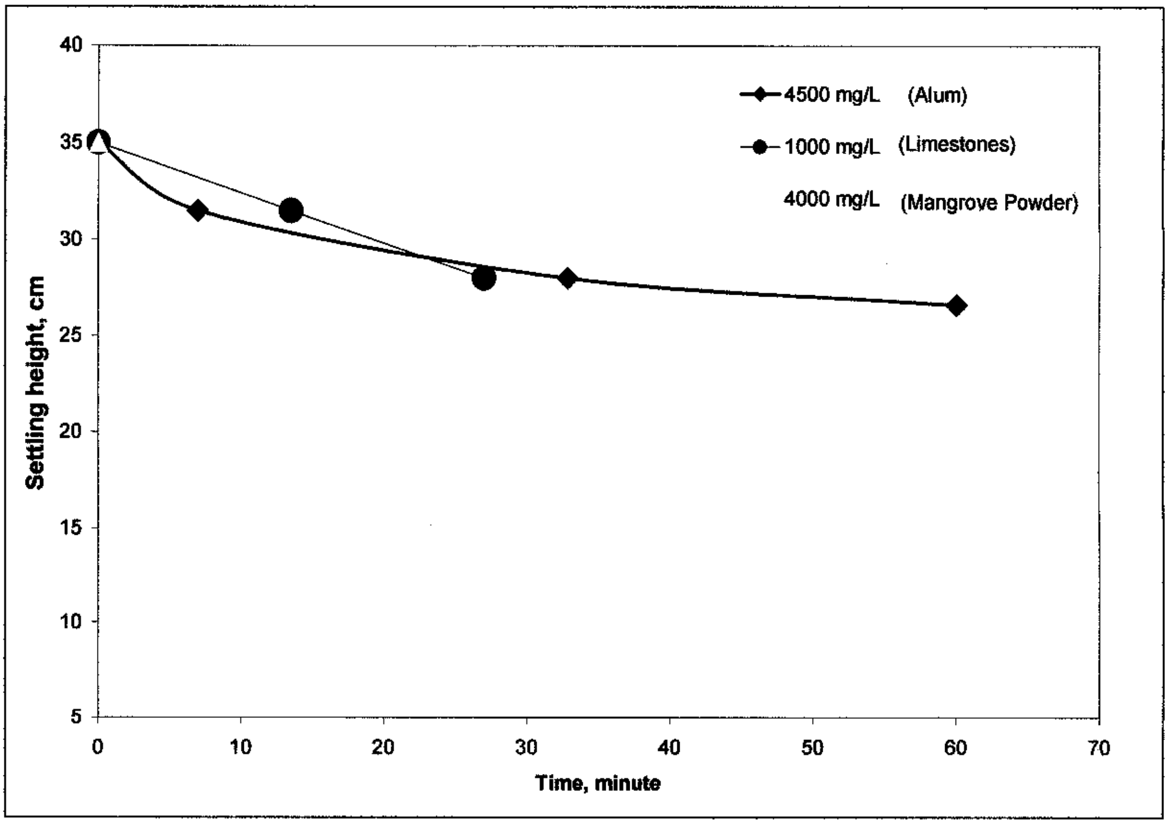

Figure 25: Comparison of best settling curve of coagulants

Figure 26 is the result from retesting the optimum dosages of coagulants that were used in second phase of the research, namely alum, and tannin extract. It was found that tannin extract with dosage of 2400 mg/L has the best settling rate of 0.769 cm/min and followed by tannin extract, 3600 mg/L. However, the dosage of tannin extract 300 mg/L and 600 mg/L also gave good results and not very far from the best dosage. As for alum, it only got 0.718 cm/min for its settling rate of sludge. It was suspected that, the inconsistency of this result in comparison with previous tests was caused by different sludge samples taken for different set of tests.

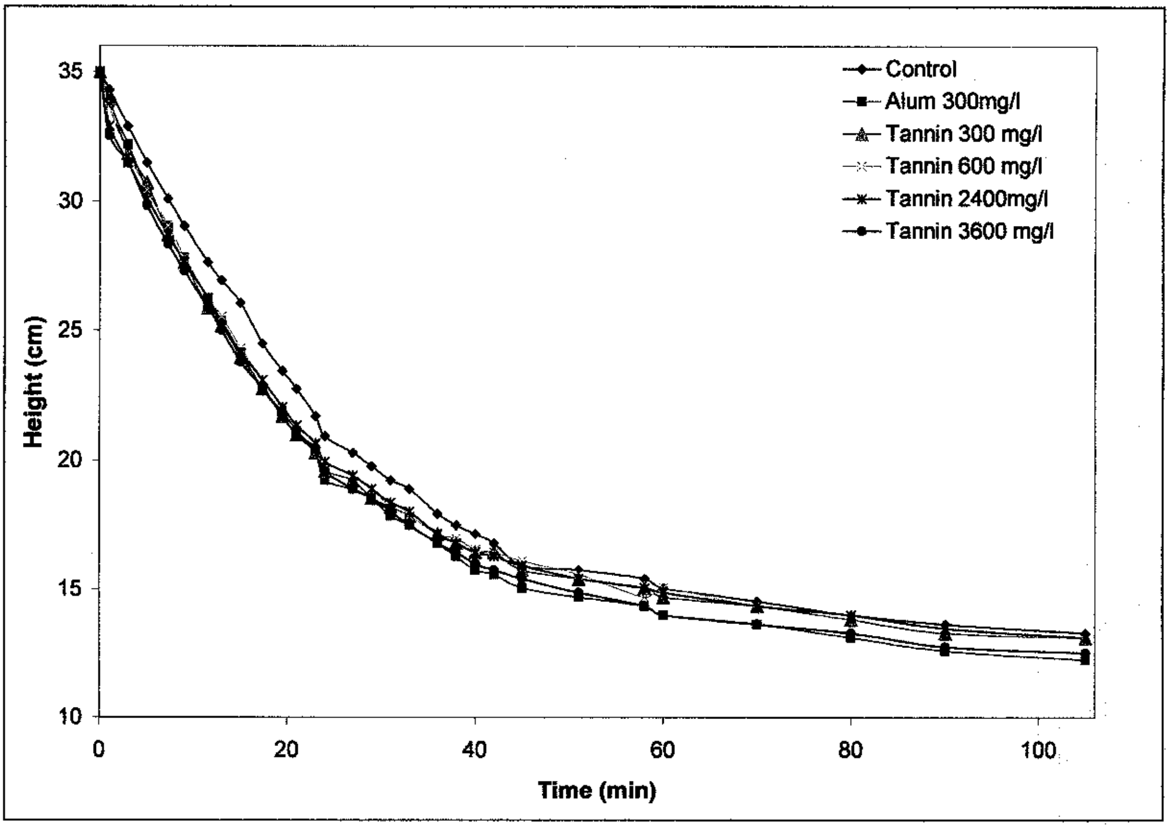

Figure 26: Settleability curve for comparison of different coagulants

4.4 COD, TSS AND PH

4.4.1 COD and pH of supernatant using alum as coagulant

Figure 27 showed the chemical oxygen demand (COD) value and pH of supernatant collected in the end of the settling test. The COD value is fluctuating at the range 100 to 300 at the dosage of 0 to 10000 mg/L. After that, the COD value increased to 450 at dosage of 12000 mg/L. Then, it dropped a little at dosage of 15000 mg/L and shot up again to 768 at dosage of 30000 mg/L. As for the pH value, the initial pH was the highest value and it decreased along with increment of alum dosage. This implied the acidity of the supernatant wass increased due to addition of more alum. The lowest COD was obtained from dosage of 6000 mg/L with pH of 5.8.

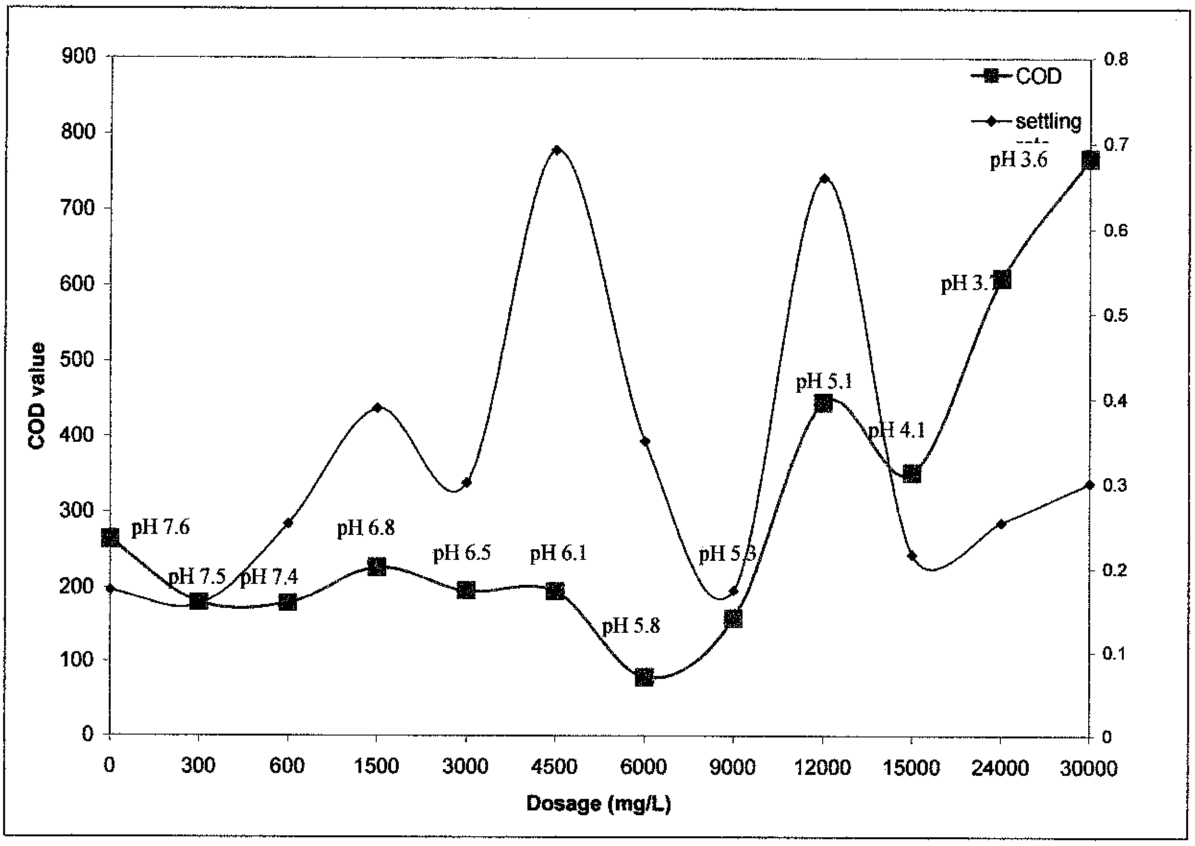

Figure 27: COD and pH of supernatant with settling rate (alum)

