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KING SAUD UNIVERSITY
COLLEGE OF ENGINEERING
CHEMICAL ENGINEERING DEPARTMENT

Performance Optimization of Coagulation/Flocculation in the Treatment of Wastewater From Polyvinyl Chloride Plant

Submitted by
Eng. Khalid Abdullah Alrumaihi

Supervised by
Prof. Dr. Abdelhamid Ajbar

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TABLE OF CONTENTS

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Firstly, I thank ALLAH for his guidance.

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ABSTRACT

The emulsion polymerization of vinyl chloride generates contaminated waste water. Before the wastewater can be returned to the sea or reused, the contaminates must be removed. The EPVC (Emulsion Poly Vinyl Chloride) particles are removed from wastewater by a treatment plant. The objective of this work is to study the coagulation and flocculation of EPVC contaminated water in order to optimize the treatment process. The experiments were carried out on a model wastewater which is chemically identical to actual plant wastewater but is more consistent. Inorganic ions and water soluble polyelectrolytes were added to the wastewater. Coagulation/flocculation efficiency was determined by measuring supernatant turbidity and by measuring the relative settlement of the flocs in the Jar Test.

The experimental results showed that aluminum sulphate (0.5% $Al_2(SO_4)_3$) combined with polyelectrolyte (PE1) at pH in the range of 7 to 8, and agitation speed of 600 rpm give the best results. Ferric chloride (2.5% $FeCl_3$) combined with polyelectrolyte (PE3) is slightly less effective. As for calcium chloride (2.5% $CaCl_2$) combined with PE3 it is the least effective since 0.7 gm of the coagulant (=19 times that of Al^{3+} ions) are needed to obtain the same coagulation as aluminum sulphate.

Chapter I:

Introduction

New environment laws made by the Kingdom authorities have encouraged the process industry to seriously reconsider their discharge policies and to introduce wastewater treatment measures before discharging to the environment. The polyvinyl chloride (PVC) industry is one of the important industries in the kingdom. SABIC at Petrokemya facility at Jubail produces around 350 ktons per year. The emulsion polymerization process that produces PVC, also generates large quantities of wastewater. The wastewater produced in the plant contains suspended solids of PVC called latex particles. Petrokemya plant has set up a wastewater treatment facility for the removal of these latex particles from water. In addition to the harmful effect of these chlorine based particles, there is an economic incentive to collect these solid particles, since they can be sold in the market. In a typical PVC plant the wastewater comes from a number of sources such as waste water stripper, plant washing and from the latex blend tanks. The collected wastewater is then pumped into the clarifier This is the most important unit in the treatment facility. Here a number of chemicals are added to the tank to allow flocculation/coagulation of the solid particles. The added chemicals are sodium hydroxide to control the pH, commercial coagulants and anionic and/or cationic based polyelectrolytes. When the flocculation/coagulation process is successful a solid coagulum forms and settles to the bottom of the clarifier and a clear supernatant water is sent to drain after checking its turbidity and pH. The concentrated slurry is then pumped to the concentrator tank and then to a moving belt for dewatering, drying and disposal. When the process is not successful, PVC solids escape into the waste water causing sometimes an overflow of solid particles and a deterioration of the performance of the wastewater treatment process.

The overall objective of the research is to optimize the performance of the clarifier in the wastewater treatment facility for the latex particles coming from the PVC production plant. The following specific objectives are sought:

- Study of the effect of the selected aluminum sulfate and alternative coagulants on the flocculation process.
- Study of the effect of selected commercial polyelectrolytes on the performance of the clarifier.
- Study of the effect of pH on flocculation.
- Study the effects of over-agitation and under-agitation on clarification.
- Determination of optimum sequence of application of the relevant chemical additives.

The research methodology uses to achieve the cited objectives consists in carrying out experimental bench scale tests using latex feed from real plant. The traditional bench scale test (*jar test*) is the fastest and most affordable way to obtain reliable data on variables that affect the treatment process and design parameters. The performance of the coagulation/flocculation process was determined by measuring the turbidity of the supernatant and the sedimentation height.

I.1 Particle Sedimentation

Small finely dispersed particles in water are prevented from settling because the gravitational forces causing them to settle are less than the kinetic/thermal energy (Brownian motion) or flow of the water molecules. Brownian motion causes the dispersed particles to continually move and collide with their neighbors. In designing settling devices for these small particles, one is interested in predicting their settling velocities. The settling velocity of a spherical impermeable aggregate is calculated from a force balance. There are three forces, gravity (F_g), buoyant (F_b), and drag (F_d), acting upon an aggregate, which balance according to

$$F_g - F_b = F_d \tag{1}$$

Where $F_g = \rho_a V_a g$, where ρ_a is the aggregate density, g is the gravitational constant, V_a is the volume of aggregate, and $F_b = \rho_l V_a g$, where ρ_l is the suspending liquid density. The sum of the gravity and buoyant forces can be replaced in this relationship as

$$V_a(\rho_a - \rho_l)g = F_d \qquad (2)$$

If all impermeable particles composing the aggregate have the same density ρ_p, the density difference in Eq 2 can be equivalently written using the identities

$$(\rho_a - \rho_l) = (1 - \varepsilon)(\rho_p - \rho_l) = (1 - \varepsilon)\,\Delta\rho \qquad (3)$$

where ε is the aggregate porosity and $\Delta\rho$ is the difference between the particle and fluid densities. It is known [2] that the drag force exerted on an object can be expressed as a function of the fluid density and the object's velocity (U), projected area (A) and an empirical drag coefficient (C_d). Using the following expression [2] $F_d = \rho U^2 A C_d/2$, equation 2 can be therefore written as

$$V_a(1 - \varepsilon)\Delta\rho g = \rho_l U^2 A C_d / 2 \tag{4}$$

At this point in the derivation we must use geometrical relationships to simplify Eq 4. For spheres, we have:

$$V_a = \pi / 6\, d^3 \tag{5}$$

$$A = \pi / 4\, d^2 \tag{6}$$

$$C_d = 24 / Re \quad (Re \leq 1) \tag{7}$$

where the Reynolds number $Re = Ud/\nu$, d is the aggregate diameter, and ν is the fluid kinematic viscosity. Combining Eqs 4-7, produces Stokes' law:

$$U = g\Delta\rho\,(1 - \varepsilon)\, d^2 / (18\,\nu\rho_l) \tag{8}$$

For an aggregate made up of N particles, each of mass m_o and volume v_o, the porosity can be derived in terms of

$$(1 - \varepsilon) = N\, v_o / V_a \tag{9}$$

where the percent solids in an aggregate is calculated as $100(1-\varepsilon)$. Substituting Eq. 9 into Eq. 8 and assuming aggregate volume as defined in Eq. 5 produces

$$U = g\Delta\rho N v_0 / (3\pi \rho_l\, d) \qquad (10)$$

For Reynolds number larger than 1, Jiang and Logan [3] proposed to use the following empirical drag correlation [4] with the power law relationship

$$C_d = a\, Re^b \qquad (11)$$

where for $Re < 1$, $a = 24$ and $b = 1$ and for $0.1 < Re < 10$, $a = 29.03$ and $b = 0.871$.

For homogeneous permeable spherical aggregates, the flow through the interior of an aggregate can increase the settling velocity of an aggregate compared to otherwise identical but impermeable particles. The settling velocity of a permeable aggregate was presented by Masumoto and Suganuma [5] as

$$U_{perm} = U\,[\zeta/(\zeta - \tanh(\zeta)) + 3\, 2/\zeta^2] \qquad (12)$$

where the dimensionless variable $\zeta = d/(2\kappa^{1/2})$ relates aggregate size to permeability of the porous media. The Davies correlation [6] provides an estimate of the aggregate permeability κ

$$1/\kappa = (16/a_c^2)(1-\rho)1.5\,[1+56(1-\rho)^3] \qquad (13)$$

where a_c is the radius of a long filament assumed to form the aggregate.

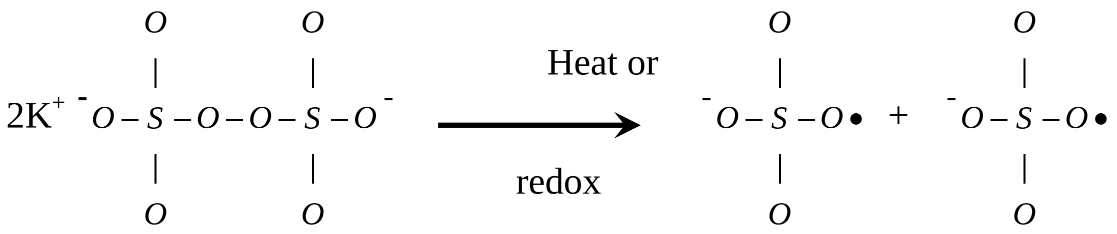
Other authors [3,7-8] predicted that the settling velocities of the aggregates were on average 4-8.3 times higher than those predicted using either an impermeable sphere model (Stokes' law) or a permeable sphere model. The main reason for deviations in experimental observations is thought to be a result of nonlinear relationships between aggregate size and porosity.

I.2 Coagulation and Flocculation

I.2.1 Structure of EPVC in Water

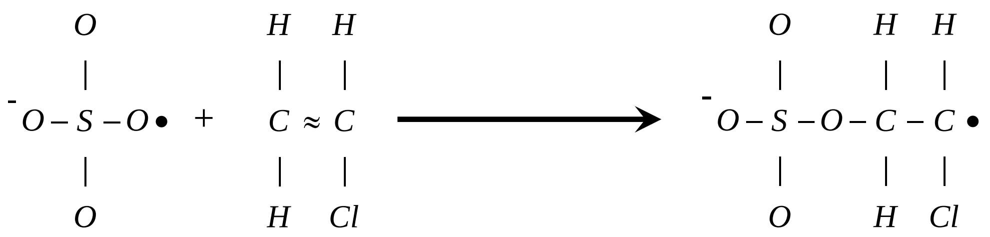
Emulsion PVC is made by the radical polymerization of vinyl chloride (VCM) using water soluble initiator (potassium persulphate) in the presence of surfactant (sodium lauryl sulphate (SLS)). The mechanisms of polymerization are described in the following [1]:

- Initiation: The potassium persulphate decomposes under heat or redox to give persulphate radicals.

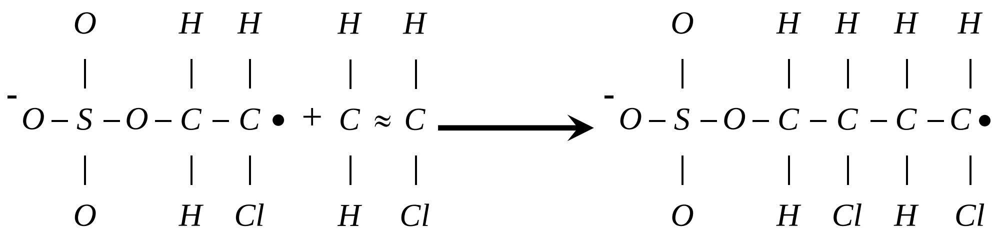


Potassium persulphate persulphate radicals

- Polymerization (propagation): free radicals react with VCM to produce Vinyl chloride radical and start propagation reaction.



Vinyl chloride Vinyl chloride radical



Vinyl chloride radical Vinyl chloride radical oligomer

- Termination: The termination of polymerization reaction may occur by:

    1- Combination
    2- Disproportionation
    3- Chain transfer (very important for VCM polymerization)

PVC is insoluble in water, so the PVC forms into spherical particles which are stabilize by surfactant (SLS). Thus the micron size EPVC particles are stabilized by negatively charged sulphate groups from initiator and from the surfactant, as show in Fig. I.1

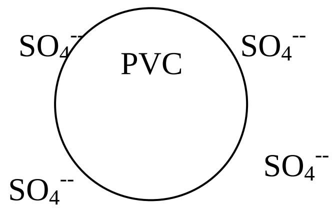


Fig. I.1 : PVC stabilized by negative Sodium Lauryl Sulphate.

- Coagulation of latex particles: The PVC latex particles are already stabilized by the negative charges of the sulfate groups. In order to coagulate these particles, the negative charge need to be neutralized. This can be done by adding metals ions (Aluminum sulphate, ferric chloride or calcium chloride)[9].

In wastewater treatment operations [10-16], the processes of coagulation and flocculation are employed to separate suspended solids from water. Although the terms coagulation and flocculation are often used interchangeably, or the single term "flocculation" is used to describe both; they are, in fact, two distinct processes.

Small particles remain dispersed because the repulsive energy between the particles exceeds the forces of attraction (Van der Waals Forces) pulling them together (Fig. I.2). Most particles dispersed in water are repelled because of the negative (anionic) charge on their surface. But repulsion between particles can also be caused by positive (cationic) surface charges or by absorbed polymer molecules (steric stabilisation) [17]. To get these suspended particles to settle, they need to be coagulated and/or flocculated into larger lumps (> 100 μm), so that gravitational forces exceed Brownian motion and they sink. Coagulation is the destabilization of colloids by neutralizing the forces that keep them apart [18]. Cationic coagulants provide positive electric charges to reduce the negative charge (zeta potential) of the colloid particles (Fig. I.3). As a result, the particles stick together to form larger particles (flocculation). Rapid mixing is required to disperse the coagulant throughout the liquid. Care must be taken not to overdose the coagulants as this can cause a complete charge reversal and restabilize the colloid complex.

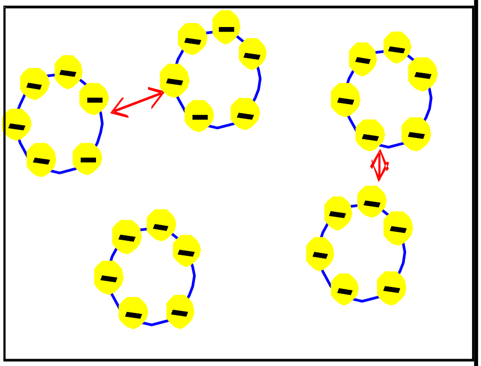


Fig. I.2 Stable negatively charge EPVC Latex Particles

Water is white [19]

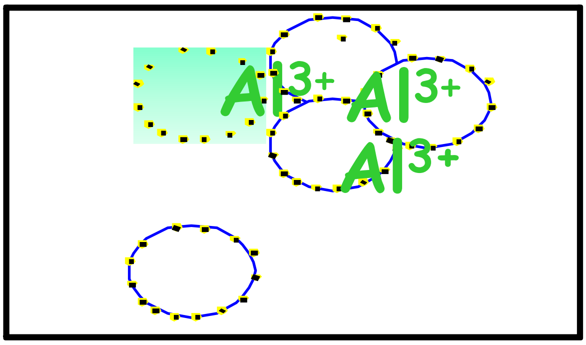


Fig. I.3 Coagulation

Adding **Al** $^{3+}$: Most latex Particles aggregate.

Water becomes cloudy [19]

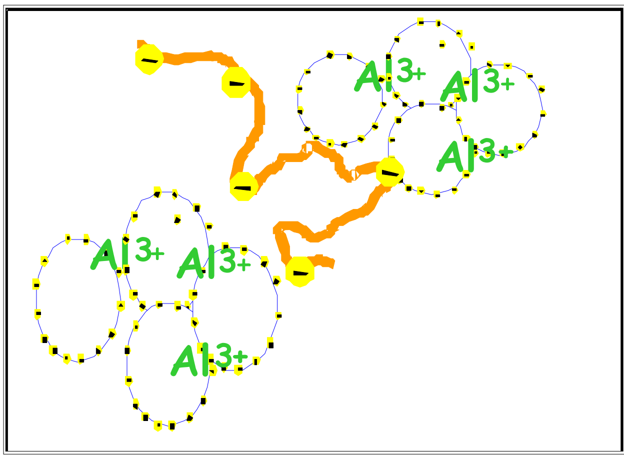


Fig.I.4 Flocculation

Adding Polyelectrolyte flocculates remaining particles and increases floc. size. Faster sedimentation

Water becomes Clear [19]

Flocculation is the action of polymers to form bridges between the coagulum and bind the particles into larger agglomerates or clumps. Bridging occurs when segments of the polymer chain adsorb on different particles, binding the particles together. An anionic flocculant will flocculate a positively charged suspension, adsorbing on the particles and causing destabilization either by bridging or charge neutralization (Fig. I.4). In this process it is essential that the flocculating agent be added by slow and gentle mixing to allow for contact between the small aggregates to form larger particles. The newly formed agglomerated particles are quite fragile and can be broken apart by shear forces during mixing. Care must also be taken to not overdose the polymer which can stabilize the particle and so will cause settling/clarification problems.

Sometimes air is trapped inside the aggregates and they float instead of settling and form a "SCUM". Once suspended particles are flocculated into larger particles, they can usually be removed from the liquid by sedimentation.

Typical coagulants are $Al_2(SO_4)_3$,$12H_2O$ and lime. The positive Al^{3+} and Ca^{2+} ions neutralize the negative charges on the particles surface, causing them to aggregate and settle. They can also change the pH of water. Polyelectrolytes are water soluble charged polymers used to flocculate the particle and separate the solids phase from water [20-23]. They are produced by copolymerisation of polyacrylamide with other monomers. The comonomers making the polyelectrolyte are:

- Cationic containing positive charges.
- Anionic containing negative charges.
- Non ionic polymer have "No Charge”

Other salts such as iron sulfates $Fe_2\ (SO_4)_3$, $FeSO_{4,}$ $Ca2^+$, Mg^{2+} salt and some special polymers are also useful. Ions such as sodium, chloride, magnesium, and potassium also affect coagulation process, but at higher concentrations, temperature and pH also affect coagulation.

Coagulation of wastewater may be accomplished with any of the common water coagulants including iron and aluminum salts, and synthetic polymers. The choice is based on suitability for a particular waste, availability and cost of the coagulant, and sludge treatment and disposal considerations.

The rate of flocculation is determined by the collision frequency induced by the relative motion. With small particles ($\leq$ 1µm) this is caused by Brownian movement, it is called perikinetic flocculation. That which is caused by velocity gradients is called orthokinetic flocculation and tends of effect larger ($\geq$ 5 µm particles). If there is no surface repulsion between the particles, then every collision leads to aggregation and the process is called rapid flocculation. If a significant repulsion exists, then only a fraction of the collisions results in aggregation. This is called slow flocculation [21].

If particles are settling at different velocities, then the faster settling particles may collide with slower settling particles, leading to aggregation. The aggregates will then settle faster due to their increased mass.

I.3 Clarification

Clarification is the process of separating solids from the liquid stream. In wastewater treatment the terms clarifier and sedimentation tank are synonymous (Fig. I.5). The purpose of the scraper mechanism mounted inside the tank, is to collect the settled solids for removal from the tank by pumping.

Fig. I.5 Photograph and Diagram of a Typical Settling Tank

Circular settling tanks and clarifiers are generally preferred, as they require less maintenance, sludge removal is faster and higher removal efficiencies can be obtained. Rectangular tanks are predominantly used in very large treatment plants or in confined spaces, making maximum use of the area available.

The residence time of the waste water in the tank and the depth of the tank must be carefully designed. The flocculated particles must have sufficient time to settle to the bottom of the tank. Otherwise the overflowing supernatant will be cloudy or the sediment sludge will be too dilute. Basically, anything that floats is removed and called scum. Anything that sinks is removed and called sludge. There are four zones to a sedimentation basin, Inlet Zone, Settling Zone, Sludge Zone, and the Outlet Zone. Regardless of its shape, the tank is designed with an inlet zone for gentle entry and distribution of treatment process water. The water flows into the settling (sedimentation) zone to settle for between 1 to 3 hours. The water is clarified as it passes through the tank. The sludge (solids) zone for sludge (solids) collection and concentration is at the bottom of the tank (Fig. I.6). In the outlet zone the clarified water is skimmed off over the weirs into the collecting launders, preventing short-circuiting through the tank. Short-circuiting refers to water that flows quickly through the tank without properly dispersing and allowing the particles to settle.

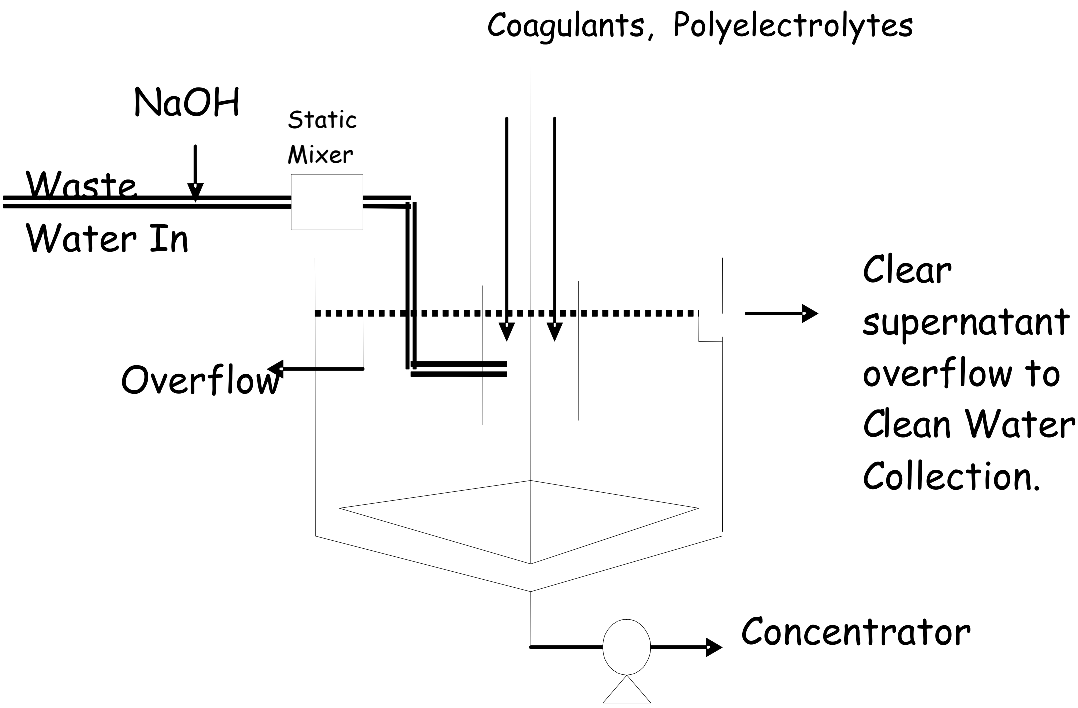


Fig. I.6 Diagram of the plant clarifier

Particle settling is affected by the particle size, shape, density, electrical charge, number of particles, water temperature and sedimentation tank physical characteristics (shape, conditions such as wind and density currents). Smooth particles settle faster than irregular shapes, dense particles faster than "fluffy light" ones. Colder water is more dense than warm water, which slows particle settling.

The settling process is inexpensive to run, but if it fails, can cause serious problems. It is important to ensure that we are removing the correct amount of sludge and scum in primary clarifiers. If the unit fails, the overflow water will become contaminated.

I.4 PVC Wastewater Treatment Plant

The EPVC wastewater treatment plant consists of a number of steps (see Fig. I.7). The wastewater feed is stored in a Tank (T01) and pumped to the clarifier where it is coagulated with metals ion, NaOH and anionic poly-electrolyte are also added. The flocculated latex settles and the sludge is transfer to a second settling tank and then to the Belt Filter.

The size of the particles determines whether they settle. Small particles do not settle. The particles coagulate or flocculate if charge neutralizing ions or a polymer flocculent is added. The much larger particle aggregates are heavy enough to settle under gravity. Water ionic strength, pH, temperature, etc., also affect coagulation and settlement.

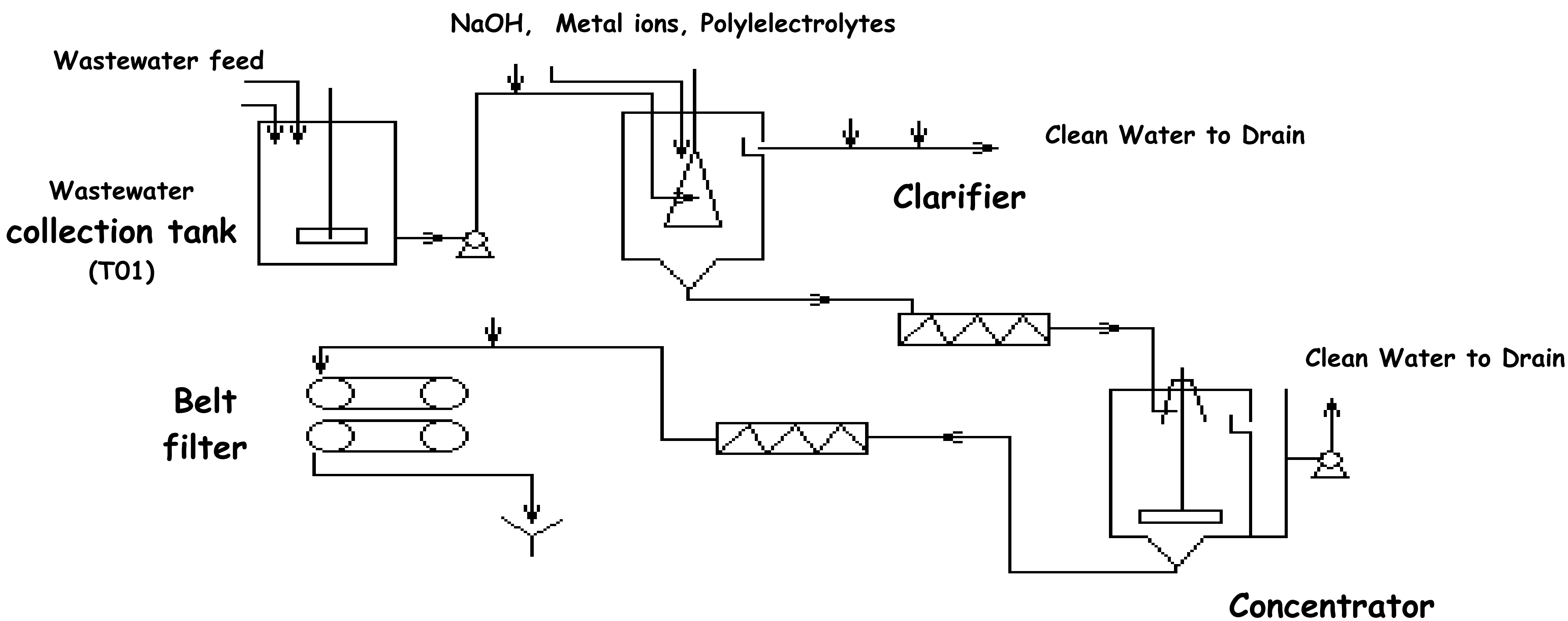


Fig. I.7 Schematic diagram of the wastewater treatment plant

I.4.1 Coagulation

The first step for wastewater treatment is to mix the coagulation chemical(s) with the water to be treated. This is usually done with mechanical mixers, hydraulic jetting, diffusers, or blending pumps that mix the coagulant chemical(s) into the treatment stream as completely and as vigorously as possible. After the coagulant chemical(s) is/are mixed into the process stream, mixing/coagulation may occur in the channels/pipes or special chambers as the process stream moves to the clarifier. Turbidity gives us an indirect measurement of the concentration of particles in suspension. This is because turbidity depends on particle size and shape as well as concentration. Low turbidities in the raw water mean fewer particles.

I.4.2 Flocculation

Flocculation is largely a physical process where the coagulated clumps are gently moved into contact with each other to form masses as a cloud, or as "a precipitate" . This is accomplished in clarifier with a slowly rotating paddle. The flocculate is fragile. We need to utilize a slow, easy, gentle mixing action to build the flocs, but not enough energy to shear them (break up the flocs).

I.4.3 Removal Water from sludge

The wastewater sludge is processed through the belt filter after treatment in the clarifier tank. As the sludge flows to the belt filter press (Fig. I.8) , a cationic polyelectrolyte is mixed with the waste water sludge. This coagulates or gels the sludge as it falls on to the belt. Excess water flows off the bed of sludge on the belt. The remaining water is squeezed out of the sludge when it is pressed between the two belts. The wet cake is scraped off the belt and falls into one ton jumbo bag for disposal. The excess water is recycled back to the collection tank (T01) of the plant.

Fig.I.8 Belt filter [24]

Chapter II:
Experimental Set-Up and Methodology

II.1 Introduction

The experimental methodology in this project consists in carrying out experimental bench scale tests using latex feed from real plant. The traditional bench scale test (*jar test*) is the fastest and most affordable way to obtain reliable data on variables that affect the treatment process and design parameters. The performance of the coagulation/flocculation process was determined by measuring the turbidity of the supernatant and the sedimentation height. In order to optimize the dosage, the following parameters must be considered:

- The solution pH.
- The chemical used to adjust the pH (i.e. NaOH, lime, $Mg(OH)_2$, Na_2CO_3).
- The coagulants and flocculants type used.
- The sequence in which chemicals are added.

II.2 Apparatus

II.2.1 Jar Test

Certainly the most familiar and widely used coagulation test employed by those acquainted with water and wastewater treatment is the jar test [25]. Essentially, a jar test is a series of equal volume, identical samples that are exposed to a controlled variety of treatment conditions. (Fig. II.1)

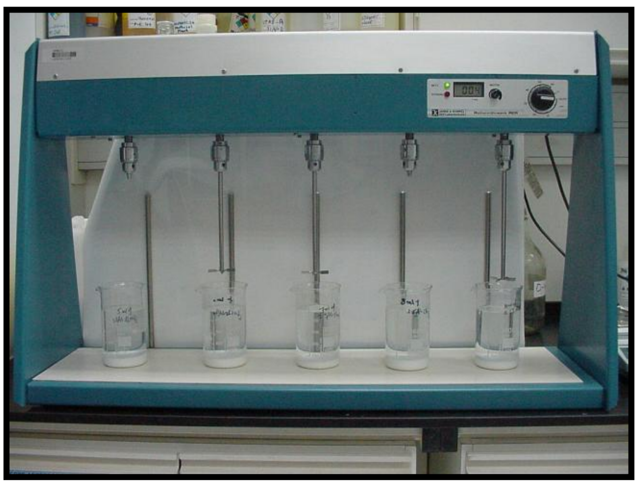


Fig.II.1 Typical Jar Test Apparatus

Since the first reported jar tests were used by Langelier and Hyde in 1918 [25], many variations of the jar test concept have come into use. The general principle is, (whatever the variation) to reproduce, as closely as possible, the existing or anticipated conditions of the treatment plant. In effect, the operation of the treatment plant is attempted in miniature in order to determine what effect a change in a single variable will have if all other variables are held at constant and representative levels. Jar tests are particularly useful and remain popular for controlling coagulation-sedimentation and precipitation-sedimentation processes. Some typical objectives sought from a jar test analysis are listed below. These parameters are not necessarily arranged in any order of priority.

1. Determine the types of coagulants that will effectively remove the suspended solids from the water or wastewater.
2. Determine the treatment chemicals that will effectively remove dissolve solids or favorably alter the chemical composition of the water or wastewater.
3. Establish effective concentration ranges of treatment chemicals/coagulants.
4. Establish optimum dosages of treatment chemicals/coagulants.
5. Establish order and time of addition for treatment chemicals/coagulants.
6. Establish optimum reaction or flocculation time.
7. Estimate the treated effluent quality.
8. Estimate settling rate of flocculated particles or precipitates.

9. Estimate the sludge volume produced as a result of each treatment parameter variation.

II.2.2 Accessories

The following equipment is also needed;

- pH meter with electrode to monitor pH
- Turbidity meter to measure turbidity
- 10 Graduated Beakers of 1000 ml, clear glass
- Magnetic Stirrer or equivalent.
- Syringe Injection for adding chemical.
- Pipettes for adding chemical and making up Modal Wastewater.
- Spoon to add solid chemicals

Disposable plastic syringes (without needles) have been used quite successfully for both measuring and dispensing solutions or slurries to the samples in a Jar Test. These can be washed many times between uses and are, therefore, relatively inexpensive. Syringes, however, enable a slow drop-wise addition of polymer solution to the sample which can be readily controlled. Pipettes are also useful for measuring and dispensing (instead of test tubes, graduated cylinders, etc.). However, when several different reagents have to be added, pipettes become less desirable because of the excessive time required for reagent addition.

After wastewater samples settling, the relative height of the settled solids layer in each beaker is recorded. Volumes of supernatant liquid are withdrawn from each of the graduated beakers to measure turbidity, pH, and other required analysis. The height (depth) of the settled solids layer can be measured and recorded again after 60 min, 120 min, and 180 min. (Note: the depth of the settled solids layer divided by the initial depth of the untreated sample" total liquid depth" gives an estimate of the relative percentage of sludge settlement).

II.3 Jar Test Procedure

It may be a common misconception that there is, or should be, a “standard” Jar Test procedure that can be used universally to determine requirement for achieving solids removal through coagulation-sedimentation processes. There are many process methods for using coagulation (and still, about as many different devices to carry them out) that it is virtually impossible to write a single standard procedure that will fit all possible applications.

Moreover, there are usually several alternative methods that can be used to achieve a desired result when dealing with water and wastewater treatment.

It is possible, however, to describe certain aspects of a Jar Test that are common to most coagulation-sedimentation processes which can be performed in a standardized manner. A standardized recommended practice for Jar Test of water is presented in the references [25-26]. These methodologies will be described in a later section.

In the treatment of water or wastewater by chemical coagulation and sedimentation, the same general principles of operation are used. Therefore, the Jar Tests used to test water and wastewater applications follow the same general practice. But waste water tend to be unpredictable. Some more common reasons for this unpredictability of wastewater are:

1. Wide range of variations in wastewater suspended solids.
2. Wide range of variations in wastewater dissolved solids
3. Critical variations in wastewater pH value.
4. Fluctuation in wastewater hydraulic flow
5. Presence of unknown or unsuspected constituents
6. Variations in wastewater temperature

7. Variations in possible synergistic effects caused by independent variations in the above parameters.

II.4 Experimental Methodology

II.4.1 Wastewater "Model"

The composition and quality of waste water feed to EPVC wastewater treatment plant is very variable. In addition, the particles are already flocculated because of the presence of recycle water (containing coagulants and flocculants) from the Belt Filter. As a result a "model" wastewater was prepared which is chemically identical to actual plant wastewater but does not contain recycle and thus has not flocculated. It was made by diluting 12.5 ml of an EPVC latex [EPVC, a monomodal 703 latex, 460 nm particle size, a solids content of 40% and stabilized by Sodium Lauryl Sulphate (SLS surfactant)] to 500 ml with tap water.

II.4.2 Measurement of Turbidity

II.4.2.1 Turbidity

In quality monitoring of water, the ”turbidity” value is of great use in many applications. This applies to drinking water and wastewater treatment, for the preparation of beverages and in the electroplating and petrochemical industry. Light passing through liquid which contains undissolved solids, such as algae, mud, microbes and other insoluble particles, is both absorbed and scattered. Turbidity increases with the amount of undissolved solids present in the sample. However, the shape, size and composition of the particles also influence the degree of turbidity. Turbidity has been determined by simply measuring light passing through the sample. Measuring the scattered light at an angle of 90° has proved to be a more accurate method particularly at lower measuring ranges. Instruments that use this method are also referred to as nephelometers [27].

Turbidity or nephelometers instruments differ by the light source they utilize. Infrared units (IR-LED) with a wavelength of 860 nm are required for methods: ISO 7027/DIN EN 27027 (EN ISO 7027). Standard methods [26] specify the use of units that use white light by a tungsten wide-band lamp for water and wastewater analysis. The NTU mean Nephelometric Turbidity Units. When the NTU value is low the water is clear [27].

Table II.4.1 Typical Turbidity Values for Various Liquids [28]

Liquid	NTU
Deionized water	0.02
Drinking water	0.02 ….. 0.5
Spring water	0.05 ….. 10
Wastewater (untreated)	70 ….. 2000
White water (Paper industry)	60 …... 800

II.4.2.2 Method of Measuring the Turbidity

The procedure for measuring the turbidity of the wastewater sample is described below. The images of the turbid meter is shown in Fig. II.2

1. The Turb 355 IR/T (WTW, Woburn, MA 01801 U.S.A) is used to measure the turbidity of the samples
2. Switch on the turbidity meter: Press the ON/OFF key.
3. Before start of experiments the turbidity meter is calibrated.
4. Rinse out a clean cuvette with the sample to be measured: Pour approximately 10 ml sample into the cuvette. Close the cuvette and rotate it several times before throwing the sample away.
5. Take a sample (approx. 15 ml) from wastewater beaker by using a syringe.