4.4.2 COD and pH of supernatant using limestones as coagulant

For limestones as coagulant, Figure 28 showed the graph of COD value with its corresponding pH values. The fluctuating pattern at the beginning occurred in range of 230 to 350 before it increased up to 540 at dosage of 2000 mg/L. After that, the value of COD decreased to 300 and rose slightly at dosage of 6000 mg/L. The lowest COD value is recorded at dosage of 1000 mg/L which was the best dosage for limestones settleability curve. As for pH, it followed the same pattern that applied to the COD value. But the range of the pH was only from7.6 to 8.0 which is considered as small. The best COD value was having the lowest pH of 7.6. This implied that limestones performed best at 1000 mg/L of dosage with lower pH and yielded the lowest COD value as well.

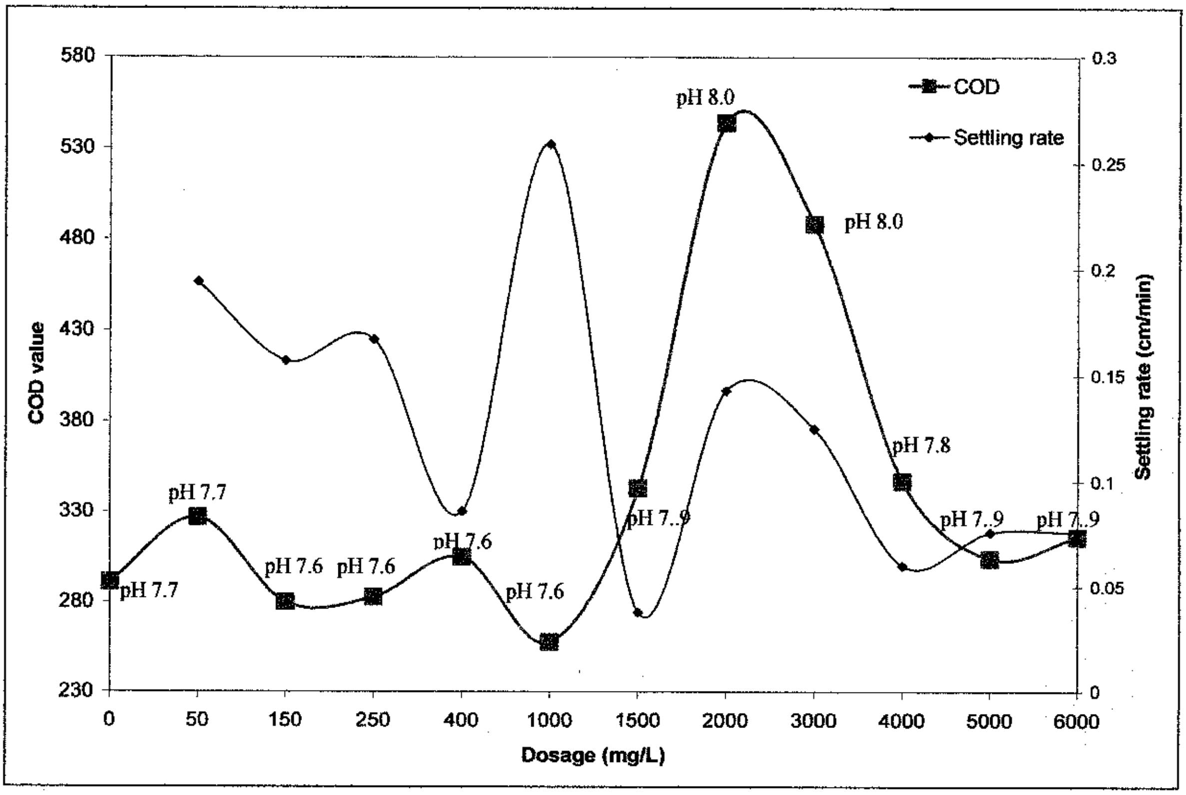

Figure 28: COD and pH of supernatant with settling rate (Limestones)

4.4.3 COD and pH of supernatant using mangrove barks powder as coagulant

Raw mangrove powder showed a very small range of COD values for every dosage. Figure 29 showed the fluctuating of COD values as the dosage of raw mangrove powder was increased. The sudden increase of COD was observed at dosage of 1500 mg/L which has the lowest settling rate as discussed in the settleability curve section. The lowest COD value was obtained at the zero dosage, 50 mg/L and 150 mg/L dosage. The values of pH obtained also in a very small range of 8.2 to 8.5. This situation suggested that raw mangrove powder has a very small effect in changing pH of the supernatant. The highest pH was achieved at the high peak of the COD values such as dosage of 250 mg/L and 1500 mg/L with both are having pH of 8.5. When, the dosage has reached more than 2000 mg/L, the pH decreased with increment of dosage. Dosage of 4000 mg/L was having the least pH value of 8.2 despite of having the highest settling rate.

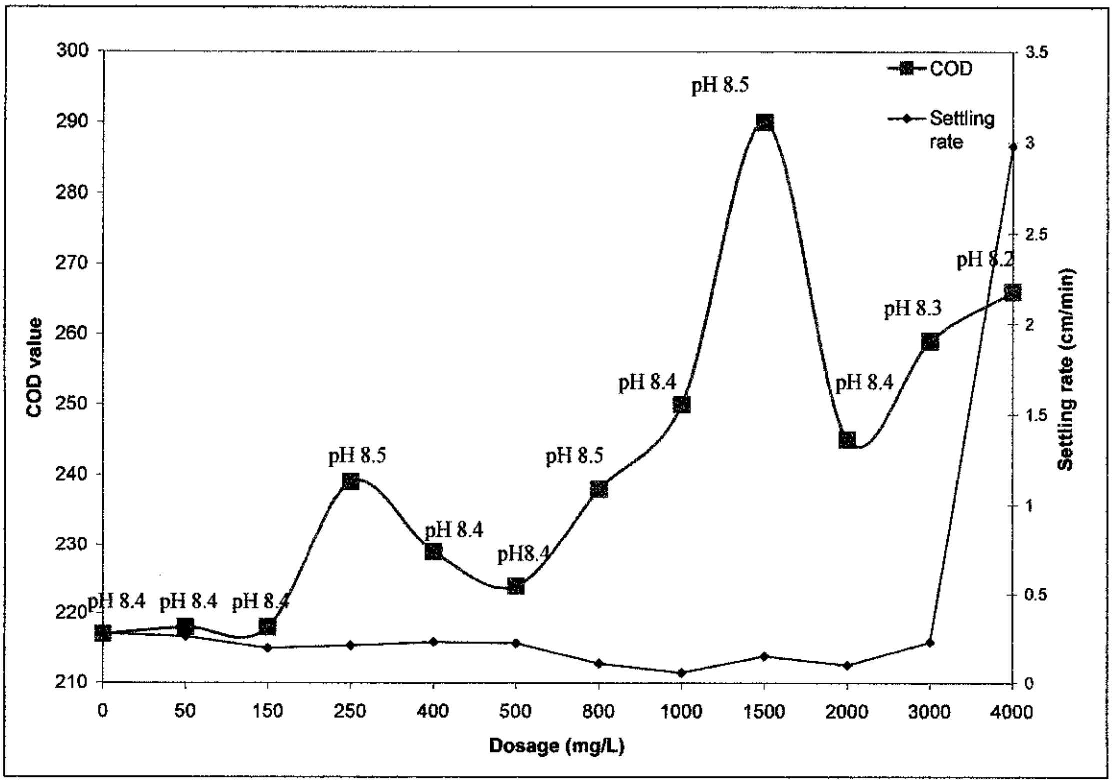

Figure 29: COD and pH of supernatant with settling rate (Mangrove powder)

4.4.4 COD of supernatant using alum as coagulant (second phase)

Figure 30 showed the COD value of supernatant obtained from settling test using alum as coagulant. The COD values were decreasing with increase of alum dosages and dosage of 1500 mg/L gave the lowest value of COD in the test. The control (0 mg/L) supernatant was having the highest COD value of 1433. The best dosage at 1500 mg/L has the highest percentage of COD removal of 98.3 percent followed by dosage 1200 mg/L with 96.6 percent COD removal. In comparison with settling rate, the COD values were proportional in terms of value but both reflected opposite efficiency. The highest COD value showed highest settling rate compared to lowest COD value also has lowest settling rate. Therefore, this result could not justify the efficiency of the lowest COD value since it has the lowest settling rate as well.