6. Fill the cuvette with the sample to be measured (approx. 15 ml). Close the cuvette with the black light protection cap.
7. Make sure that the outside of the cuvette is clean, dry, and free of fingerprints.
8. Insert the cuvette in the cuvette shaft so that it clicks into place.
9. Press the measuring key.
10. Dashes are displayed while the measured value is being determined.
11. Read the measured value when it is displayed.
12. Repeat steps 3 to 10 for further samples.

Figs. II.2) Measurement of turbidity by using portable turbidity meter

II.5 Procedure for Determining Optimum Quantity of Metal Ions

This procedure was used for 0.5% $Al_2(SO_4)_3$, 2.5% $FeCl_3$ and 2.5% $CaCl_2$ solution.

II.5.1 Procedure for Determining Optimum Quantity of 0.5% $Al_2(SO_4)_3$

1. Preparation of 0.5% $Al_2(SO_4)_3$ solution. Dissolve 2.5 g $Al_2(SO_4)_3$ in 497.5 g water.
2. Pour a sample of untreated model wastewater into a beaker. While mixing, adjust the pH using Sodium-Hydroxide or sulfuric acid to optimum pH for samples, i.e. pH 7-8. Off-center location of mixing blades, i.e. about 6 mm (1/4 in.) from the beaker wall provides better (more thorough) mixing conditions in graduated cylindrical beakers. Measure the pH value.
3. Load the coagulant solution into the syringe and place it near the graduated beaker that is to receive it.
4. Add 1 ml of coagulant solution to the beaker using the syringe.
5. Run the stirrer at 200 rpm for 1 minute.

6. Turn off stirrer and leave for 10 minutes. Observe the coagulation (agglomeration) of the precipitated particles.
7. Remove 12ml of supernatant using syringes and measure its turbidity using the portable turbidity meter. Remove all supernatant samples from the same depth.
8. Record the turbidity and coagulation level (height). Calculate the relative height by dividing the height (ml) by 500 ml.
9. Plot turbidity and different amount of the coagulant with time.
10. Plot turbidity and flocculation level (height) Vs. time.
11. The procedure was repeated from step 2 using 2, 3ml …… of the coagulant solution.

II.5.2 Procedure for Determining Optimum Quantity of 2.5% $FeCl_3$

Preparation of 2.5% $FeCl_3$ solution. Dissolve 12.5 g $FeCl_3$ in 487.5 g water. Steps (2-11) of the previous section are repeated for this coagulant.

II.5.3 Procedure for Determining Optimum Quantity of 2.5% $CaCl_2$

Preparation of 2.5% $CaCl_2$ solution. Dissolve 12.5 g $CaCl_2$ in 487.5 g water. Steps (2-11) of the previous section are repeated for this coagulant.

II.5.4 Procedure for Determining Optimum Quantity of 0.02% polyelectrolyte (PE1)

1. Preparation of 0.02% PE1 solution . Dissolve 0.08 g PE1 in 400 g water. (The PE1 solution is left for a number of days to ensure it has dissolve.)
2. Pour a sample of untreated model wastewater into a beaker. While mixing, adjust the pH using sodium hydroxide or sulfuric acid to optimum pH for samples, i.e. pH 7-8. Off-center location of mixing blades, i.e. about 6 mm (1/4 in.) from the graduated beaker wall provides better (more thorough) mixing conditions in graduated cylindrical beakers. Measure pH value.
3. Add the optimum amount of metal ions solution.

4. Load the PE1 solution into the syringes and place it near the graduated beaker that is to receive it.
5. Add 1ml, 2ml,…. of PE1 flocculent solution (0.02% PE1) to the beakers using the syringe.
6. Run the stirrer at 200 rpm for 1 minute.
7. Turn off stirrer and leave for 10 minutes. Observe the coagulation (agglomeration) of the precipitated particles.
8. Remove 12ml of supernatant using syringes and measure its turbidity using the portable turbidity meter.
9. Record the turbidity and coagulation level (height). Calculate the relative height.
10. Plot turbidity and different amount of PE1 Vs. time.
11. Plot sediment height and different amount of PE1 Vs. time.

II.5.5 Procedure for Determining Optimum Quantity of 0.02% CIBA [29] polyelectrolyte (PE2)

Preparation of 0.02% PE2 solution. Dissolve 0.08 g CIBA PE2 in 400 g water.(The PE2 solution is left for a number of days to insure it has dissolve). Steps [2-11] of the previous section are repeated for polyelectrolyte PE2.

II.5.6 Procedure for Determining Optimum Quantity of 0.02% CYTEC [30] polyelectrolyte (PE3)

Preparation of 0.02% PE3 solution. Dissolve 0.08 g CYTEC PE3 in 400 g water.(The PE3 solution is left for a number of days to insure it has dissolved). Steps [2-11] of the previous section are repeated for polyelectrolyte PE3.

II.5.7 Procedure for Determining Optimum pH for Metal Ions

1. Pour a sample of untreated model wastewater into a graduated beaker.
2. Adjust the pH of the wastewater to pH=2 by adding sulphric acid to reduce the model wastewater. Off-center location of mixing

blades, i.e. about 6 mm (1/4 in.) from the beaker wall provides better (more thorough) mixing in graduated cylindrical beakers. Measure pH value.

3. Load the optimum amount of metals ions solution into the syringes and place it near the graduated beaker that is to receive it.
4. Add the optimum amount of metals ions solution to the beaker using the syringe.
5. Run the stirrers at 200 rpm for 1 minute.
6. Turn off stirrer and leave the treated wastewater sample for 10 minutes. Observe the coagulation (agglomeration) of the precipitated particles.
7. Remove 12ml of supernatant from using syringes and measure its turbidity using the portable turbidity meter. Remove all supernatant samples from the same depth.
8. Record the turbidity and coagulation level (height). Calculate the relative height.
9. Plot turbidity Vs. pH
10. Plot turbidity and pH Vs. time

11. Repeat the same procedure with different pH (pH=3, 4… 9) by adding sodium hydroxide to raise the pH of the model waste water.

II.5.8 Procedure for Determining Optimum Agitation Speed for Metal Ions

1. Pour a sample of untreated model wastewater into a graduated beaker (ex 1000 ml).
2. Adjust the pH of the wastewater as required. Off-center location of mixing blades, i.e. about 6 mm (1/4 in.) from the graduated beaker wall provides better (more thorough) mixing in graduated cylindrical beakers. Measure pH value.
3. Load the optimum amount of metals ions solution into the syringes and place it near the beaker that is to receive it.
4. Load the optimum amount of polyelectrolyte solution into the syringes and place it near the beaker that is to receive it.
5. Add the optimum amount of metals ions and polyelectrolyte solution to the graduated beaker using the syringe.
6. Run the stirrer at 200 rpm for 5 minute.

7. Turn off stirrer and leave the treated wastewater sample for 10 minutes. Observe the coagulation (agglomeration) of the precipitated particles.
8. Remove 12ml of supernatant from using syringes and measure its turbidity using the portable turbidity meter.
9. Record the turbidity and coagulation level (height). Calculate the relative height.
10. Plot sediment height Vs. rpm
11. Plot the turbidity Vs. rpm
12. Plot Turbidity and agitation speed Vs. time
13. The procedure was repeated from step 1 using 200 up to 1000 rpm.

Chapter III:

Results and Discussion

III.1 Introduction

In the previous chapter we have explained the methodology which is to be used to carry out measurements in the Jar test and Turbidimeter.

The parameters to be investigated are as follow:

- Effect of metals ions: They include
    - Aluminum Sulphate
    - Ferric Chloride
    - Calcium Chloride
- Effect of poly-electrolytes: They include
    - Polyelectrolyte (PE1)
    - CIBA Poly-electrolyte (PE2)
    - CYTEC Poly-electrolyte (PE3)
- Effect of pH.
- Effect of Agitation speed.

Table III.1 summarize the range for each parameter. These values were selected to be in the range that are used in the industrial plant.

Table III.1 Range of values of operational parameters used in the experimental

Parameter	range
Aluminum Sulphate	2-10 ml
Ferric Chloride	1-10 ml
Calcium Chloride	5-30 ml
Polyelectrolyte (PE1)	1-10 ml
CIBA Polyelectrolyte (PE2)	1-9 ml
CYTEC Polyelectrolyte (PE3)	1-9 ml
pH	2-10
Agitation speed	200-1000 rpm

III.2 Optimization Procedure

The number of parameters to be investigated is large (=8) and the range of values of these parameters is also wide as shown by Table III.1. The following procedure has been selected to optimize the performance of the wastewater:

1- We start by investigating the effect of aluminum sulphate alone. The procedure for determining optimum quantity of aluminum sulphate was described in II.5.1

2- We fix the dosage of aluminum sulphate at the optimum value which found in step 1, and then we investigate the effect of adding poly-electrolyte (PE1). The procedure for determining optimum quantity of poly-electrolyte (PE1) was described in II.5.4

3- We fix the dosage of aluminum sulphate at the optimum value which were found in step 1, and then we investigate the effect of pH. The optimum value of pH is determined by using procedure which was described in II.5.7

4- We fix the optimum value of aluminum sulphate and poly-electrolyte (PE1), and then investigate the effect of agitation speed. The optimum value of agitation speed is determined by using procedure which was described in II.5.8

5- Steps 2-4 are repeated for polyelectrolyte CIBA (PE2) and polyelectrolyte CYTEC (PE3).

6- Steps 1-5 are repeated for the other metal ions: Ferric chloride and Calcium chloride.

III.3 Coagulation of Wastewater Using Aluminum Sulphate

III.3.1 Effect of aluminum sulphate alone

Figure III.1 shows that variations of turbidity with different dosages of aluminum sulphate. The figure shows that the best settlement and clearest supernatant occurred at dosage of 7.5 ml of aluminum sulphate solution (measured at 300 minutes). The optimum turbidity is 20 NTU.

Figure III.2 show the change in turbidity with time when the model wastewater (500 ml water contain 12.5 gm of 40% solid EPVC latex) was coagulated by 0.5% $Al_2(SO_4)_3$ solution. The range of the aluminum sulphate solution is from 2 ml up to 10 ml. We notice from figure that as the volume of aluminum sulphate solution increases, the turbidity decreases . We have chosen five hours as the time to compare final performance of the metals ion added to wastewater. From Fig. III.2 we note that the minimum value for turbidity corresponds to the volume of aluminum sulphate solution in the range of 6 to 8 ml. We further investigated the effect of adding volume of 6.5, 7.5, and 8.5 ml as shown in Fig. III.3.

Fig III.1 Supernatant Turbidity of Latex Coagulated with 0.5%of $Al_2(SO_4)_3$ Solution.
after 5 hr Settlement

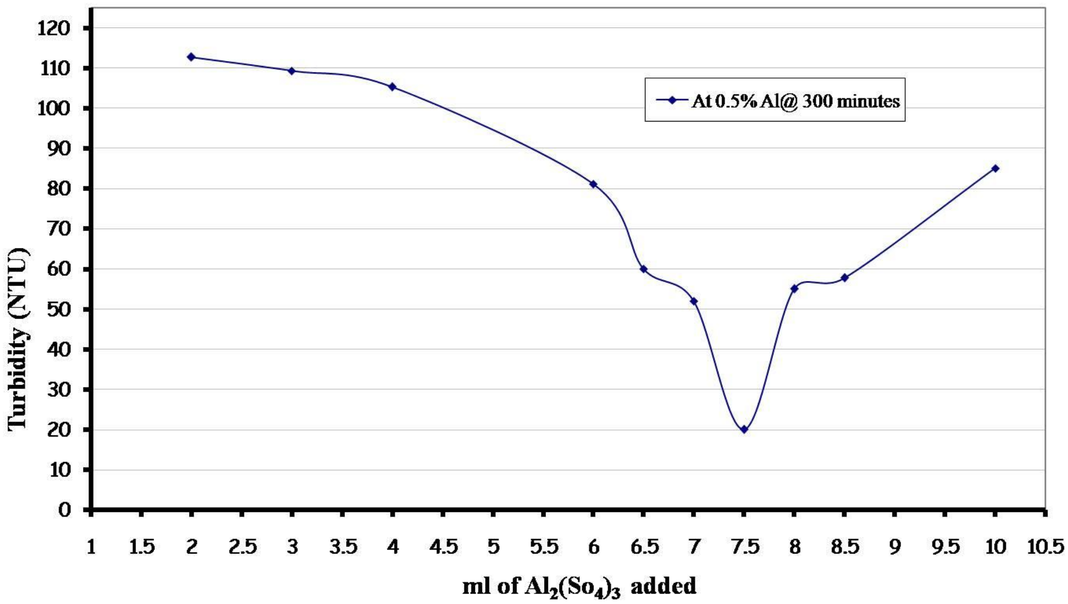


Fig. III.2 Supernatant Turbidity of Latex Coagulated with 0.5% of $Al_2(SO_4)_3$ Solution (range 2-10ml)

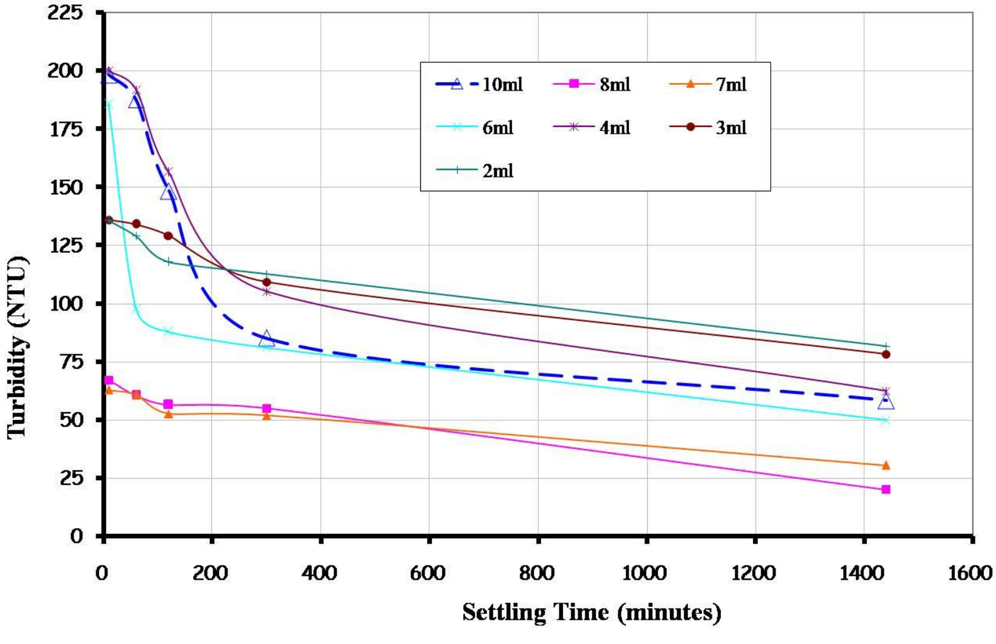


Figure III.4 shows the sedimentation heights with the time for the same volumes of aluminum sulphate solution. The optimum height is at 110 ml when the volume of aluminum sulphate solution is 7.5 ml.

Fig. III.3 Supernatant Turbidity of Latex Coagulated with 0.5% of $Al_2(SO_4)_3$ Solution (range 6.5-8.5 ml)

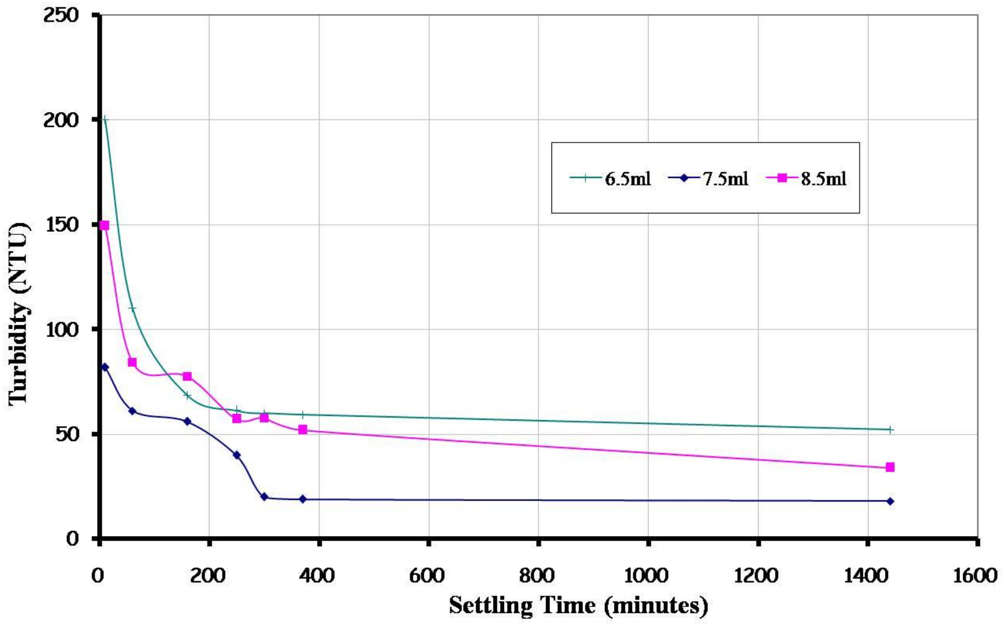
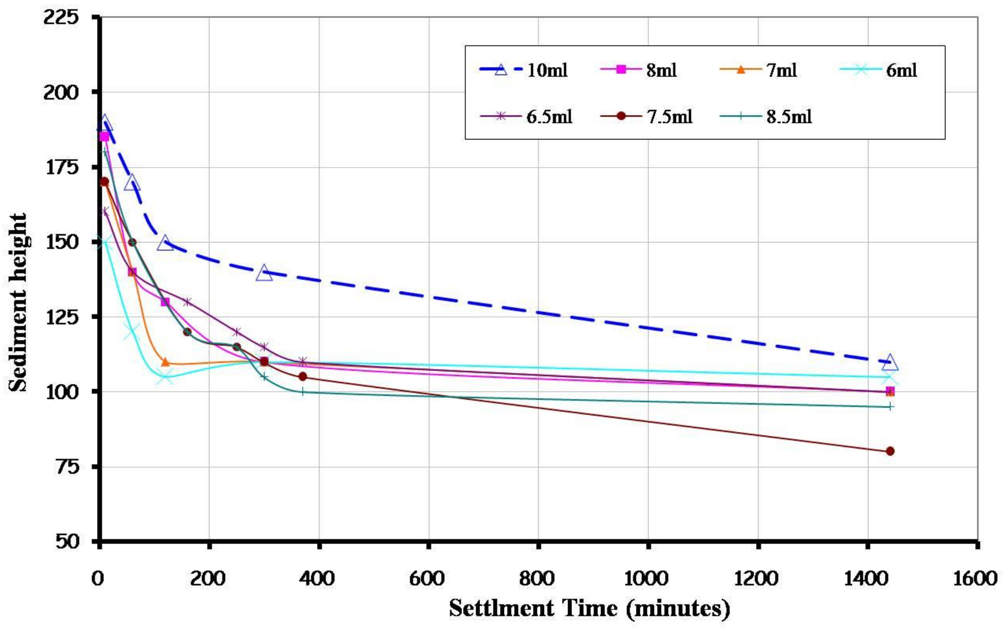


Fig. III.4 Sediment Height of Latex Coagulated with 0.5% of $Al_2(SO_4)_3$ Solution



III.3.2 Effect of Polyelectrolyte (PE1)

The model wastewater (500 ml water contain 12.5 gm of 40% solid EPVC latex) is prepared with the addition of the aluminum sulphate solution at the optimum value of 7.5 ml found early. Figure III.5 shows the variations of the turbidity with different added volumes of polyeletctrolyte (PE1). It can be seen that the best settlement occurred at 1.5 ml of polyelectrolyte (PE1) solution (measured at 300 minutes). The turbidity is at the low value of 14 NTU. Figure III.6 shows the effect of turbidity with settling time . The range of polyelectrolyte (PE1) solution from 1 up to 10 ml . From Fig.III.6 we note that the minimum value for turbidity corresponds to the volume of polyelectrolyte (PE1) solution in the range of 1 to 3 ml. We further investigated the effect of adding volume of 0.5, 1.5, and 2 ml as shown in Fig.III.7. It can be seen that the optimum value of turbidity occurs at volume of PE1 of 1.5 ml.

Fig. III.5 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE1 and 7.5 ml of (0.5% of $Al_2(SO_4)_3$) solution.
After 5 hr Settlement

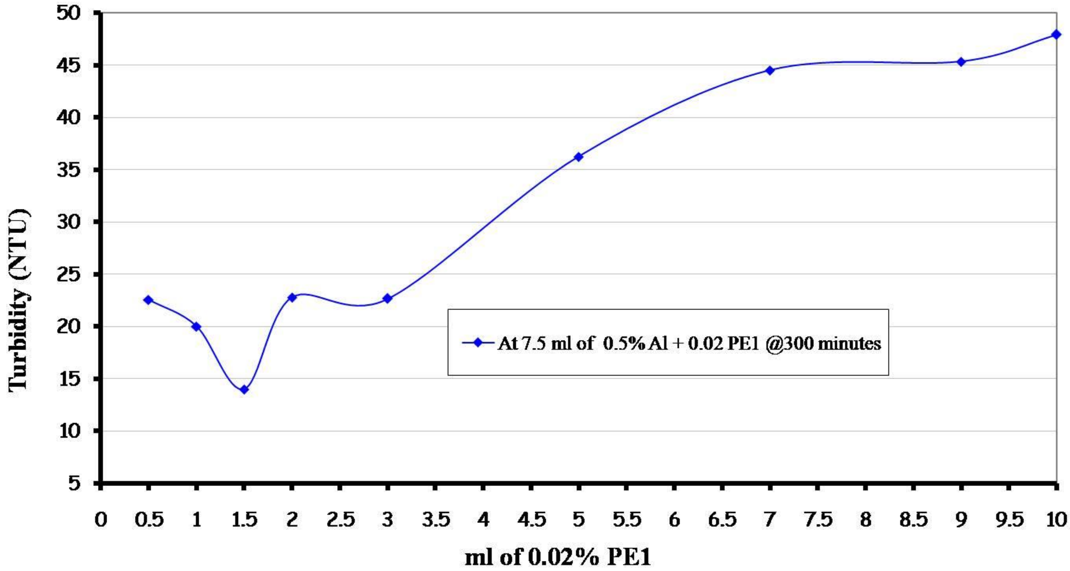


Fig. III.6 Supernatant Turbidity of Latex Coagulated with 7.5 ml of (0.5% of $Al_2(SO_4)_3$) Solution with different amount of 0.02% PE1 (range 1-10 ml)

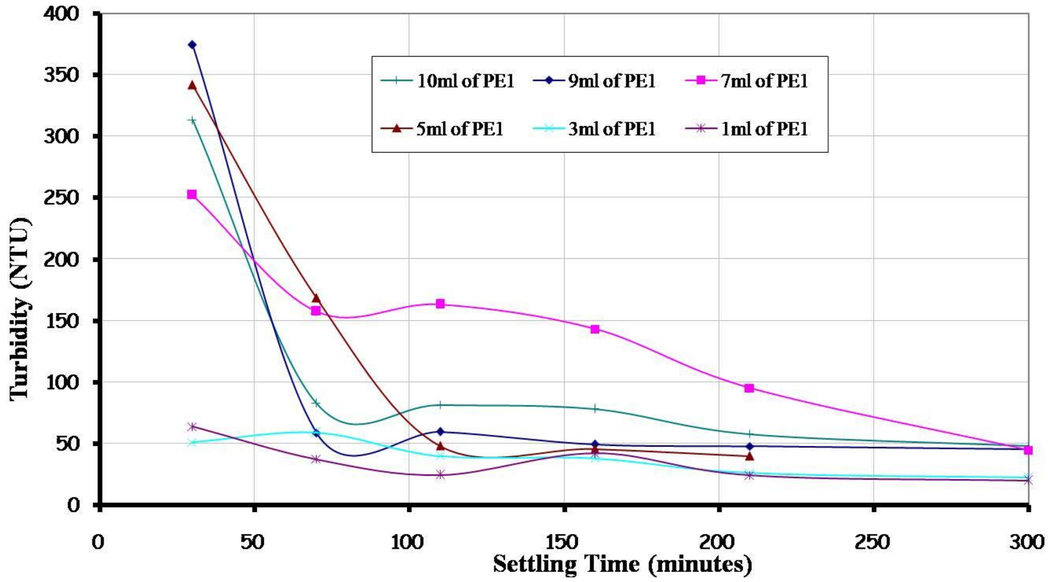


Fig. III.7 Supernatant Turbidity of Latex Coagulated with 7.5 ml of (0.5% of $Al_2(SO_4)_3$) Solution with different amount of 0.02% PE1 (range 0.5-2 ml)

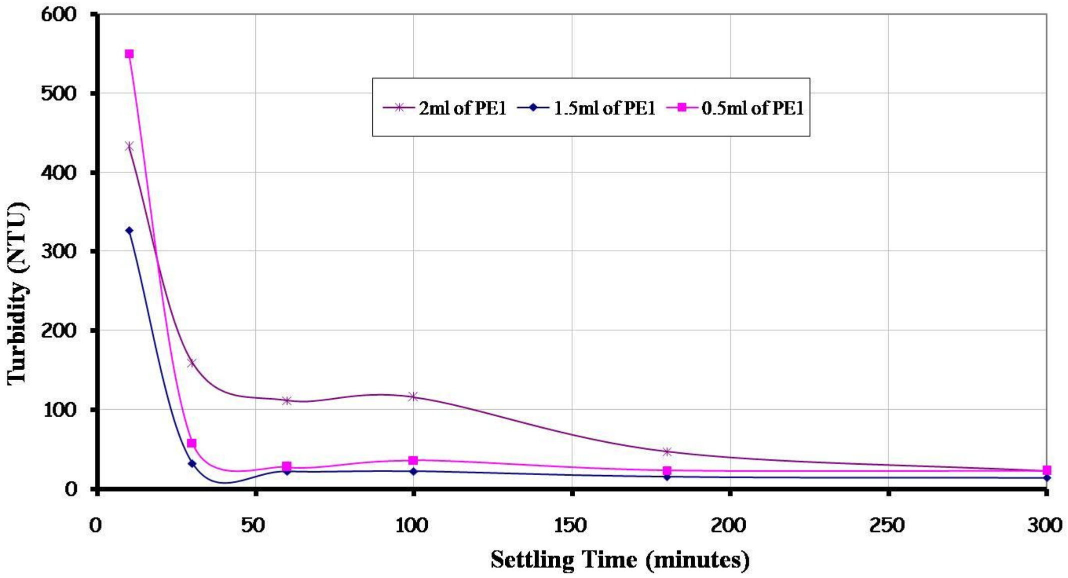
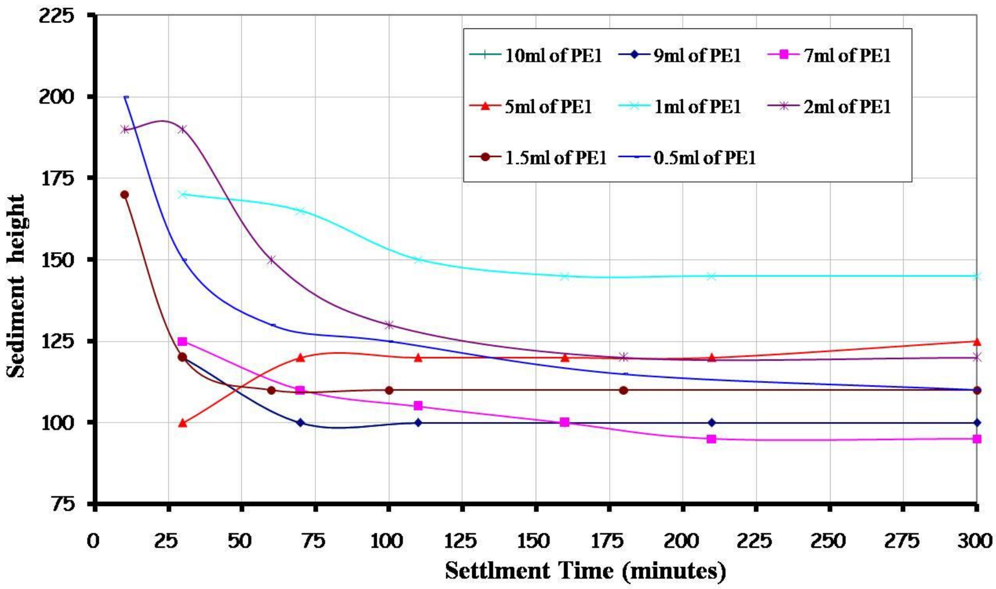


Figure III.8 shows the sedimentation height when different volume of PE1 are added to the aluminum sulphate. It can be shown that the optimum sedimentation height occurs at 110 for volume of 1.5 ml of PE1. Table III.2 summarize the effect of combined addition of aluminum sulphate and polyelectrolyte (PE1) solution. With aluminum sulphate solution alone (at optimum valve of 7.5 ml), the turbidity is 20 NTU after five hours while the turbidity is 22 NTU after only one hour when aluminum sulphate solution and PE1 are added together.

Table III.2 Comparison between performance of $Al_2(SO_4)_3$ alone and combined $Al_2(SO_4)_3$ and PE1

Volume added per 500 ml waste water	Time(hr)	Sedimentation height(ml)	Turbidity (NTU)
0.5% $Al_2(SO_4)_3$ (7.5 ml)	5	110	20
0.5% $Al_2(SO_4)_3$ (7.5 ml) + PE1 (1.5 ml)	1	110	22

Fig. III.8 Sediment Height of Latex Coagulated with 7.5 ml of (0.5% of $Al_2(SO_4)_3$) Solution with different amount of 0.02% PE1



III.3.3 Effect of pH

Figure III.9 shows the affect of pH on the coagulation of the model latex, for values of pH from 2.7 to 9.8. We can observe that overall turbidity decreases with time for all value of pH. Figure III.10 shows the variations of turbidity with pH after 300 minutes. We can see that turbidity decreases until the pH value of 6.5 and then remains almost constant. For this reason the value of pH selected in the industry is between 6 and 8. Acidic values of pH do not affect turbidity, but will encourage corrosion of material.

Fig. III.9 Supernatant Turbidity of Latex Flocculated with 7.5 ml ($0.5\%\ Al_2(SO_4)_3$) at different pHs

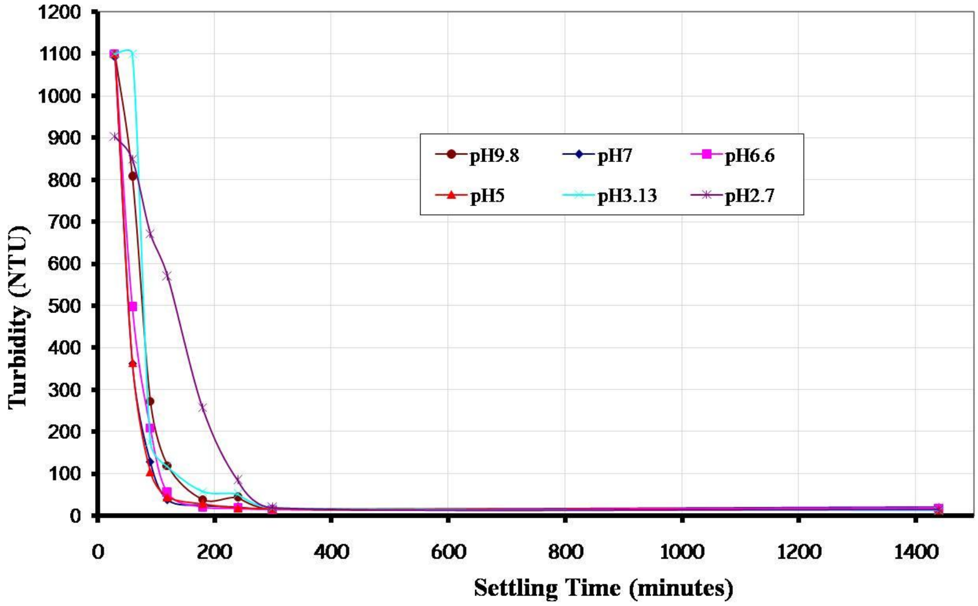
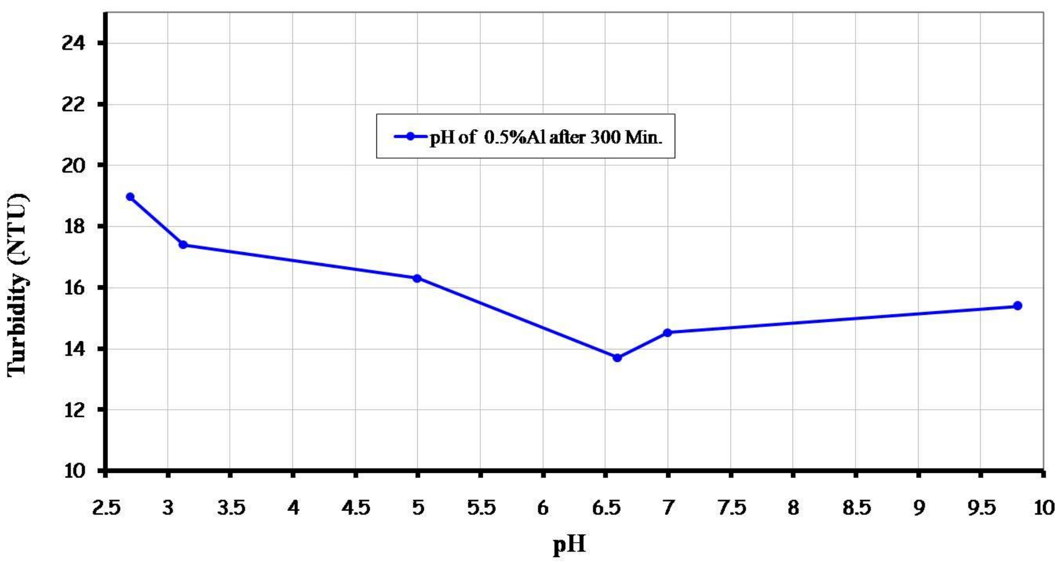


Fig. III.10 Supernatant Turbidity of Latex Flocculated with 7.5 ml ($0.5\%\ Al_2(SO_4)_3$) at different pHs
after 5 hr settlement



III.3.4 Effect of Agitation speed

Figures III.11 to III.13 show the affect of stirrer agitation on turbidity and settlement. The range of agitation speed is from 200 to 1000 rpm. Figure III.11 shows the change in turbidity with settling time for different agitation speeds. It can be seen that the agitation speed has an affect on the turbidity. Figure III.12 shows that the turbidity decreases with agitation speed until it reaches a minimum at around 600 rpm and then increases. Figure III.13 shows that the settlement height is increasing with the increase in the agitation speed, for speeds above 400 rpm.