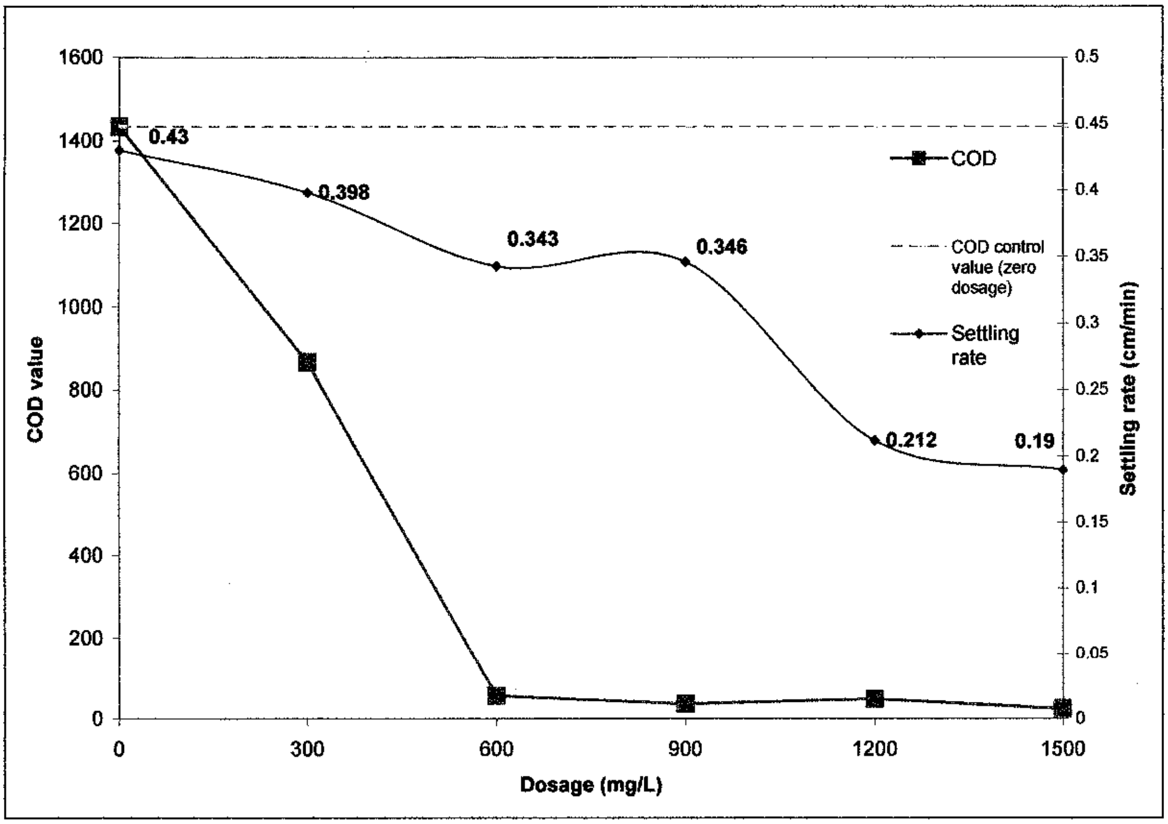

Figure 30: COD values of supernatant with settling rate (alum, second phase)

4.4.5 COD of supernatant using tannin extract as coagulant (first trial)

The COD of supernatant using tannin extract coagulant is described in the Figure 31 below. In average, the values of COD were the inverse of the settling rate for respective dosages. The lowest COD value was achieved by dosage of 120 mg/L with percentage of COD removal of 76.7 percent followed by 600 mg/L dosage with 633 (55.8 percentage of removal). On the other hand, the dosage of 1200 mg/L has the highest COD value of 3100 and added 116 percent of COD in the supernatant. The pattern for both COD and settling fluctuated heavily with increment of dosages. The dosage with highest settling rate (2400 mg/L) also has an increment of COD values for 20.9 percent from the original COD control value. The most optimum settling rate and COD removal was obtained with dosage of 180 mg/l (3.17 cm/min) with 32.6 percent removal. The increase of the COD was caused by the leaching of tannin during coagulation process in jar test. This is the first drawback that identified with tannin application in sludge settleability test.

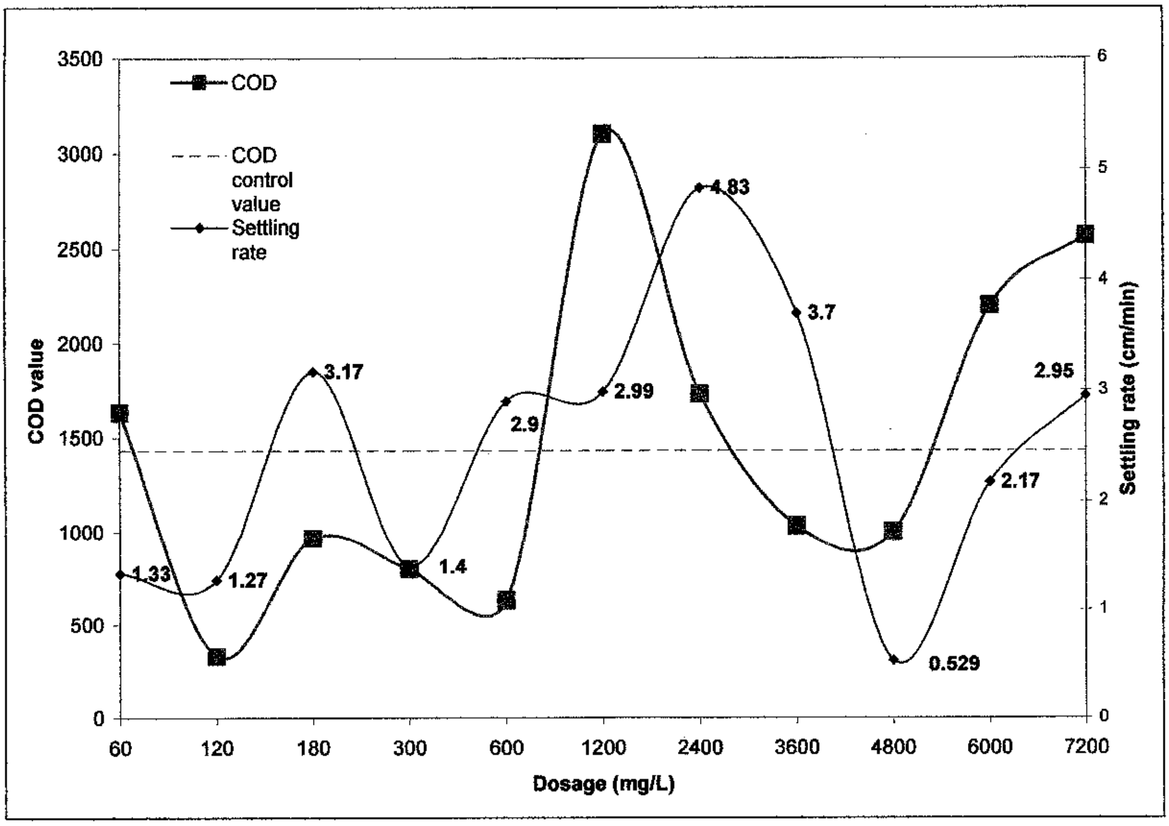

Figure 31: COD values of supernatant with settling rate (tannin extract, first trial)

4.4.6 COD of supernatant using tannin extract as coagulant (second trial)

For second trial of using tannin extract as coagulant, the COD values of supernatant showed reduction in every dosages. The dosage with highest COD removal was 300 mg/L with 72.3 percent and followed by 1200 mg/L dosage with 70.2 percent COD removal. The least removal was obtained by 4800 mg/L dosage with 34.6 percent of COD removal. Based on the Figure 32, the optimum dosage would be 1200 mg/L since it did fairly well with average settling rate and second best COD removal percentage. The pattern observed in this graph was better than in Figure 31 as all dosages have reduced in COD values. However, the average settling rate for first 5 dosages was very low as compared in Figure 31. In spite of better aggregation of sludge particles with application of tannin, the COD removed was not enough. At higher dosages, fluctuation of settling rate also occurred and has affected the COD value.

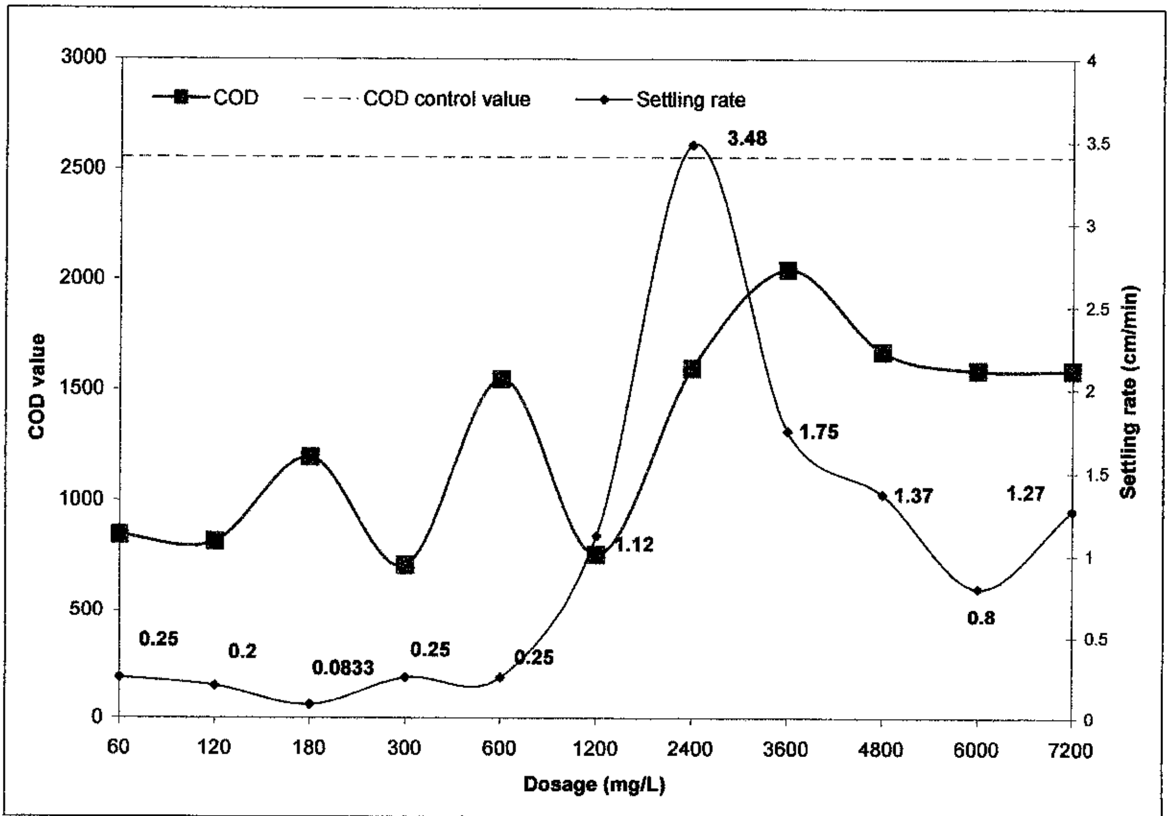

Figure 32: COD values of supernatant with settling rate (tannin extract, second trial)