Fig. III.11 Supernatant Turbidity of Latex Flocculated with 7.5 ml ($0.5\% Al_2(SO_4)_3$) and 1.5 ml (0.02% PE1) at different agitator speed

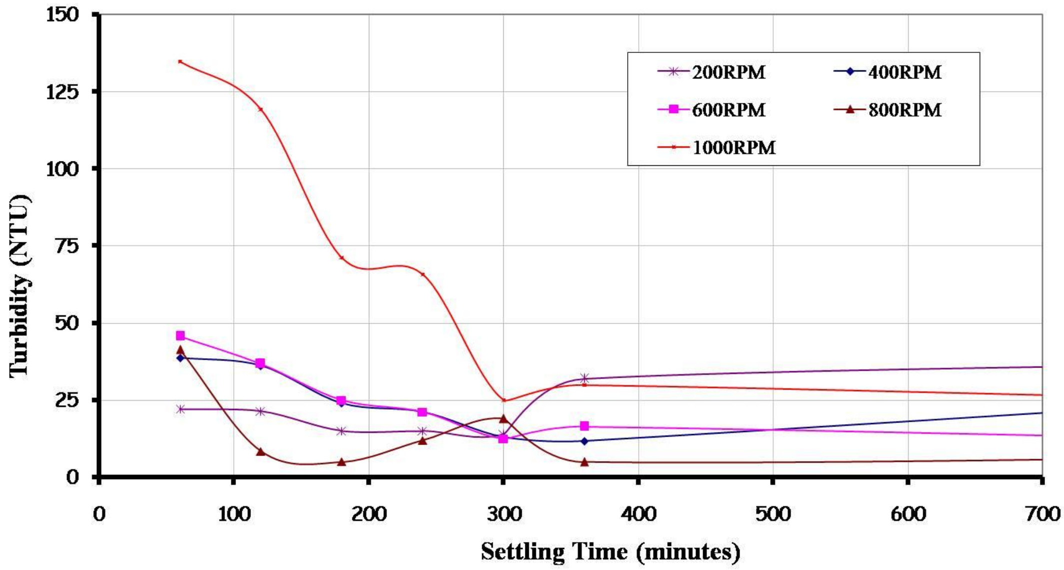


Fig. III.12 Supernatant Turbidity of Latex Flocculated with 7.5 ml (0.5% Al2(SO4)3) and 1.5 ml (0.02% PE1) at different agitator speed
after 5 hr settlement

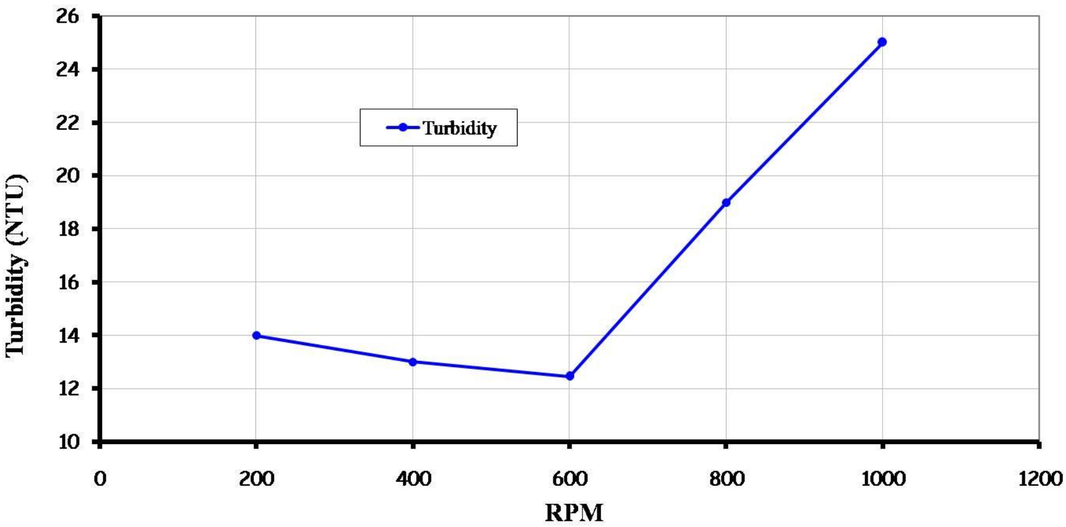
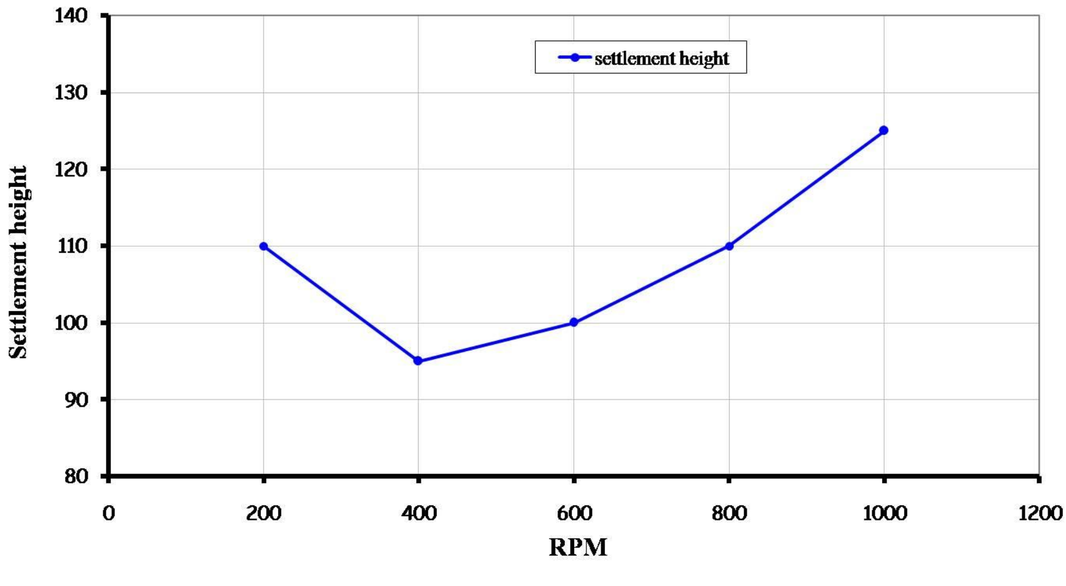


Fig. III.13 Settlement Height of Latex Flocculated with 7.5 ml (0.5% $Al_2(SO_4)_3$) and 1.5 ml (0.02% PE1) at different agitator speeds
after 5 hr settlement



III.3.5 Effect of CIBA Polyelectrolyte (PE2)

The model wastewater is prepared with the addition of the aluminum sulphate solution at the optimum value of 7.5 ml that found early. Figure III.14 shows the effect of addition of CIBA poly-electrolyte (PE2) solution. The range of CIBA poly-electrolyte (PE2) solution is from 1 up to 9 ml . Figure III.14 shows the change in turbidity with the different amounts of added polyelectrolyte (PE2). The figure shows that the best settlement and clearest supernated occurred at 6 ml of CIBA poly-electrolyte (PE2) solution. It can be noted that the optimum value of volume of PE1 and PE2 are different(1.5 ml of PE1, 6ml of PE2). However the optimum value of sedimentation height is almost the same at the value of 110 for the two poly-electrolytes (PE1,PE2). (Figs.III.8 , III.16). Figure III.15 shows, on the other hand, the change of turbidity with the settling time.

Fig. III.14 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE2 and 7.5 ml of (0.5% of $Al_2(SO_4)_3$) solution.
After 5 hr Settlement

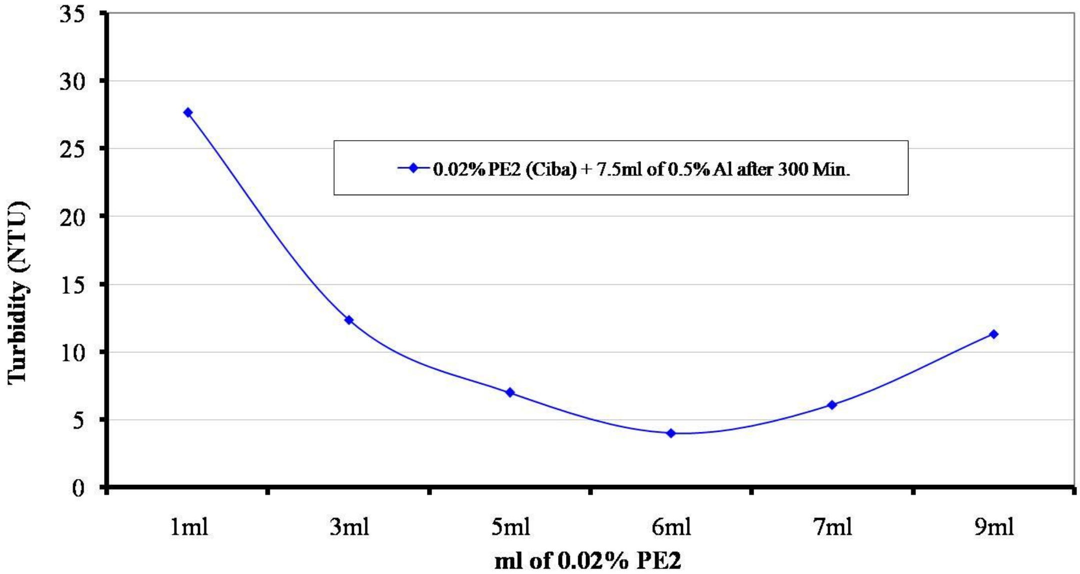


Fig. III.15 Supernatant Turbidity of Latex Coagulated with 7.5 ml of (0.5% of $Al_2(SO_4)_3$) Solution with different amount of 0.02% PE2

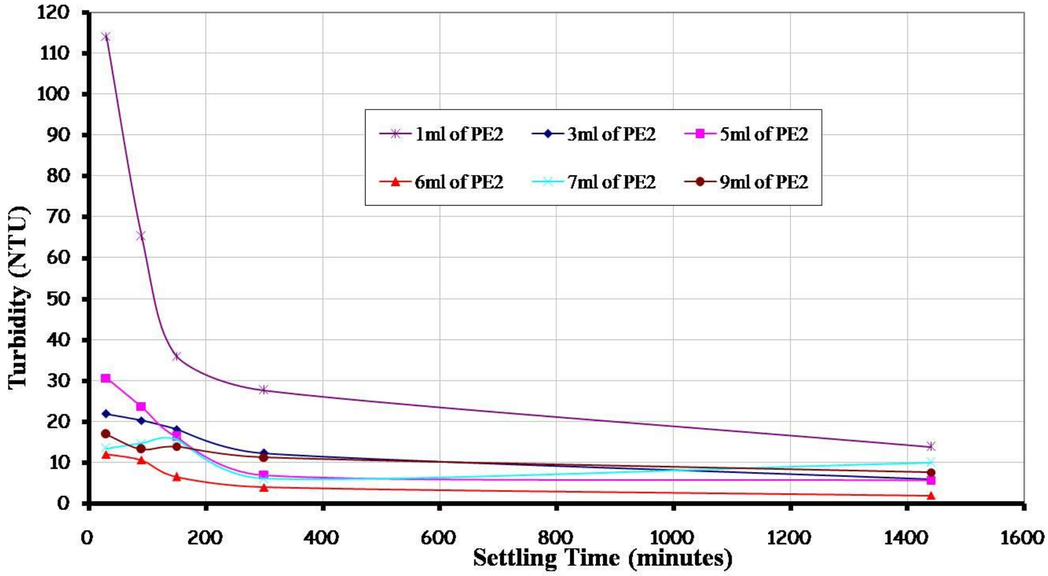
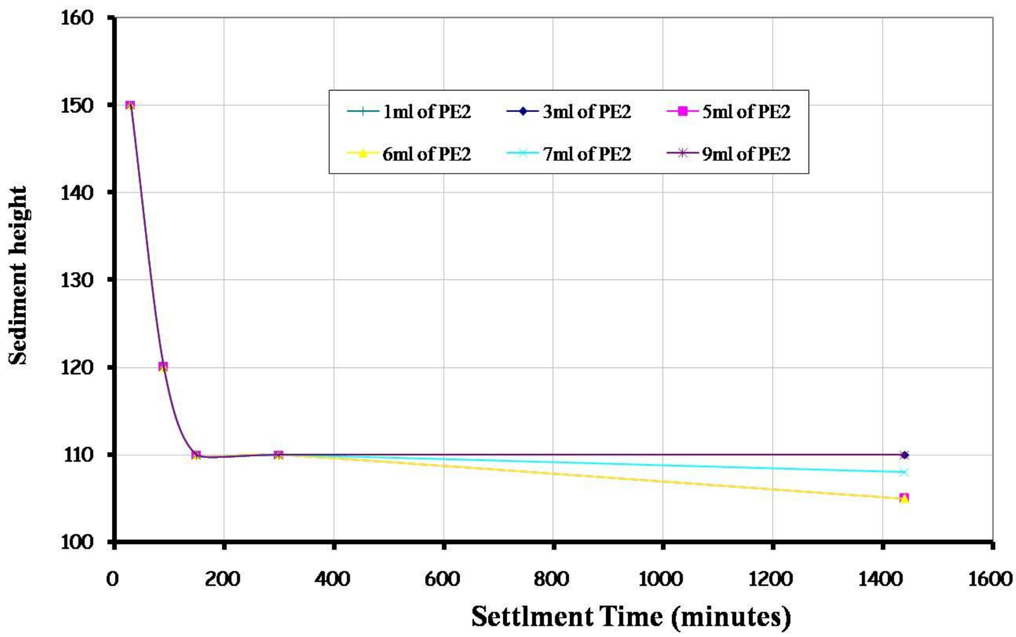


Fig. III.16 Sediment Height of Latex Coagulated with 0.5% of $Al_2(SO_4)_3$ Solution



III.3.6 Effect of CYTEC Polyelectrolyte (PE3)

The model wastewater is prepared with the addition of the aluminum sulphate solution at the optimum value of 7.5 ml that found early. Figure III.17 shows the effect of addition of CYTEC poly-electrolyte (PE3) solution. The range of CYTEC poly-electrolyte (PE3) solution is from 1 up to 9 ml. From Fig.III.17 we noted that the minimum value for turbidity corresponds to the volume of CYTEC poly-electrolyte (PE3) solution is 7 ml. Figure III.18 shows that the best settlement and clearest supernated occurred at 7 ml of CYTEC poly-electrolyte (PE3) solution. The value of the sedimentation height for PE3 is similar to that obtained for PE1 and PE2 poly-electrolytes .(Figs. III.8, III.16, III.19)

Fig. III.17 Supernatant Turbidity of Latex Coagulated with 7.5 ml of (0.5% of $Al_2(SO_4)_3$) Solution with different amount of 0.02% PE3

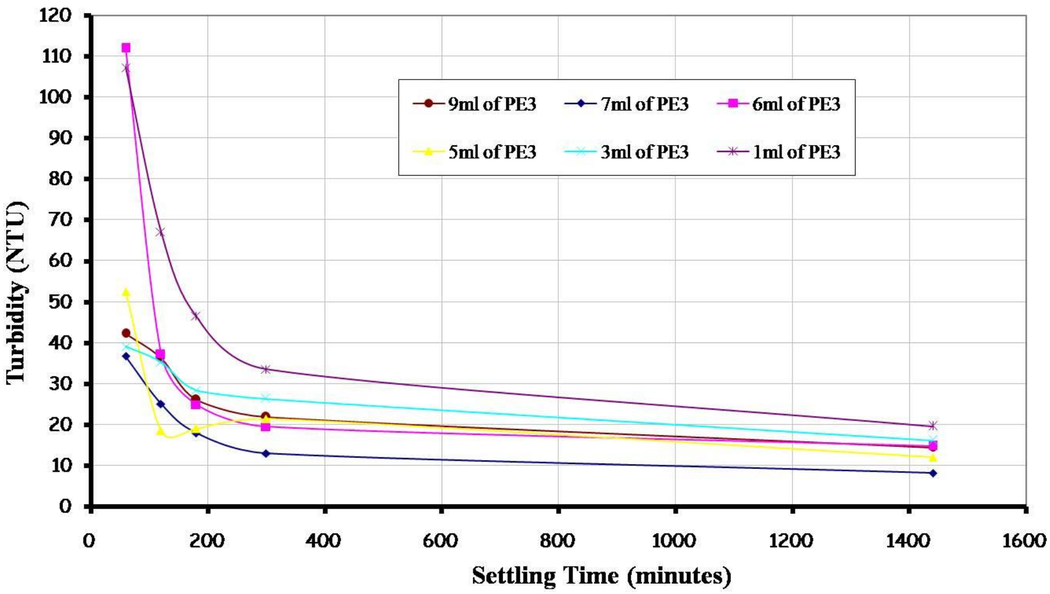


Fig. III.18 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE3 and 7.5 ml of (0.5% of $Al_2(SO_4)_3$) solution.
After 5 hr Settlement

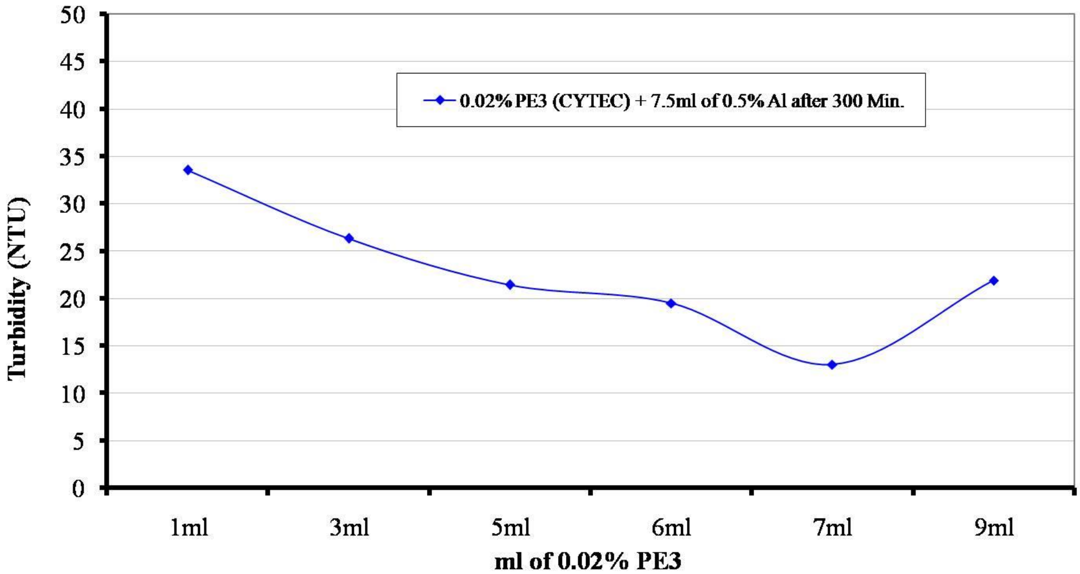
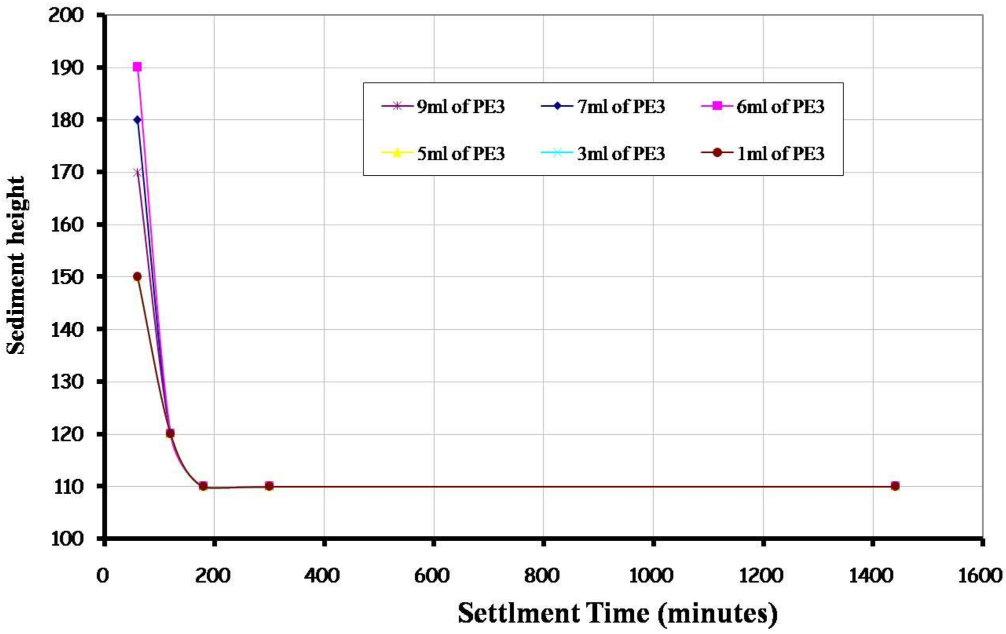


Fig. III.19 Sediment Height of Latex Coagulated with 0.5% of $Al_2(SO_4)_3$ Solution



III.3.7 Summary of Effect of Aluminum Sulphate

Table (III.3) shows a summary of the results associated with the effect of aluminum sulphate combined with different poly-electrolytes, pH and agitation speed. It can be seen from this table that PE1 yields the best performance. Therefore the optimum value of parameters are as follow:

- Aluminum sulphate = 0.0375 gm
- PE1 = 0.0003 gm
- pH = any value larger than 7, but preferably less than 8.
- Agitation speed = 600 rpm.