4.4.7 COD of supernatant using modified tannin extract as coagulant (first trial)

The usage of modified tannin was intended for inhibition of COD leaching in tannin. However, in the first trial (Figure 33), only three dosages managed to get COD reduction and other nine dosages had increased the COD in the supernatant. This time, the pattern was difference as some dosages with lower settling rate tended to have high COD values such as dosage of 180 mg/L and 300 mg/L. Dosage of 1200 mg/L has the most optimum efficiency as it reduced the COD values by 30 percent and its settling rate was second best. The highest increment of COD values was obtained by dosage of 300 mg/L and 4800 mg/L with 53.5 and 51.1 percent increment. Dosage of 60 mg/L was competitive since it reduced 37.2 percent of COD with 2.766 cm/min settling rate following behind dosage 1200 mg/L. This result explained that tannin leaching problem is still rampant and most probably, the modification of tannin sample was not fully completed.

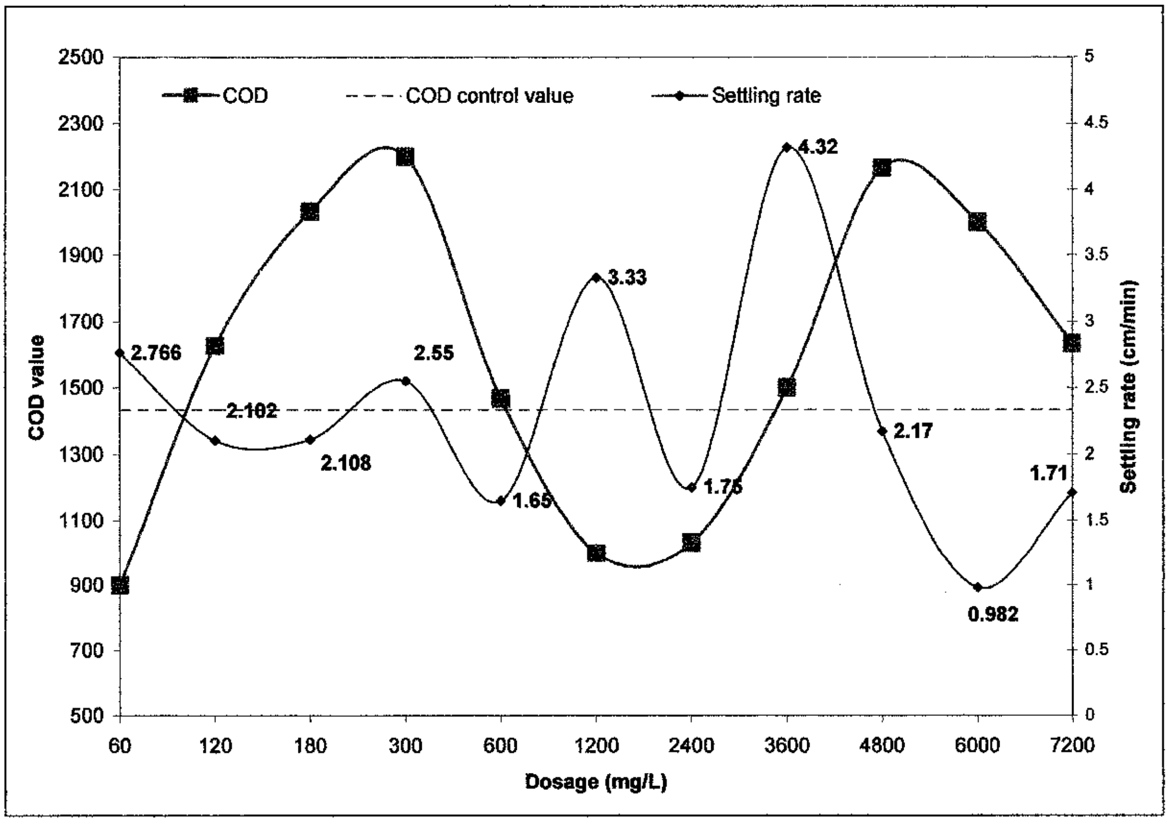

Figure 33: COD values of supernatant with settling rate (modified tannin. first trial)

4.4.8 COD of supernatant using modified tannin extract as coagulant (second trial)

In the second trial, the result was completely different with the first trial. Figure 34 showed that all dosages that removed some COD and more. The highest removal was achieved by dosage of 7200 mg/L with 84.5 percent removal and has the second best settling rate to become the most optimum dosage. The lower dosages in range of 60 mg/L to 600 mg/L only appeared to remove 25 percent whilst the higher dosages continued to remove more COD with average of 65 percent removal. The best settling rate (2400 mg/L) also displayed high COD removal at 54.6 percent. This encouraging result has proved that the modified tannin is able to facilitate dewatering of sludge with CDO removal as well and the modification process was successful as the COD leaching was inhibited.

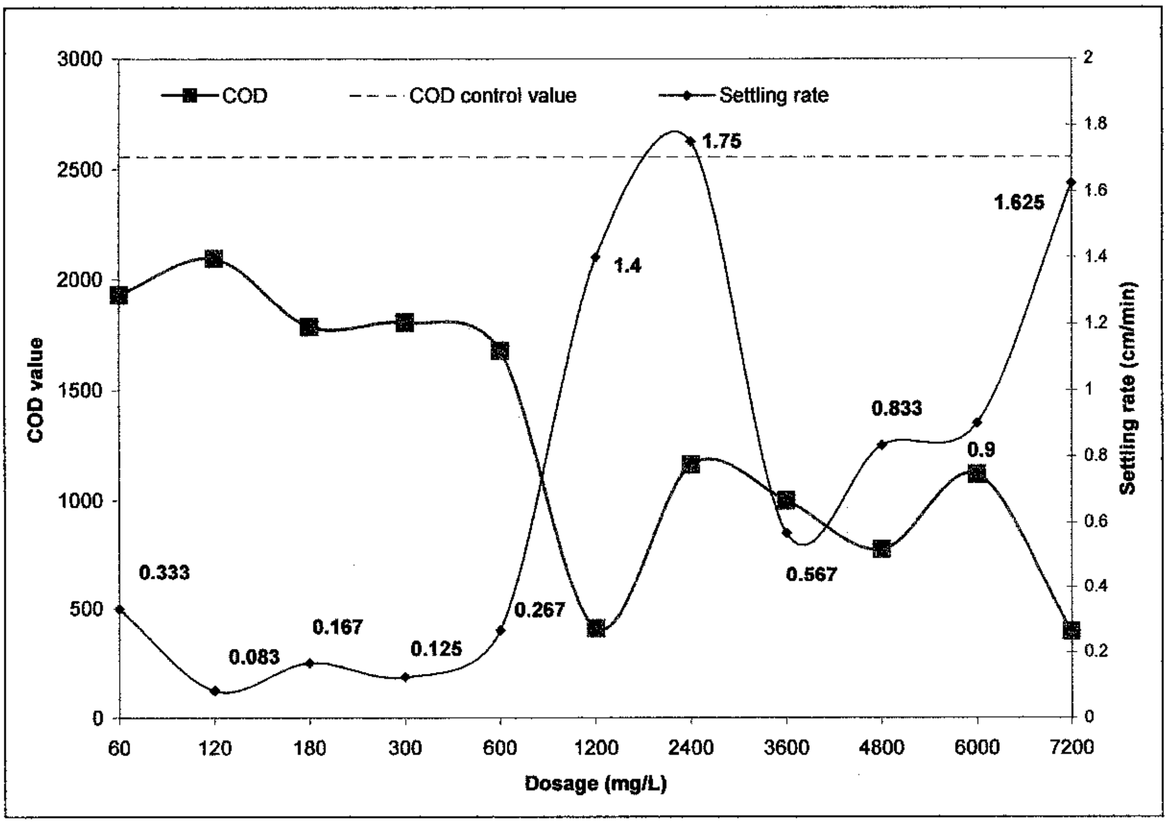

Figure 34: COD values of supernatant with settling rate (modified tannin, second trial)

4.4.9 Comparison of lowest COD value of coagulants

Table 3 is comparing the lowest of COD values achieved of every coagulant. Alum has the lowest value of COD in overall which means it is the best coagulant for COD removal in this comparison. The second best is followed by raw mangrove powder and the limestones powder. However, the raw mangrove powder did not remove the COD but added some COD as dosage was increased. The same thing also observed for limestones powder but dosage of 1000 mg/L has lesser COD value than zero dosage which was the best in its group. In the meanwhile, the alum fluctuated in its COD removal but dosage of 6000 mg/L still has highest COD removal.

Coagulants	Dosage (mg/L)	COD value
Alum	6000	79
Limestones powder	1000	258
Mangrove powder	4000	217

Table 3: Comparison of best COD values for every coagulant

For the second phase of the research, the lowest COD values of every coagulant are described in Table 4. However, these values did not represent the most optimum by both COD removal and settling rate. In terms of COD removal, alum has the best removal at 98.3 percent but the worst in settling rate. Following in second place, the modified tannin (second trial) did remove 84.5 percent with settling rate of 1.625 cm/min which is considered the most optimum in this comparison. The dosage with highest settling rate only removed 37.2 percent of COD. As for other dosages like tannin extract, both first and second trial showed almost same percent of COD removal but the second trial was not better in its settling rate. Somehow, it implied that dosage of coagulant with low settling rate has more COD removal and vice versa. Only modified tannin extract was fairly good with high removal percentage of COD and high settling rate in the second trial. It was inferred that tannin modification could control leaching of COD and function comparatively good as a commercial coagulant did.

Coagulant/Trial		Dosage, mg/L	COD value	Percentage of removal, %	Settling rate, cm/min
Alum		1500	24	98.3	0.19
Tannin	First trial	120	333	76.7	1.29
	Second trial	300	707	72.3	0.25
Modified tannin	First Trial	60	900	37.2	2.766
	Second trial	7200	397	84.5	1.625

Table 4: Comparison of COD values for coagulants (Phase 2)

4.4.10 Turbidity and final sludge volume

Figure 35 showed the turbidity of supernatant after being added with raw mangrove powder as coagulant. The turbidity value decreased with addition of mangrove powder. The best dosage was 4000 mg/L which gave the lowest turbidity value of 54 NTU. Evidently, the use of raw mangrove powder is efficient in removing turbidity. It is expected the extract of tannin will show more promising result compared to the raw mangrove powder.

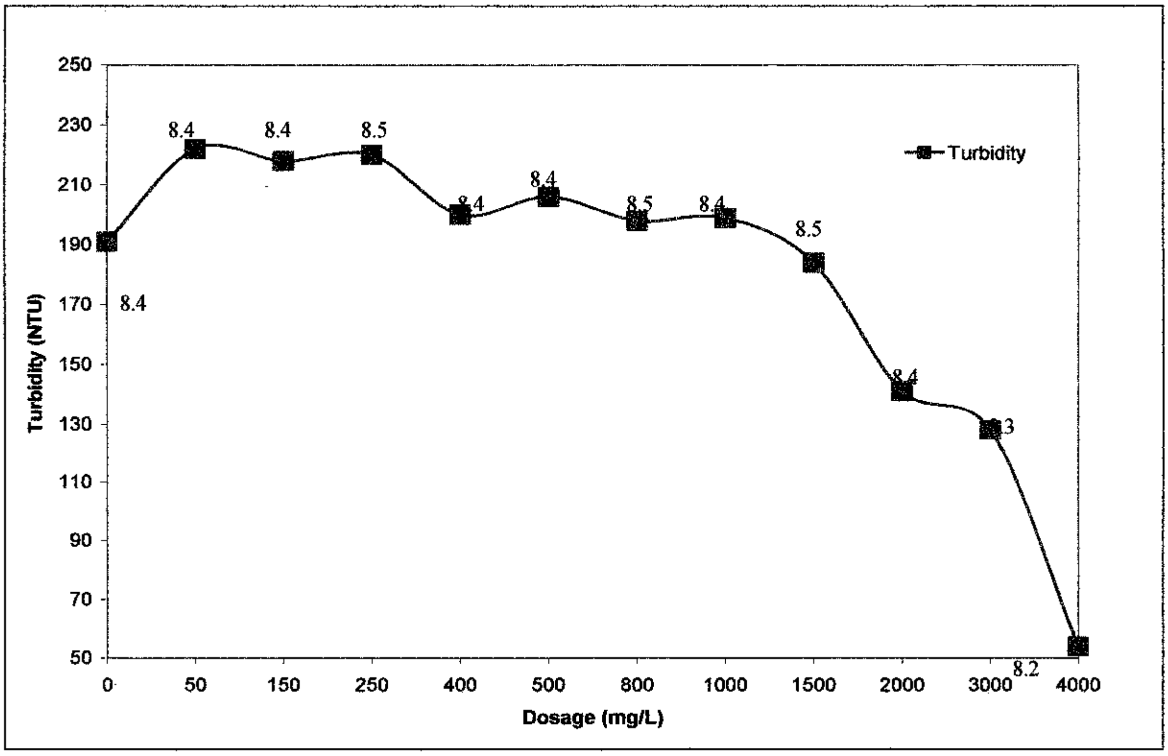

Figure 35: Turbidity and pH of supernatant for mangrove powder

While in Figure 36, it showed the final sludge volume after the settling test for limestones and raw mangrove powder as coagulant. The limestones final sludge volume fluctuated in between 720 to 910 ml. The smallest volume achieved by limestones was at dosage 1000 mg/L with volume of 720 ml. As for raw mangrove powder, the initial dosages varied between 650 to 730 ml and the smallest volume was at dosage of 4000 mg/L with 535 ml. The results reflected dewatering ability of raw mangrove powder when applied to wastewater sludge.

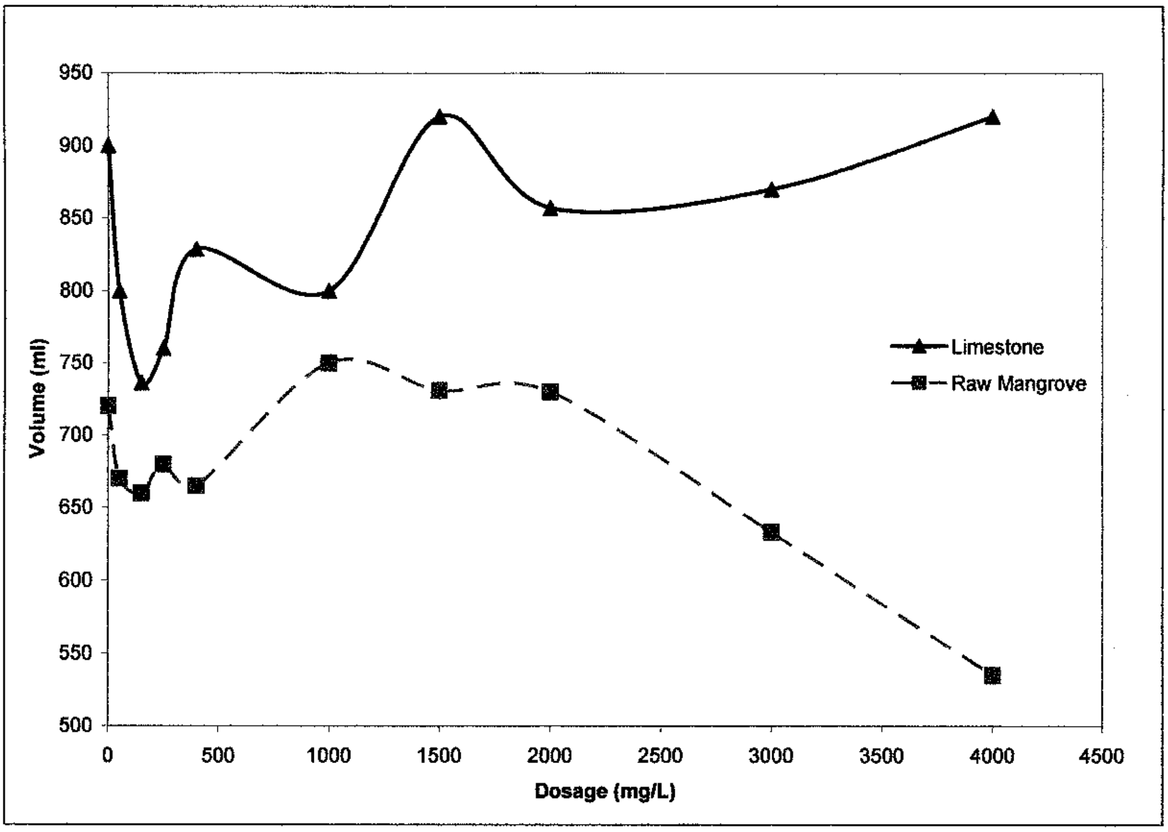

Figure 36: Final Sludge Volume

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This project still has a long way to go with what has been accomplished since early this year. To date, the main task to produce or extract the tannin from the mangrove bark has completed successfully. In the first phase, the settleability tests have produced promising results with the best settling rate of sludge for alum is 0.692 cm/min at dosage of 4500 mg/ L but raw mangrove powder has proved to get the best settling rate at 2.98 cm/min at dosage of 4000 mg/L. As for limestones powder, the best settling rate is only 0.259 cm/min.

Later, in the second phase, for alum, the settling rate for zero dosage was the best at 0.436 cm/min. For tannin extract in the first trial, the best dosage in the test was 2400 mg/L of tannin with 4.833 cm/min. In the second trial of settling test using tannin extract, dosage of 2400 mg/L has the highest settling rate with 3.48 cm/ min and dosage of 180 mg/L has the lowest settling rate of 0.0833 cm/min. For modified tannin extract in first trial, the best dosage was 3600 mg/L with settling rate of 4.32 cm/min while in the second trial the best settling rate was achieved at dosage of 2400 mg/L with settling rate of 1.75 cm/min.

In COD removal, alum (1500 mg/L) has the best percentage removal by 98.3 percent followed by modified tannin at 7200 mg/L dosage with 84.5 percent removal. For tannin, it has achieved 76.7 percent of COD removal at settling rate of 1.29 cm/min.

As for recommendations, the capillary suction tests should be conducted in the upcoming term of this research. By conducting this test, the dewaterability parameter can be determined exclusively and feasibility of tannin as coagulant in sludge thickening can be further explored. In the meantime, the colour and COD leaching problem of tannin extract needed to be tackled in attaining the efficiency in its application. Moreover, the extraction cost also has to be analyzed to produce an economical coagulant with better performance.