Table III.3:Summary of performance of aluminum sulphate with other parameters (The optimum values are for a settling time of 5 Hours).

Parameters	**Al^{3+}(ml)**	**PE1(gm)**	**PE2(gm)**	**PE3(gm)**	**pH**	**Optimum rpm**
Optimum Value	**7.5**	**0.0003**	**0.0012**	**0.0014**	**7-8**	**600**
Optimum Turbidity	**20**	**14**	**4**	**13**	**7-9**	**13**

III.4 Coagulation of Modal Waste Latex using Ferric Chloride

III.4.1 Effect of Ferric Chloride

Figure III.20 shows the change in turbidity when the model waste water (500 ml water contain 12.5 gm of 40% solid EPVC latex) was coagulated by 2.5% $FeCl_3$ solution. The range of the 2.5% $FeCl_3$ solution is from 1 ml up to 10 ml. for each volume of 2.5% $FeCl_3$ solution the figure shows a minimum. We notice from figure that as the volume of 2.5% $FeCl_3$ solution increases, the turbidity decreases. From Fig. III.20 we noted that the minimum value for turbidity corresponds to the volume of 2.5% $FeCl_3$ solution in the range of 4 to 6 ml. We further investigate the effect of adding volume of 4, 5, and 6 ml as shown in Fig.III.21. Figure III.21 shows and confirms that the best settlement and clearest supernated occurred at 4 ml of 2.5% $FeCl_3$ solution and the turbidity is at the low value of 21 NTU. Figure III.22 shows the sedimentation height with the time for the same volume of 2.5% $FeCl_3$ solution. The optimum height is at 150 ml when the volume of 2.5% $FeCl_3$ solution is 4 ml.

Fig. III.20 Supernatant Turbididity of Latex Coagulated with 2.5% $FeCl_3$ Solution

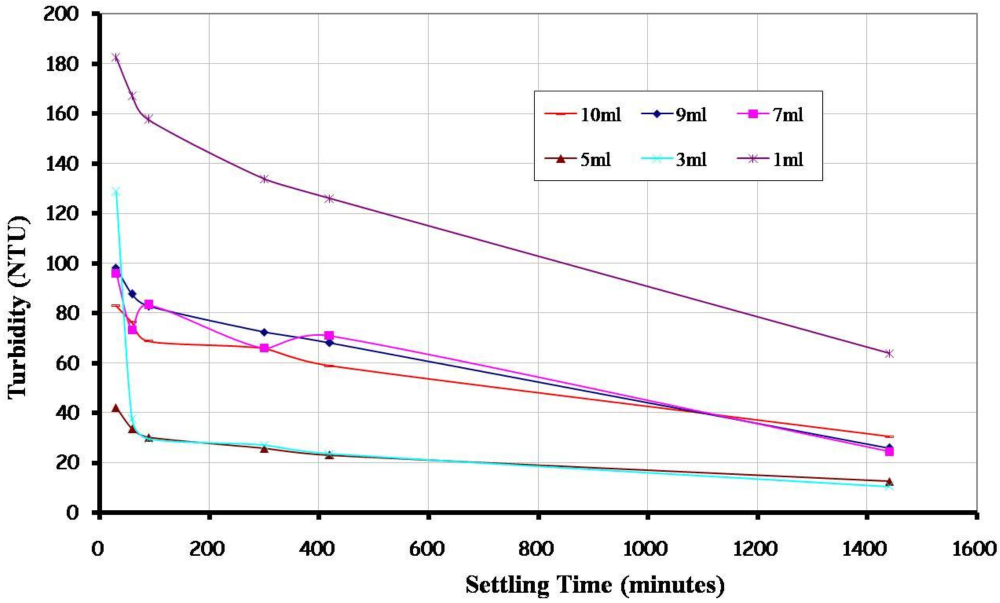


Fig. III.21 Supernatant Turbidity of Latex Coagulated with 2.5% $FeCl_3$ Solution

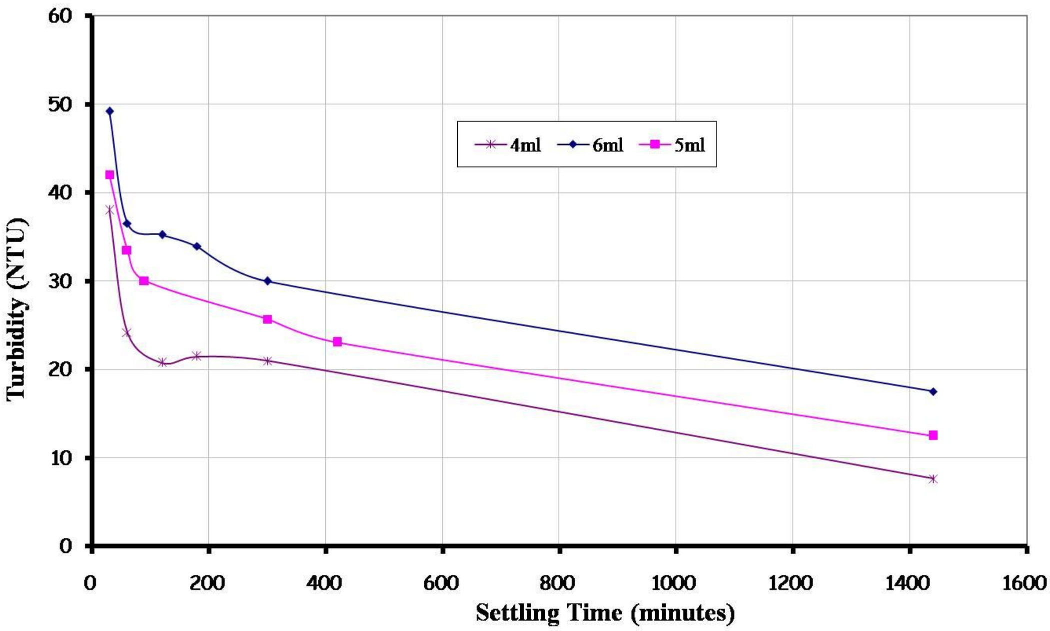
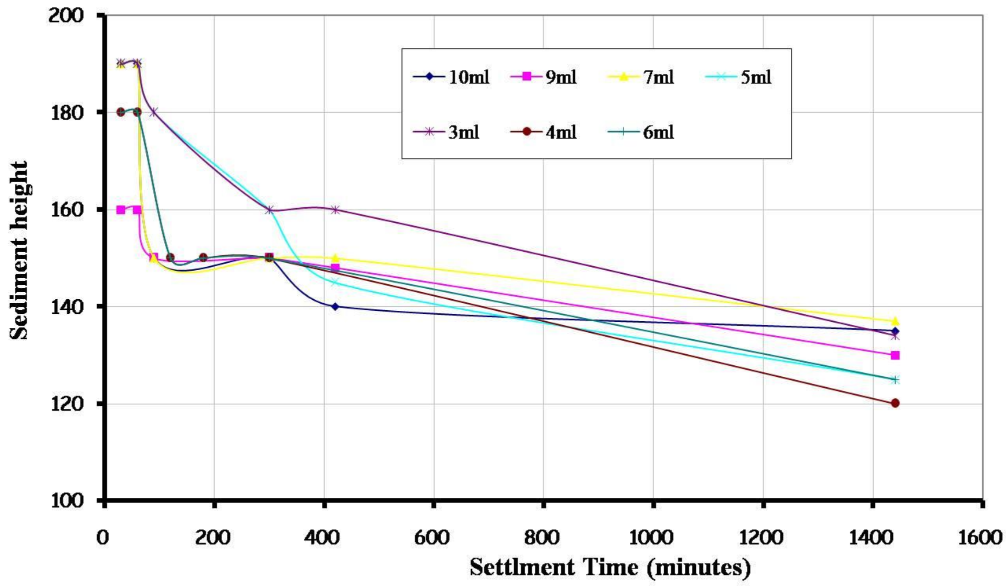


Fig. III.22 Sediment Height of Latex Coagulated with 2.5% $FeCl_3$ Solution



III.4.2 Effect of Polyelectrolyte (PE1)

The model wastewater (500 ml water contain 12.5 gm of 40% solid EPVC latex) is prepared with the addition of the 2.5% $FeCl_3$ solution at the optimum value of 4 ml that found early. Figure III.23 shows the effect of addition of poly-electrolyte (PE1) solution. The range of poly-electrolyte (PE1) solution is from 1 up to 10 ml . Figure III.23 shows and confirms that the best settlement and clearest supernated occurred at 5 ml of poly-electrolyte (PE1) solution, and the turbidity is at the low value of 20 NTU. Figure III.24 shows that the poly-electrolyte (PE1) increased the rate of settlement and the clarity of the supernatant. The optimum height is 150 ml.

Fig. III.23 Supernatant Turbidity of Latex Coagulated with 4 ml of (2.5% $FeCl_3$) Solution with different amount of 0.02% PE1

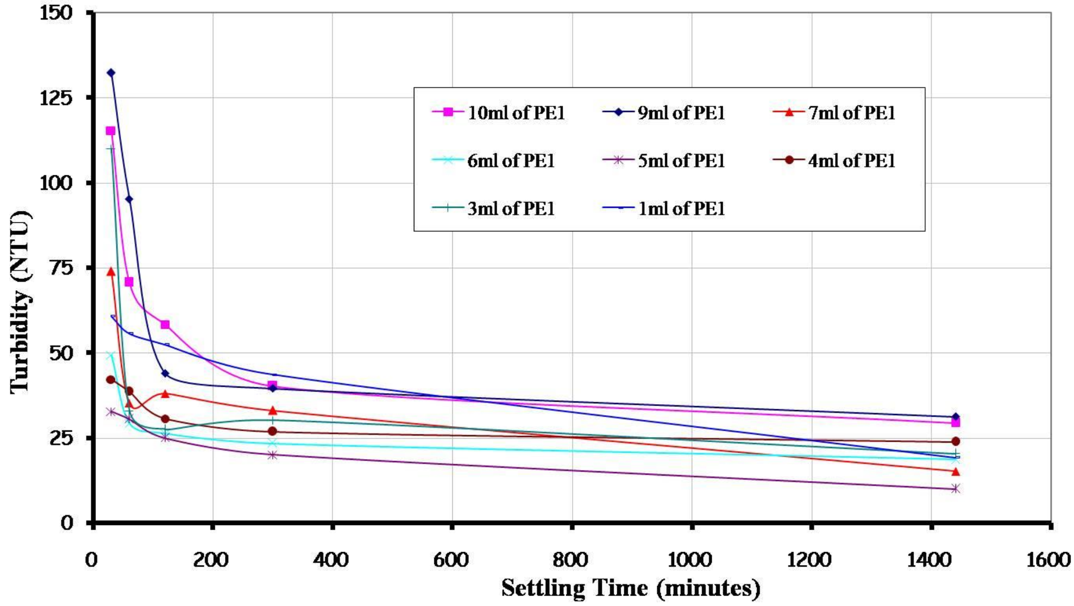


Fig. III.24 Sediment Height of Latex Coagulated with 4 ml of (2.5% $FeCl_3$) Solution with different amount of 0.02% PE1

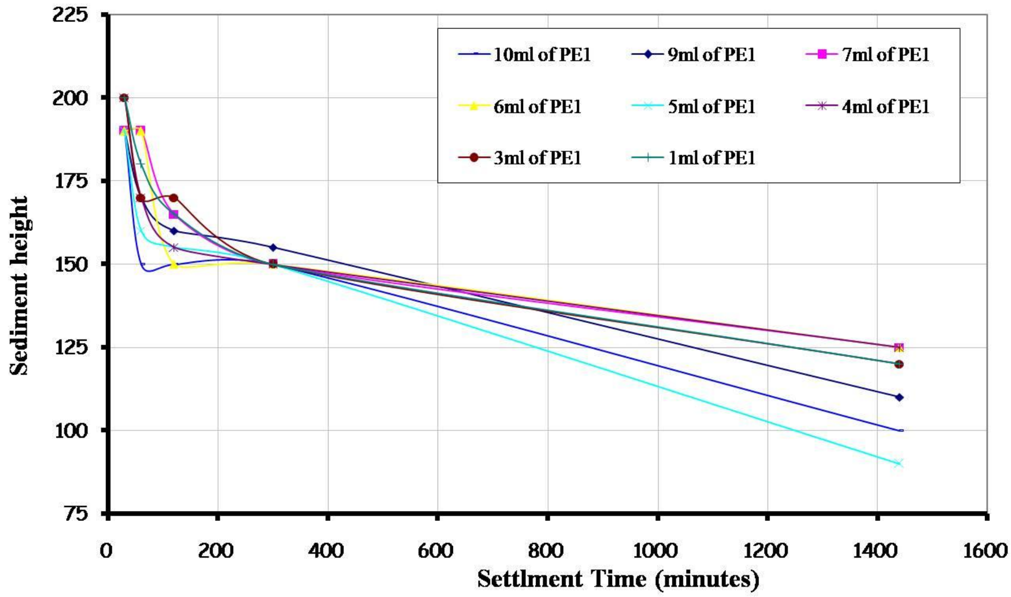


Table III.4 summarizes the effect of combined addition of 2.5% $FeCl_3$ and poly-electrolyte (PE1) solution. With 2.5% $FeCl_3$ solution alone (at optimum value of 4 ml), the turbidity is 21 NTU after five hours while the turbidity is 30 NTU after one hour only when 2.5% $FeCl_3$ solution and PE1 are added together.

Table III.4 Comparison between performance of 2.5% $FeCl_3$ alone and combined 2.5% $FeCl_3$ and PE1

Volume added per 500 ml waste water	Time(Hr)	Sedimentation height	Relative sedimentation%	Turbidity
2.5% $FeCl_3$ (4 ml)	5	150	30	21
2.5% $FeCl_3$ (4 ml) + 0.02% PE1 (5 ml)	1	160	32	30

III.4.3 Effect of pH

Figure III.25 shows the affect of pH on the coagulation of the model latex, for values of pH from pH=2.6 to pH=9.5. We can observe that overall turbidity decrease with time for all value of pH. Figure III.26 shows the variations of turbidity with pH after 300 minutes. We can see that turbidity is affected by pH. The turbidity decreases rapidly for pH less than 6 and is almost constant for larger values of pH.

Fig. III.25 Supernatant Turbidity of Latex Flocculated with 4 ml (2.5% $FeCl_3$) at different pHs

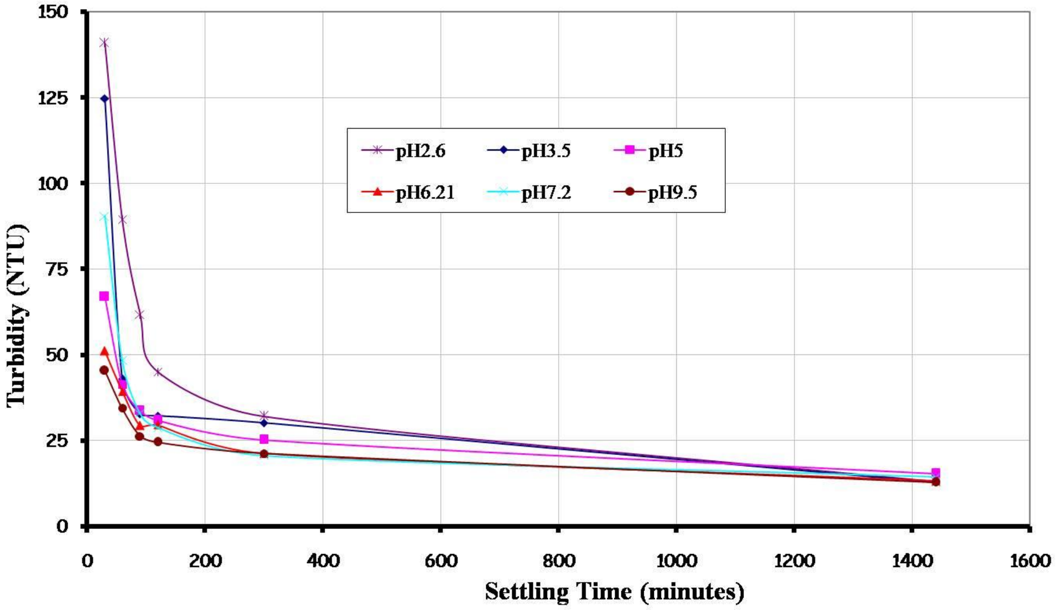
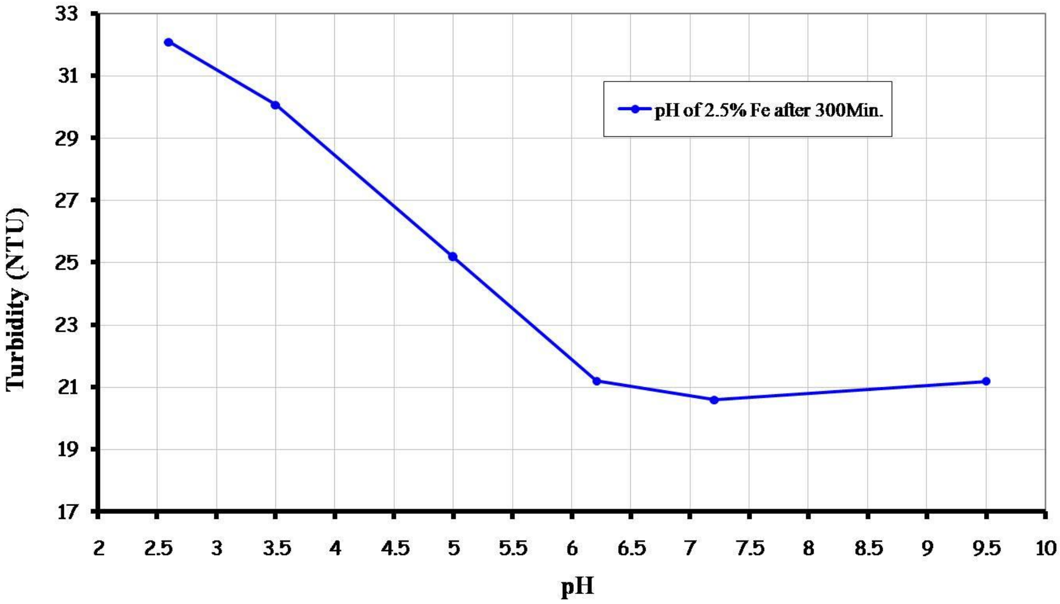


Fig. III.26 Supernatant Turbidity of Latex Flocculated with 4 ml (2.5% $FeCl_3$) at different pHs

after 5 hr settlement



III.4.4 Effect of Agitation speed

Figure III.27 shows the affect of stirrer agitation on turbidity and settlement. The range of agitation speed is from 200 to 1000 rpm. It can be see that agitation speed has an affect on the turbidity. Figures III.28 to III.29 show that the turbidity and sedimentation height are decreasing with agitation speed until it reaches a minimum at around 600 rpm and then increases. Optimum clarity and sediment height is obtained at 600rpm.

Fig. III.27 Supernatant Turbidity of Latex Flocculated with 4 ml (2.5% $FeCl_3$) and 5 ml (0.02% PE1) at different agitator speed

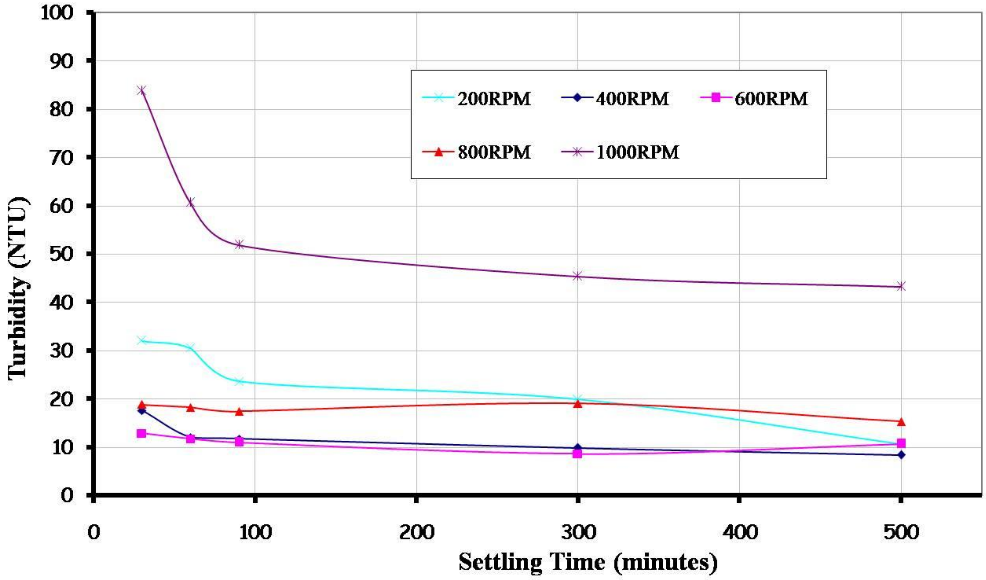


Fig. III.28 Supernatant `Turbidity of Latex Flocculated with 4 ml ($2.5\%\ FeCl_3$) and 5 ml (0.02% PE1) at different agitator speed
after 5 hr settlement

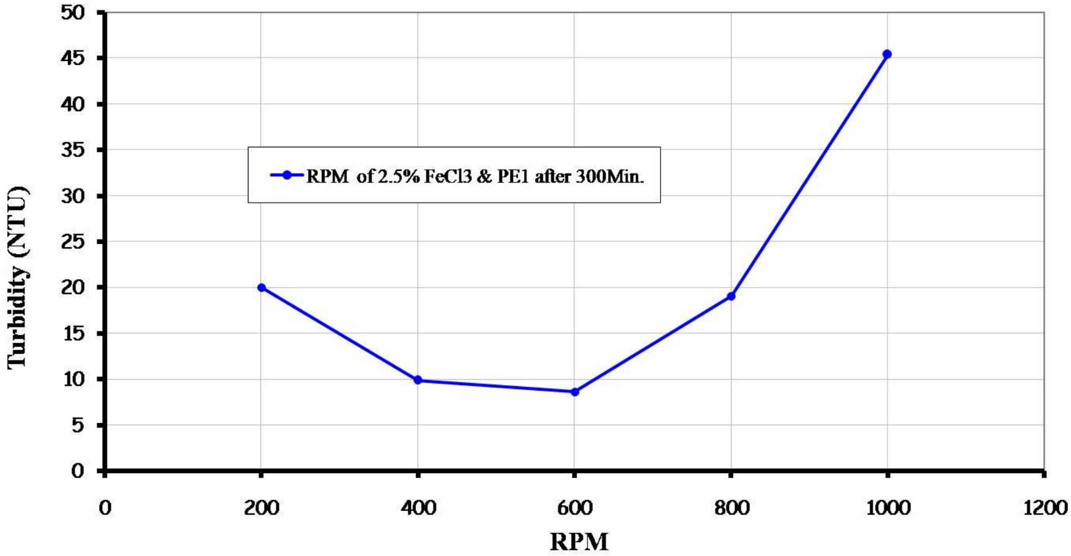
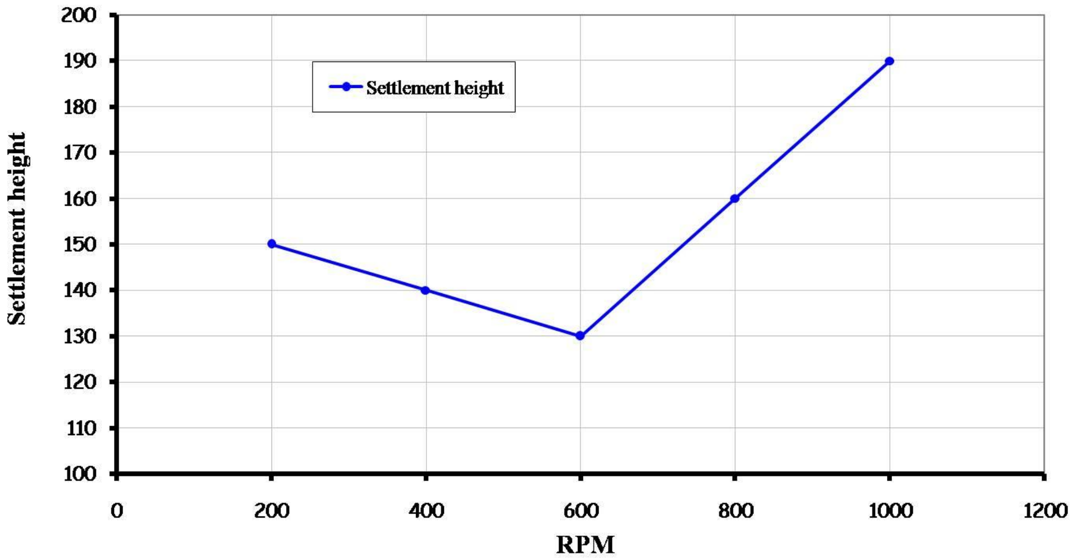


Fig. III.29 Settlement Height of Latex Flocculated with 4 ml ($2.5\%\ FeCl_3$) and 5 ml (0.02% PE1) at different agitator speed



III.4.5 Effect of CIBA Polyelectrolyte (PE2)

The model wastewater is prepared with the addition of the 2.5% $FeCl_3$ solution at the optimum value of 4 ml that found early. Figure III.30 shows the effect of addition of CIBA poly-electrolyte (PE2) solution. The range of CIBA poly-electrolyte (PE2) solution is from 1 up to 9 ml. From Fig.III.30 we noted that the minimum value for turbidity corresponds to the volume of CIBA poly-electrolyte (PE2) solution of 5 ml. Figure III.31 shows and confirms that the best settlement and clearest supernated occurred at 5 ml of CIBA poly-electrolyte (PE2) solution. So the PE1 and PE2 give the same behavior with 2.5% $FeCl_3$. It can be noted that the sedimentation height of 2.5% $FeCl_3$ with PE2 is lower (110) than with PE1 (150). (Figs.III.24, III.32).

Fig. III.30 Supernatant Turbidity of Latex Coagulated with 4 ml of (2.5% of $FeCl_3$) Solution with different amount of 0.02% PE2

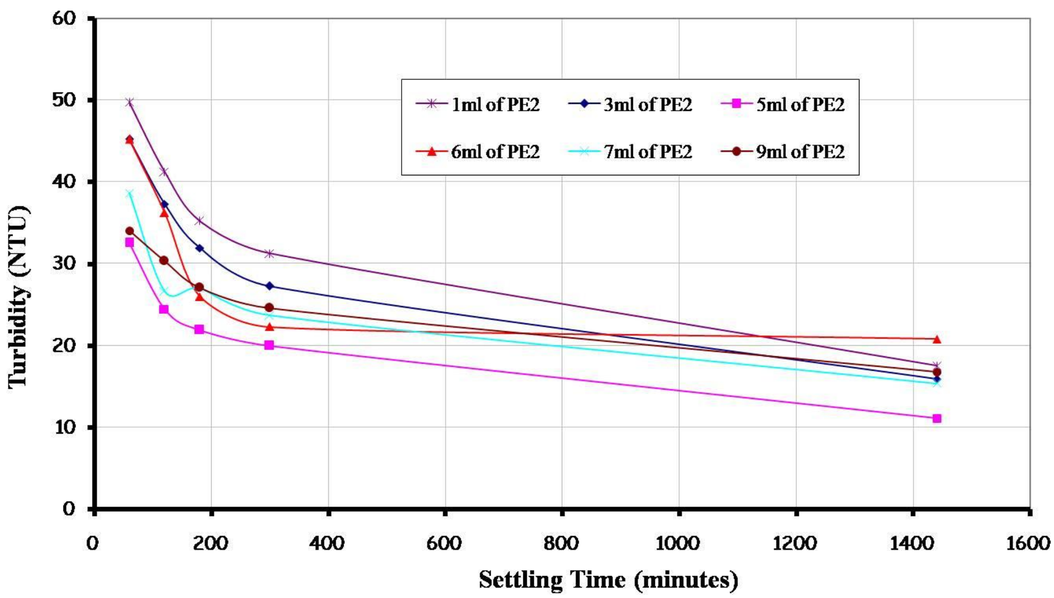


Fig. III.31 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE2 and 4 ml of (2.5% of $FeCl_3$) solution.
after 5 hr Settlement

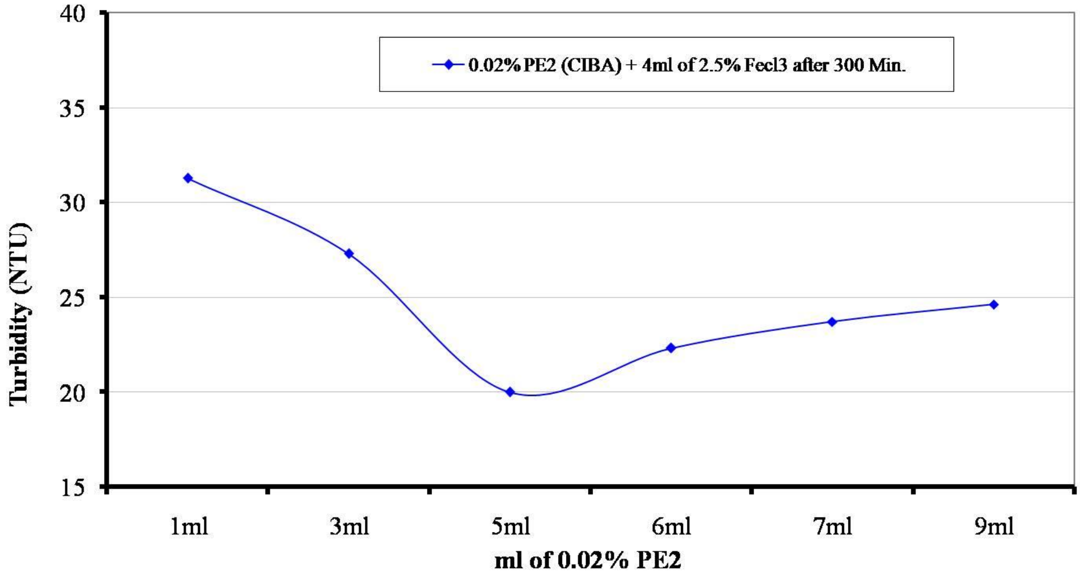
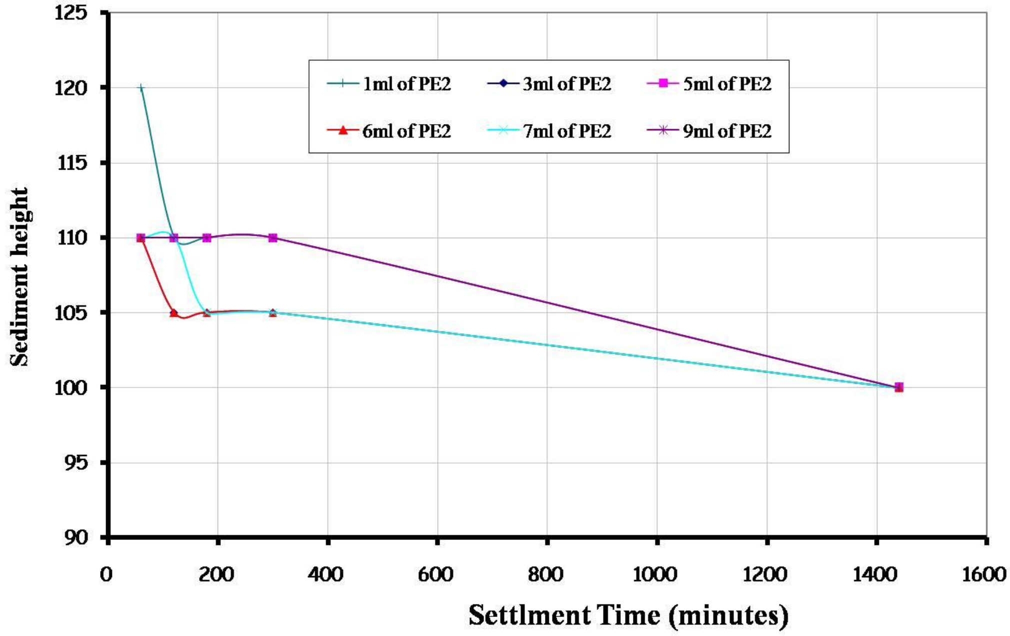


Fig. III.32 Sediment Height of Latex Coagulated with 2.5% of $FeCl_3$ Solution



III.4.6 Effect of CYTEC Polyelectrolyte (PE3)

The model wastewater is prepared with the addition of 2.5% $FeCl_3$ solution at the optimum value of 4 ml that found early. Figure III.33 shows the effect of addition of CYTEC poly-electrolyte (PE3) solution. The range of CYTEC poly-electrolyte (PE3) solution is from 1 up to 9 ml. From Fig.III.33 we noted that the minimum value for turbidity corresponds to the volume of CYTEC poly-electrolyte (PE3) solution of 5 ml. Figure III.34 confirms that the best settlement and clearest supernated occurred at 5 ml of CYTEC poly-electrolyte (PE3) solution. So the PE1, PE2 and PE3 give the same behavior with 2.5% $FeCl_3$. It can be noted that the sedimentation height of 2.5% $FeCl_3$ with PE3 is lower (120) than with PE1 (150). (Figs.III.24, III.35).