CHAPTER 6

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CHAPTER 7

APPENDICES

Appendix A: Phase 1 ....A-1

A.1 Settling test results A-1

A.2 COD, pH and TSS results A-4

Appendix B: Phase 2 ....B-1

B.1 First trial..B-1

B.1.1 Settleability test results...B-1

B.1.2 COD values and settling rate..B-4

B.2 Second Trial..B-5

B.2.1 Settleability test results B-5

B.2.2 COD values and settling rate...B-9

APPENDIX A1: SETTLING TEST RESULTS

Coagulant: Alum — Phase 1

JAR NO. / DOSAGE (mg/L)

1/0		2/300		3/600		4/1500		5/3000		6/4500	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
33.25	0	31.5	0	35	0	35	0	35	0	35	0
31.5	10	28	22	31.5	14	31.5	9	31.5	11	31.5	7
28	20	24.5	38	29.75	25	29.75	21	30.45	16	28	33
26.6	60			28	41	28	44	30.1	18	26.6	60
				27.3	50	27.65	52	29.75	20		
				26.6	60	27.3	58	29.4	22		
								29.05	25		
								28.7	28		
								28.35	30		
								28	34		
								27.65	37		
								27.3	41		
								26.95	46		
								26.6	52		
								26.25	60		

JAR NO. / DOSAGE (mg/L)

7/6000		8/9000		9/12000		10/15000		11/24000		12/30000	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
35	0	31.5	0	42	0	35	0	37.8	0	35	0
31.5	10	28	20	35	11	31.5	16	35	11	33.25	4
31.15	11	26.6	35	31.5	21	28	30	31.5	22	31.5	8
30.8	12	25.9	50	28	33	26.25	52	28	34	29.75	12
30.45	13					25.9	79	25.55	58	28	17
30.1	15									26.25	25
29.75	17										
29.4	19										
29.05	22										
28.7	24										
28.35	27										
28	31										
27.65	38										
27.3	40										
26.95	46										
26.6	48										
26.25	60										

APPENDIX A1: SETTLING TEST RESULTS

Coagulant: Limestones Powder — Phase 1

JAR NO. / DOSAGE (mg/L)

1/0		2/50		3/150		4/250		5/400		6/1000	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
35	0	35	0	35	0	35	0	35	0	35	0
31.5	34	33.25	9	31.5	22	31.5	21	34	12	31.5	14
		31.5	18	29.4	30	28	42	33	18	28	27
		29.75	30	28	44	26.6	60	32	23		
		28	42	25.9	58			31	27		
				25.76	60			30	34		
								29	47		

JAR NO. / DOSAGE (mg/L)

7/1500		8/2000		9/3000		10/4000		11/5000		12/6000	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
35	0	35	0	35	0	35	0	35	0	34.93	0
33.95	28	34	7	33.25	14	33.25	29	33.25	23	33.25	22
33.6	36	33	17	31.5	34	32.9	36	31.5	37	31.5	39
33.25	38	32	24	31.15	41	32.55	44	30.1	60	29.75	63
32.9	39	31	33	30.8	52	32.2	51				
32.55	47	30	48	30.45	57						
32.2	55										

APPENDIX A1: SETTLING TEST RESULTS

Coagulant	Raw Mangrove Powder	Phase 1

JAR NO. / DOSAGE (mg/L)

1/0		2/50		3/150		4/250		5/400		6/500	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
36.505	0	33.95	0	32.9	0	35	0	33.25	0	33.25	0
35	5.47	32.55	5.47	31.85	5.47	33.775	5.98	31.85	6.18	31.85	6.37
33.25	10	31.15	10.07	30.8	10.2	32.2	10.38	30.1	10.52	30.275	10.73
30.8	15.42	28.525	15.65	28.7	15.82	30.275	15.95	28	16.13	28	16.23
29.05	20	26.6	20.18	26.95	20.4	28.35	20.53	26.25	20.7	26.25	20.82
27.65	25	24.85	25.12	24.675	25.38	27.125	25.72	24.5	25.85	24.5	25.98
26.25	30.18	23.8	30.55	23.625	30.77	26.25	30.87	23.275	31.05	23.45	31.17
25.55	35.63	23.45	35.88	22.925	36.08	25.55	36.22	22.4	36.48	22.75	36.77
25.2	40.08	22.75	40.23	22.4	40.33	25.2	40.45	22.05	40.58	22.4	40.73
24.675	45.12	22.4	45.25	22.05	45.45	24.85	45.58	21.525	45.78	22.05	45.97
24.15	50	22.05	50.12	21.7	50.23	24.5	50.33	21.175	50.52	21.7	50.68
23.8	55.15	21.7	55.37	21.35	55.57	24.15	55.75	20.825	55.92	21.35	56.02
23.45	60.05	21.35	60.37	21	60.48	23.8	60.63	20.475	60.82	21	61.13

JAR NO. / DOSAGE (mg/L)

7/800		8/1000		9/1500		10/2000		11/3000		12/4000	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
32.2	0	38.115	0	35.315	0	35	0	35.245	0	27.125	29
31.5	6.5	37.73	6.68	34.3	6.88	34.3	7.12	33.6	7.25	24.15	30
29.925	10.95	35.35	11.3	33.25	11.3	33.425	11.72	32.375	12.08	15.75	32.22
28	16.53	33.6	16.67	31.85	16.82	32.2	16.98	30.625	17.02	13.3	38.15
26.25	21.05	31.675	21.28	30.8	21.45	30.1	21.6	28.35	21.7	12.25	42.12
24.5	26.22	29.75	26.35	29.4	26.48	28.525	26.65	26.425	26.83	11.2	47.08
23.45	31.38	28	31.5	28.35	31.63	27.3	31.8	24.85	31.95	10.85	51.72
22.75	37.03	26.95	37.25	27.65	37.52	26.6	37.78	24.15	37.9	10.15	57.33
22.4	40.92	26.6	41.18	27.3	41.32	25.9	41.58	23.45	41.78	9.8	63.45
21.875	46.18	26.075	46.35	26.775	46.57	25.55	46.73	23.1	46.88		
21.525	50.88	25.55	51.05	26.32	51.25	25.13	51.48	22.75	51.58		
21.175	56.18	25.2	56.32	25.9	56.45	24.605	56.92	22.4	57.05		
21	62.18	24.85	62.82	25.55	62.97	24.325	63.18	22.05	63.28		

APPENDIX A2: COD, pH and TSS RESULTS

Phase 1

Coagulant	Jar No	Dosage	pH	Turbidity (NTU)	Chemical Oxygen Demand (COD) (mg/l)	Weight of Filter Paper Before drying (g)	Weight of Filter Paper After Drying (g)	Total Suspended Solid (TSS) (mg/l)	Settling Rate (cm/min
Alum	1	0	7.586	N/A	264	1.3374	1.3321	5.3	0.175
	2	300	7.496	N/A	180	1.3187	1.3134	5.3	0.157
	3	600	7.396	N/A	179	1.3223	1.3193	3	0.253
	4	1500	6.822	N/A	227	1.2771	1.2736	3.5	0.3888
	5	3000	6.498	N/A	196	1.3361	1.3295	6.6	0.301
	6	4500	6.142	N/A	195	1.278	1.277	1	0.692
	7	6000	5.831	N/A	79	1.30699	1.3069	0.09	0.35
	8	9000	5.316	N/A	158	1.3267	1.3257	1	0.175
	9	12000	5.113	N/A	446	1.2828	1.2818	1	0.66
	10	15000	4.077	N/A	352	1.3225	1.3229	-0.4	0.217
	11	24000	3.729	N/A	610	1.2677	1.2685	-0.8	0.255
	12	30000	3.646	N/A	768	1.2904	1.3016	-11.2	0.301
Limestone	1	0	7.68	N/A	291	1.307	1.3073	0.3	
	2	50	7.704	N/A	327	1.3518	1.513	161.2	0.194
	3	150	7.63	N/A	280	1.2661	1.2664	0.3	0.157
	4	250	7.633	N/A	283	1.3236	1.3242	0.6	0.167
	5	400	7.598	N/A	305	1.4644	1.3226	-141.8	0.086
	6	1000	7.613	N/A	258	1.2785	1.2792	0.7	0.259
	7	1500	7.894	N/A	343	1.3375	1.3376	0.1	0.038
	8	2000	7.952	N/A	544	1.3582	1.3172	-41	0.143
	9	3000	7.955	N/A	488	1.3165	1.3576	41.1	0.125
	10	4000	7.84	N/A	347	1.4212	1.2977	-123.5	0.06
	11	5000	7.898	N/A	304	1.4545	1.4181	-36.4	0.076
	12	6000	7.891	N/A	316	1.2987	1.3035	4.8	0.076
Mangrove Powder	1	0	8.442	191	217	N/A	N/A	N/A	
	2	50	8.42	222	218	N/A	N/A	N/A	0.275
	3	150	8.412	218	218	N/A	N/A	N/A	0.258
	4	250	8.453	220	239	N/A	N/A	N/A	0.192
	5	400	8.454	200	229	N/A	N/A	N/A	0.208
	6	500	8.435	206	224	N/A	N/A	N/A	0.227
	7	800	8.453	198	238	N/A	N/A	N/A	0.22
	8	1000	8.439	199	250	N/A	N/A	N/A	0.108
	9	1500	8.45	184	290	N/A	N/A	N/A	0.058
	10	2000	8.448	141	245	N/A	N/A	N/A	0.148
	11	3000	8.3405	128	259	N/A	N/A	N/A	0.098
	12	4000	8.25	54	266	N/A	N/A	N/A	0.227

APPENDIX B1.1: SETTLING TEST RESULTS

Coagulant Alum **Phase 2**

JAR NO. / DOSAGE (mg/L)

1/0		2/300		3/600		4/900		5/1200		6/1500	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
29	0	29	0	29	0	29	0	29	0	29	0
26.1	7	26.1	7	26.1	8	26.1	8	26.1	14	26.1	15
23.2	12	23.2	12	23.2	15	23.2	16	23.2	25	23.2	26
20.3	24	20.3	21	20.3	26	20.3	26	20.3	40	20.3	39
17.4	66	17.4	43	17.4	48	17.4	44	17.6	45	17.4	44
16.5	71	15.25	48	15.65	53	15.25	49	17.6	50	17.4	49
16.5	76	15.25	53	15.65	58	15.25	54	17.6	55	17.4	54
16.5	81	15.25	58	15.65	63	15.25	59				

JAR NO. / DOSAGE (mg/L)

Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min

APPENDIX B1.1: SETTLING TEST RESULTS

Coagulant: Liquid Tannin — Phase 2

JAR NO. / DOSAGE (mg/L)

1/60		2/120		3/180		4/300		5/600		6/1200	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
29.5	0	29	0	29	0	28	0	28	0	29.2	0
28.8	1	28	2	26.1	1	25.2	2	25.2	1	28.8	1
25.95	3	25.2	3	23.2	2	22.4	4	22.4	2	25.95	2
23.1	5	22.4	5	20.3	3	19.6	6	19.6	3	23.1	4
20.25	7	19.6	8	17.4	5	16.8	10	16.8	4	20.25	6
17.4	12	16.8	14	14.5	8	14	23	14	7	17.4	10
14.55	28	14	41	13.78	16	13.3	31	11.2	14	14.55	23
12.75	38	13.3	59	13.23	21	12.6	36	9.8	23	13.05	38
12.35	50	12.6	73	12.78	26	12.43	41	9.45	28	12.35	47
12.35	60	12.6	93	12.38	31	12.25	46	9.1	33	11.7	65
12.35	69	12.6	108	12.18	38	12.08	51	8.87	38	11.7	70
				11.98	43	11.9	56	8.63	43	11.7	75
				11.88	48	11.9	61	8.4	48	11.7	80
				11.78	53	11.9	66	8.22	53		
				11.68	58			8.05	60		
				11.58	63			8.05	63		
				11.58	68						
				11.58	73						

JAR NO. / DOSAGE (mg/L)

7/1200		8/2400		9/3600		10/4800		11/6000		12/7200	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
29	0	29	0	29	0	29	0	29	0	29	0
26.1	1	26.1	1	26.1	1	26.1	5	26.1	1	26.1	1
23.2	2	23.2	2	23.2	2	23.2	11	23.2	2	23.2	2
20.3	4	20.3	2	20.3	3	20.3	22	20.3	4	20.3	3
17.4	6	17.4	4	17.4	5	17.4	62	17.4	6	17.4	5
14.5	9	14.5	6	14.5	8	17.34	66	14.5	10	14.5	8
11.6	23	11.6	12	11.6	18	17.26	71	11.6	27	11.6	21
10.44	45	10.88	19	10.88	28	17.11	76	10.88	37	10.15	36
10.44	50	10.88	24	10.88	33			10.88	42	10.15	41
10.44	55	10.88	30	10.88	38			10.88	47	10.15	46

APPENDIX B1.1: SETTLING TEST RESULTS

Coagulant: Modified Liquid Tannin — Phase 2

JAR NO. / DOSAGE (mg/L)

1/60		2/120		3/180		4/300		5/600		6/1200	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
35	0	35	0	35	0	35	0	35	0	35	0
31.5	1	31.5	1	31.5	1	31.5	1	31.5	3	31.5	2
28	3	28	3	28	3	28	3	28	4	28	2
24.5	5	24.5	6	24.5	5	24.5	5	24.5	7	24.5	3
21	7	21	11	21	8	21	8	21	11	21	3
17.5	12	17.5	28	17.5	15	17.5	13	17.5	24	20.65	4
16.4	28	15	33	14.7	30	14.35	32	16.98	29	20.41	15
16	33	15	38	14.35	35	11.2	35	16.45	34	19.64	30
15.24	38	15	43	14	40	8.05	40	16.03	39	19.25	35
14.84	43			13.65	45	6.48	45	15.68	44	19.18	40
14.44	48			13.3	50	6.48	50	15.12	49	18.9	55
14.44	48			13.13	55	6.48	55	14.7	54	18.62	60
14.44	48			12.95	60			14.7	59	18.55	65
				12.95	65			14.7	64	18.55	70
				12.95	70						

JAR NO. / DOSAGE (mg/L)

7/1200		8/2400		9/3600		10/4800		11/6000		12/7200	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
28.8	0	28.8	0	28.8	0	28.8	0	28.8	0	28.8	0
25.92	1	25.92	2	25.92	1	25.92	1	25.92	3	25.92	2
23.04	4	23.04	3	23.04	1	23.04	3	23.04	6	23.04	2
20.16	6	20.16	4	20.16	2	20.16	4	20.16	8	20.16	4
17.28	10	17.28	5	17.28	3	17.28	7	17.28	15	17.28	5
14.4	21	14.4	8	14.4	5	14.4	11	14.69	30	14.4	6
11.52	26	11.52	18	11.52	10	11.52	29	14.69	35	11.52	35
10.8	31	11.23	23	8.64	15	11.52	34	14.69	40	9.5	40
10.8	36	11.23	28	8.64	20	11.52	39			9.5	45

APPENDIX B1.2: COD, pH and TSS RESULTS — Phase 2

Coagulants	Dosage / mg/L	COD Value	Percentage Removal, %	Settling rate, cm/min
Alum	0	1433	0	0.43
	300	867	-40	0.398
	600	56	-96	0.343
	900	36	-97	0.346
	1200	48	-97	0.212
	1500	24	-98	0.19
Tannin	60	1633	14	1.33
	120	333	-77	1.27
	180	967	-33	3.17
	300	800	-44	1.4
	600	633	-56	2.9
	1200	3100	116	2.99
	2400	1733	21	4.83
	3600	1033	-28	3.7
	4800	1000	-30	0.529
	6000	2200	53	2.17
	7200	2567	79	2.95
Modified Tannin	60	900	-37	2.766
	120	1627	13	2.102
	180	2033	42	2.108
	300	2200	53	2.55
	600	1467	2	1.65
	1200	1000	-30	3.33
	2400	1033	-28	1.75
	3600	1500	5	4.32
	4800	2167	51	2.17
	6000	2000	40	0.982
	7200	1633	14	1.71

Note: In percentage removal, positive sign means addition and negative sign means removal

JAR NO. / DOSAGE (mg/L)

1/60		2/120		3/180		4/300		5/600		6/1200	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
35	0	37	0	35.5	0	35	0	36.2	0	36.5	0
34	4	36.2	4	35.5	4	34	4	34.6	4	35.5	4
33	6	35.5	6	35	6	33.3	6	33.6	6	34.7	6
32.2	8	34.4	8	34.5	8	32.5	8	32.4	8	33.9	8
31.5	10	33.4	10	33.5	10	31.9	10	31.2	10	33	10
30.8	12	32.4	12	32.5	12	30.9	12	29.7	12	31.9	12
30.2	14	31.5	14	31.5	14	29.8	14	28.7	14	31.2	14
29.8	16	30.7	16	30.5	16	29.1	16	27.4	16	30.3	16
29.6	18	29.9	18	30	18	28.6	18	26.4	18	29.7	18
29.2	20	29.45	20	29.5	20	28.1	20	25.9	20	29.1	20
28.8	22	28.9	22	29	22	27.7	22	25.5	22	28.7	22
28.6	24	28.7	24	28.5	24	27	24	25.3	24	28.3	24
28	26	28	26	27.9	26	26.8	26	25.1	26	28	26
27.6	28	27.7	28	27.4	28	26.7	28	24.7	28	28	28
27.2	30	27.5	30	27.3	30	26.7	30	24.3	30	27.5	30
27.2	32	27.1	32	27	32	26	32	23.9	32	27.4	32
27.2	34	26.9	34	26.7	34	26	34	23.5	34	27.2	34
				26.6	35	26	35	23.2	35	27	35
				26.6	36			23.2	36	27	36
				26.6	37			23.2	37	27	37

JAR NO. / DOSAGE (mg/L)

7/1200											
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
0	29.5										
1	28.8										
2	27.26										
3	25.72										
4	24.32										
5	23.2										
6	22.08										
7	21.1										
8	20.4										
9	19.7										
10	19.28										
11	18.86										
12	18.44										
13	18.3										
15	17.6										
17	17.18										
19	16.9										
21	16.48										
24	16.2										
27	15.864										
30	15.5										
35	15.22										
40	14.8										
45	14.66										
50	14.38										
55	14.1										
60	14.1										

APPENDIX B2.1: SETTLING TEST RESULTS

Coagulant	Liquid Tannin (cont.)	Phase 2

JAR NO. / DOSAGE (mg/L)

8/2400		8/2400 (cont.)		9/3600		10/4800		11/6000		12/7200	
ht/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
29	0.25	11.51	14.25	29.9	0	29.5	0	29.5	0	29	0
6.1	0.5	11.5	14.5	29.4	1	26.25	1	28.9	1	28.3	1
.81	0.75	11.48	14.75	26.4	2	26	2	27.6	2	26.8	2
.94	1	11.47	15	23.9	3	25.4	3	26.5	3	25.2	3
.07	1.25	11.46	15.25	22.9	4	24.7	4	25.5	4	23.8	4
3.2	1.5	11.43	15.5	21.8	5	23.7	5	24.5	5	22.5	5
.91	1.75	11.4	15.75	20.6	6	23.1	6	23.5	6	21.3	6
.04	2	11.37	16	19.7	7	22.3	7	22.5	7	20.3	7
.17	2.25	11.34	16.25	18.7	8	21.6	8	21.8	8	19.5	8
.88	2.5	11.31	16.5	17.9	9	20.8	9	21	9	18.9	9
.01	2.75	11.31	16.75	17.6	10	20.1	10	20.5	10	18.5	10
.43	3	11.31	17	16.4	11	19.5	11	19.9	11	18.2	11
.14	3.25	11.17	17.25	15	12	18.8	12	19.5	12	17.8	12
.27	3.5	11.11	19.25	14.4	13	18.4	14	19.2	13	17.6	13
.84	3.75	11.02	20.25	14.1	14	18.1	15	18.9	14	17.3	14
7.4	4	11.02	21.25	13.8	15	17.9	16	18.6	15	17	15
.26	4.25	10.88	22.25	13.5	16	17.8	17	18.2	16	16.9	16
.11	4.5	10.82	23.25	13.3	17	17.5	18	18	17	16.7	17
.68	4.75	10.73	24.25	13.1	18	17.4	19	17.9	18	16.5	18
.24	5	10.67	25.25	12.9	19	17.1	20	17.7	19	16.4	19
.81	5.25	10.5	26.25	12.7	20	17	21	17.5	20	16.3	20
.37	5.5	10.44	27.25	12.4	21	16.9	22	17.4	21	16.1	21
.31	5.75	10.38	28.25	12.3	23	16.8	23	17.2	22	15.9	22
.23	6	10.38	29.25	12.1	24	16.5	24	17	23	15.7	23
.65	6.25	10.3	30.25	12	25	16.3	26	16.9	24	15.6	25
4.5	6.5	10	31.25	11.9	26	16.1	28	16.8	25	15.4	26
.44	6.75	10	32.25	11.8	27	15.9	30	16.7	26	15.3	27
.36	7	9.95	33.25	11.7	28	15.7	32	16.5	27	15.1	28
4.3	7.25	9.72	34.25	11.6	29	15.5	35	16.4	28	14.9	30
.21	7.5	9.57	35.25	11.5	30	15.3	37	16.3	29	14.8	31
3.8	7.75	9.57	36.25	11.4	31	15.2	39	16.1	30	14.7	33
.76	8	9.51	37.25	11.3	32	15.1	40	15.8	35	14.5	35
.49	8.25	9.51	38.25	11.2	33	14.9	44	15.6	40	14.4	37
.43	8.5	9.43	39.25	11.1	34	14.8	47	15.2	45	14.3	38
3.4	8.75	9.43	40.25	11	36	14.6	51	15	50	14.2	39
.34	9	9.28	41.25	10.8	37	14.4	53	14.8	55	14.1	41
.31	9.25	9.22	42.25	10.7	40	14.3	55	14.6	60	14	43
3.2	9.5	9.22	43.25	10.6	42	14.2	56	14.2	65	13.9	44
.05	9.75	9.22	44.25	10.5	44	14.1	60	14.1	70	13.8	47
.76	10	9.22	45.25	10.4	46	14	64	13.9	75	13.7	48
2.7	10.25	9.14	46.25	10.3	48	13.9	65	13.7	80	13.6	50
.56	10.5	8.99	47.25	10.2	49	13.9	69			13.5	51
.47	10.75	8.93	48.25	10.1	51					13.4	54
.44	11	8.76	49.25	10	54					13.3	55
.33	11.25	8.76	50.25	9.9	55					13.3	59
.18	11.5	8.7	51.25	9.8	59						
.12	11.75	8.7	52.25	9.7	60						
.04	12	8.7	53.25	9.6	65						
.98	12.25	8.7	54.25	9.5	68						
.89	12.5	8.64	55.25	9.4	70						
.83	12.75	8.64	56.25	9.3	80						
.75	13	8.61	57.25	9.2	84						
.67	13.25	8.58	58.25	9.1	88						
1.6	13.5	8.58	59.25	9	93						
.54	13.75	8.58	60.25	8.9	95						
.53	14	8.58	61.25	8.8	100						
				8.7	107						
				8.6	111						
				8.5	114						
				8.5	123						

APPENDIX B2.1: SETTLING TEST RESULTS

Coagulant Modified Liquid Tannin **Phase 2**

JAR NO. / DOSAGE (mg/L)									
1/60		2/120		3/150		4/300		5/720	
ght/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
29.5	0	29.5	0	29.5	0	29.5	0	29.5	0
28.5	3	29.3	2	29.2	3	29.2	1	28.8	3
27.5	6	29.25	4	28.5	6	29.2	2	27.9	6
26.5	9	29	6	27.5	9	29.1	3	26.5	9
24.5	12	28.6	8	26.5	12	29	4	25	12
23.5	15	28.1	10	25.5	15	28.5	5	22.5	15
23	16	27.7	12	25	16	28.2	6	22.4	18
22.5	17	27.3	14	24.8	17	27.8	7	22.3	21
22.1	18	27	16	24.8	18	27.5	8	22.2	24
21.9	19	26.5	18	24.5	19	27.1	9	22.2	27
21.5	20	26.4	20	24.3	20	26.8	10	22.2	30
21.3	21	26.2	22	24.1	21	26.3	11		
21.2	22	26	24	23.8	22	26	12		
20.8	23	25.7	26	23.7	23	25.7	13		
20.8	24	25.5	28	23.5	24	25.4	14		
20.3	25	25.5	30	23.3	25	25.1	15		
20	26	25.5	32	23	26	24.9	16		
20	27	25.5	34	22.9	27	24.6	17		
19.5	28			22.9	28	24.2	18		
19.5	29			22.9	29	24.1	19		
19.5	30			22.9	30	23.9	20		
						23.8	21		
						23.7	22		
						23.6	23		
						23.5	24		
						23.4	25		
						23.2	26		
						23	27		
						22.9	28		
						22.8	29		
						22.7	30		
						22.6	31		
						22.5	32		
						22.4	33		
						22.3	34		
						22.3	35		
						22.2	36		
						22.1	37		
						22	38		
						22	39		
						21.9	40		
						21.8	41		
						21.7	42		
						21.7	43		
						21.6	44		
						21.5	45		
						21.5	46		
						21.5	47		
						21.4	48		
						21.4	49		
						21.4	50		
						21.2	51		
						21.2	52		
						21.2	53		
						21.2	54		
						21.2	55		
						21	56		

APPENDIX B2.1: SETTLING TEST RESULTS

Coagulant Modified Liquid Tannin (cont.) **Phase 2**

JAR NO. / DOSAGE (mg/L)

6/1200		7/2400		8/3600		9/4800		10/6000		11/7200	
Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min	Height/cm	Time taken /min
35	0	35	0	35	0	35	0	35	0	35	0
33.5	1	33	1	34.5	1	33.7	1	34.1	1	32.5	1
32.5	2	31.5	2	34	2	33.3	2	33	2	31	2
30.8	3	30.3	3	33.3	3	32.5	3	32.4	3	30	3
29.5	4	28.7	4	32.5	4	31.5	4	31.4	4	28.5	4
28.2	5	27.2	5	31.4	5	30.5	5	30.3	5	27	5
26.8	6	25.8	6	30.4	6	29.5	6	29.3	6	25.6	6
25.3	7	24.6	7	29.5	7	28.6	7	28.2	7	25	7
24.3	8	23.5	8	28.5	8	27.5	8	27.2	8	23	8
23.5	8.5	22.8	8.5	28.1	8.5	27.4	8.5	26.7	8.5	22.6	8.5
23.1	9	22.3	9	27.7	9	27	9	26.2	9	22	9
22.7	9.5	22	9.5	27.2	9.5	26.5	9.5	25.7	9.5	21.5	9.5
22.1	10	21.6	10	26.9	10	26	10	25.3	10	21.1	10
21.7	10.5	21.2	10.5	26.6	10.5	25.7	10.5	24.9	10.5	20.9	10.5
21.5	11	20.8	11	26.2	11	25.3	11	24.5	11	20.5	11
21	11.5	20.5	11.5	25.8	11.5	24.2	11.5	24.2	11.5	20.3	11.5
20.8	12	20.2	12	25.5	12	24	12	23.9	12	19.8	12
20.3	13	19.8	13	24.7	13	23.8	13	23.2	13	19.3	13
20	13.5	19.7	13.5	24.5	13.5	23.6	13.5	22.8	13.5	19.3	13.5
19.7	14	19.4	14	24.3	14	23.2	14	22.7	14	19.2	14
19.6	14.5	19.2	14.5	24.1	14.5	23	14.5	22.5	14.5	18.9	14.5
19.4	15	19	15	23.4	15	22.9	15	22.3	15	18.8	15
19.2	15.5	18.7	15.5	23.5	15.5	22.8	15.5	22	15.5	18.5	15.5
18.7	17	18.5	17	23.2	17	22.3	17	21.7	17	18.2	17
18.4	19	18	19	22.5	19	21.5	19	21	19	17.5	19
17.8	21	17.4	21	22	21	21.2	21	20.7	21	17.2	21
17.1	25	17	25	21.3	25	20.3	25	19.8	25	16.4	25
16.4	30	16.3	30	20.6	30	19.5	30	19.1	30	15.7	30
15.5	40	15.5	40	19.5	40	18.3	40	18	40	14.7	40
15.4	42	15.2	42	19.3	42	18.2	42	17.9	42	14.6	42
15.2	44	15	44	18.9	44	18	44	17.7	44	14.3	44
14.9	46	15	46	18.8	46	17.9	46	17.6	46	14.3	46

APPENDIX B2.2: COD, pH and TSS RESULTS — Phase 2

Coagulant	Dosage, mg/L	COD value	Percentage removal, %	Settling rate, cm/min
Tannin	60	843	-66.97	0.25
	120	813	-68.14	0.2
	180	1193	-53.26	0.0833
	300	707	-72.32	0.25
	600	1547	-39.42	0.25
	1200	753	-70.49	1.12
	2400	1597	-37.46	3.48
	3600	2043	-19.96	1.75
	4800	1670	-34.59	1.37
	6000	1587	-37.85	0.8
	7200	1587	-37.85	1.27
Modified Tannin	60	1930	-24.4	0.333
	120	2095	-17.93	0.083
	180	1787	-30.02	0.167
	300	1807	-29.23	0.125
	600	1677	-34.33	0.267
	1200	410	-83.94	1.4
	2400	1160	-54.56	1.75
	3600	997	-60.96	0.567
	4800	777	-69.58	0.833
	6000	1117	-56.26	0.9
	7200	397	-84.46	1.625

Note: In percentage removal, positive sign means addition and negative sign means removal