Fig. III.33 Supernatant Turbidity of Latex Coagulated with 4 ml of (2.5% of $FeCl_3$) Solution with different amount of 0.02% PE3

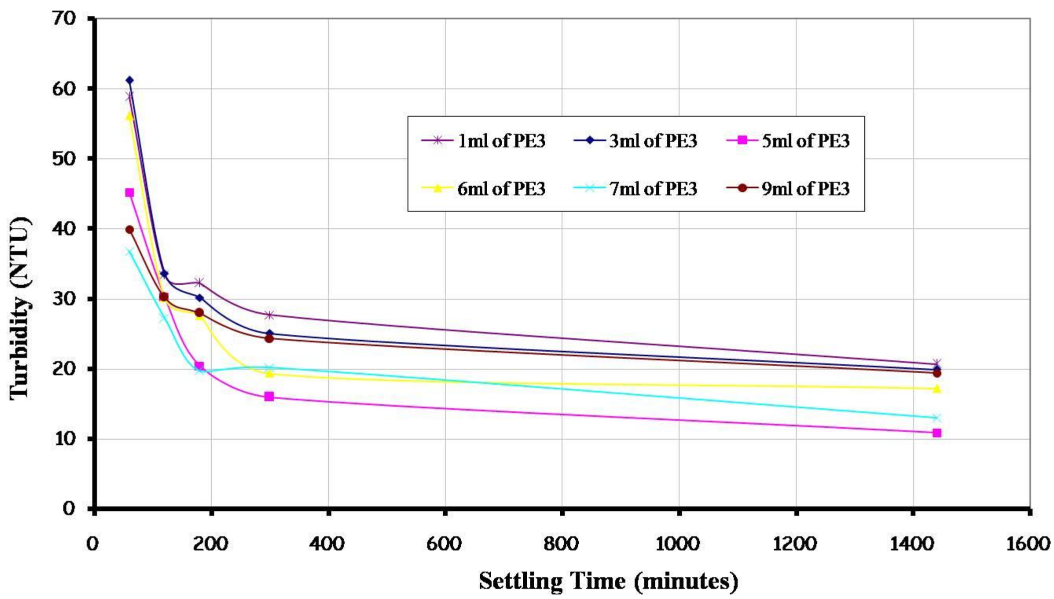


Fig. III.34 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE3 and 4 ml of (2.5% of $FeCl_3$) solution.
After 5 hr Settlement

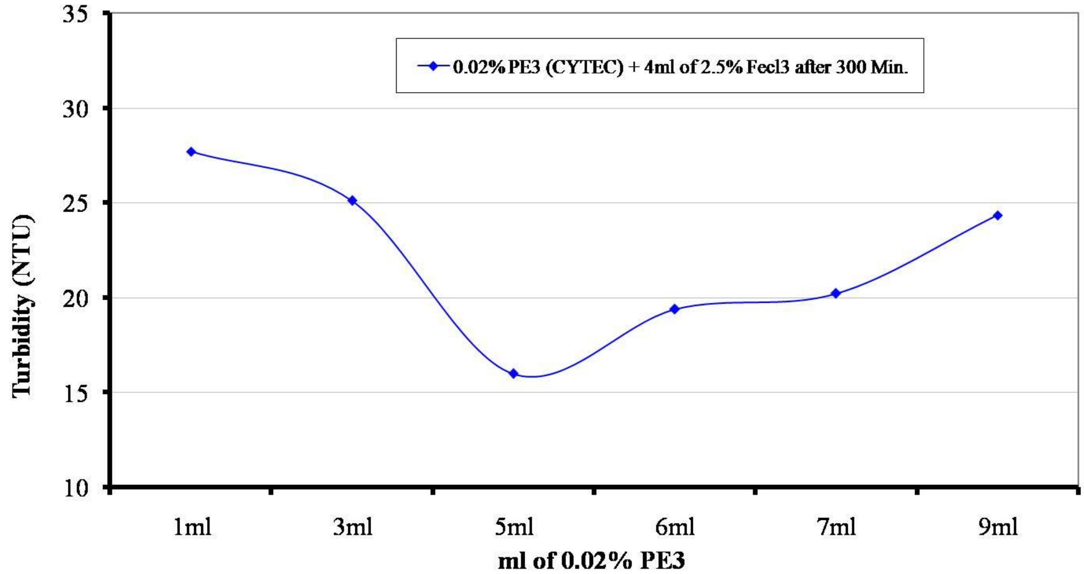
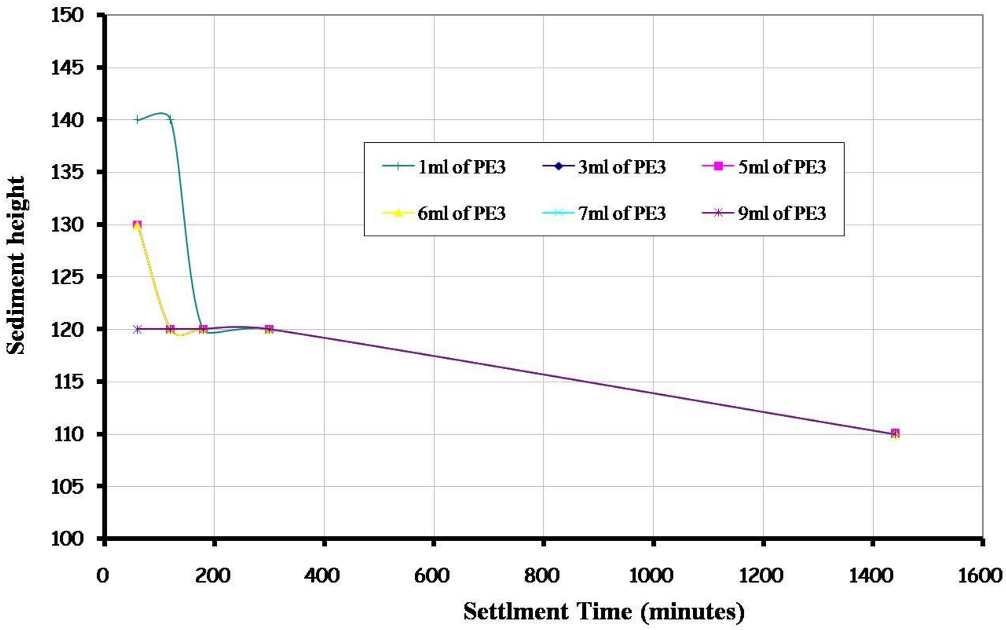


Fig. III.35 Sediment Height of Latex Coagulated with 2.5% of $FeCl_3$ Solution



III.4.7 Summary of Effect of Ferric Chloride

Table (III.5) shows a summary of the results associated with the effect of ferric chloride combined with different poly-electrolytes, pH and agitation speed. It can be seen from this table that PE3 gives the best performance. Therefore the optimum value of parameters are as follow;

- Ferric Chloride = 0.1 gm
- PE3 = 0.001 gm
- pH = any value larger than 7, but preferably smaller than 8.
- Agitation speed = 600 rpm

Table III.5:Summary of performance of ferric chloride with other parameters

Parameters	Fe^{3+}(ml)	PE1(gm)	PE2(gm)	PE3(gm)	pH	Optimum rpm
Optimum Value	**4 ml**	**0.001**	**0.001**	**0.001**	**7-8**	**600**
Optimum Turbidity	**21**	**20**	**20**	**16**	**7-8**	**9**

III.5 Coagulation of Modal Waste Latex Using Calcium Chloride

III.5.1 Effect of Calcium Chloride

Figure III.36 shows the change in turbidity when model waste water (500 ml water contain 12.5 gm of 40% solid EPVC latex) was coagulated by 2.5% calcium chloride solution. The range of the calcium chloride solution is from 5 ml up to 30 ml. For each volume of calcium chloride solution the figure shows a minimum. Figure III.36 shows that the optimum volume of calcium chloride solution is 28 ml and the turbidity is at the low value of 10 NTU. Figure III.37 shows the sedimentation height with the time for the same volume of calcium chloride solution. The optimum height is at 135 ml when volume of calcium chloride solution is 28 ml.

Fig. III.36 Supernatant Turbididity of Latex Coagulated with 2.5% $CaCl_2$ Solution

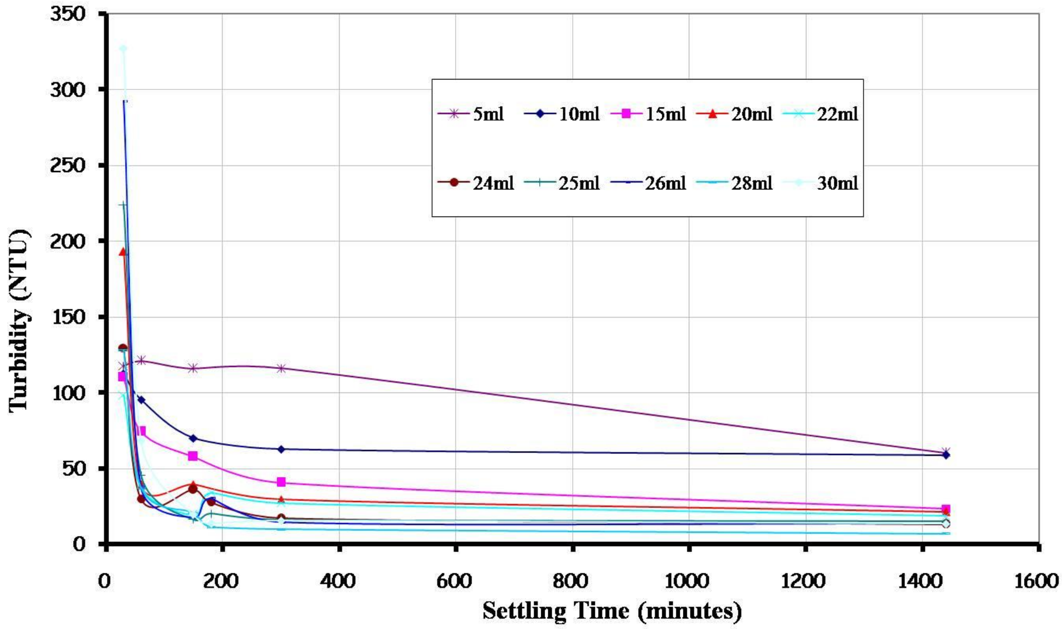
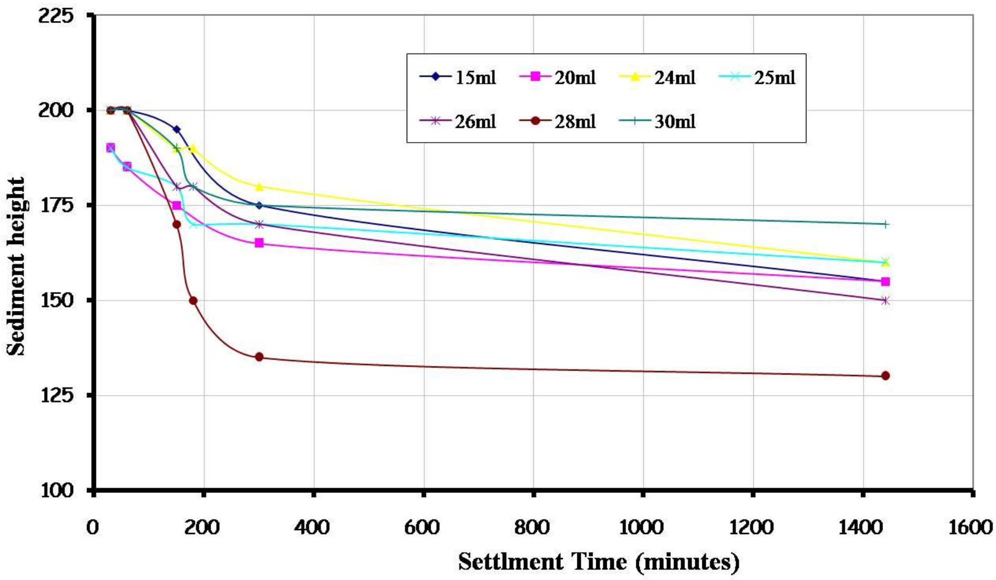


Fig. III.37 Sediment Height of Latex Coagulated with 2.5% $CaCl_2$ Solution



III.5.2 Effect of Polyelectrolyte (PE1)

The model wastewater (500 ml water contain 12.5 gm of 40% solid EPVC latex) is prepared with the addition of the calcium chloride solution at the optimum value of 28 ml that found early. Figure III.38 shows the effect of addition of poly-electrolyte (PE1) solution. The range of poly-electrolyte (PE1) solution is from 1 up to 10 ml. Figure III.38 shows that the clearest supernated occurred at 5 ml of poly-electrolyte (PE1) solution, and the turbidity is at the low value of 8.37 NTU. Figure III.39 shows that the poly-electrolyte (PE1) increased the rate of settlement and the clarity of the supernatant. The best settlement and optimum height was 140 ml when using 5 ml of 0.02% PE1 solution.

Fig. III.38 Supernatant Turbidity of Latex Coagulated with 28 ml of ($2.5\%\ CaCl_2$) Solution with different amount of 0.02% PE1

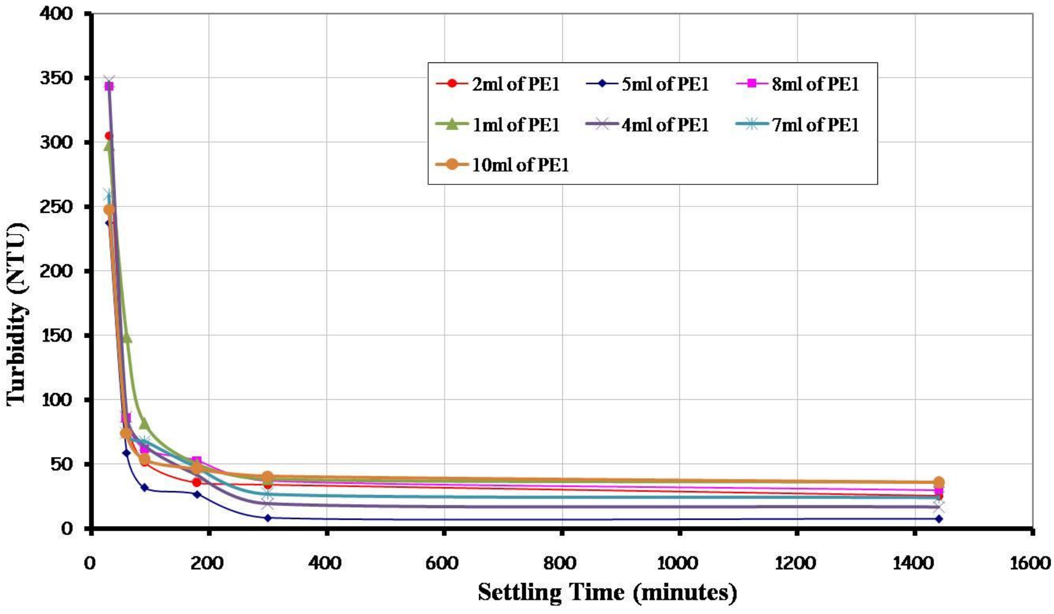
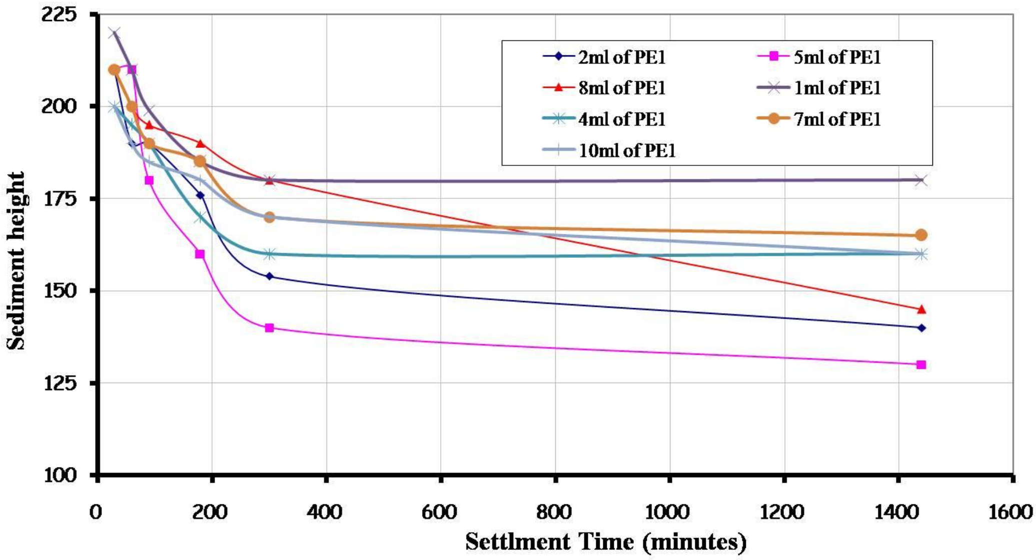


Fig. III.39 Sediment Height of Latex Coagulated with 28 ml of (2.5% $CaCl_2$) Solution with different amount of 0.02% PE1



III.5.3 Effect of pH

Figure III.40 shows the affect of pH on the coagulation of the model latex, for values of pH from pH=2.6 to pH=9. We can observe that overall turbidity decrease with time for all value of pH. Figure III.41 shows the variations of turbidity with pH after 5 hr. We can see that turbidity is decreasing by increasing pH value.

Fig. III.40 Supernatant Turbidity of Latex Flocculated with 28 ml ($2.5\% \ CaCl_2$) at different pHs

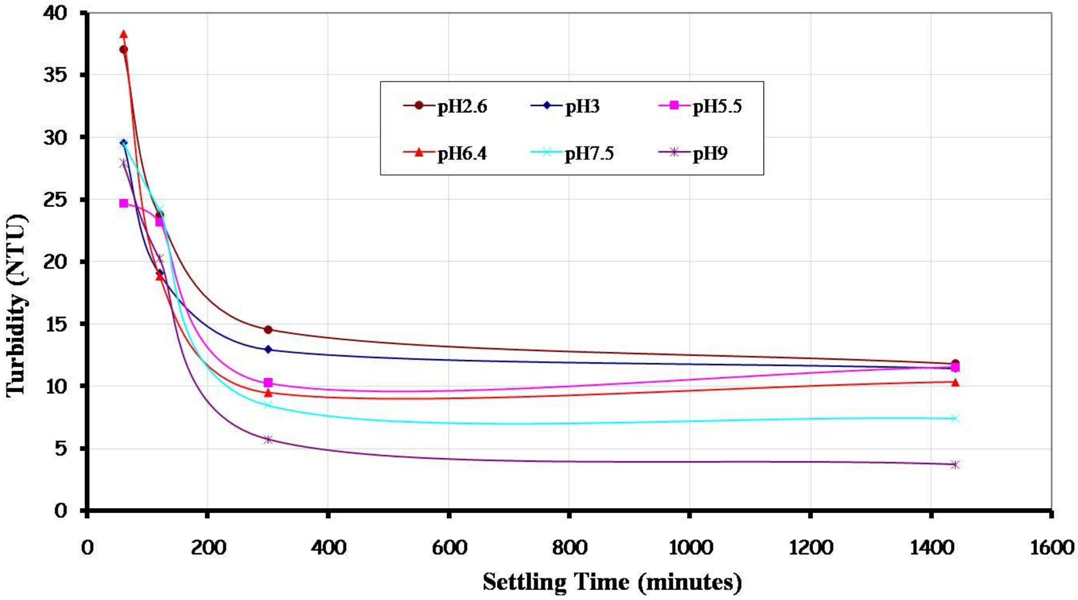
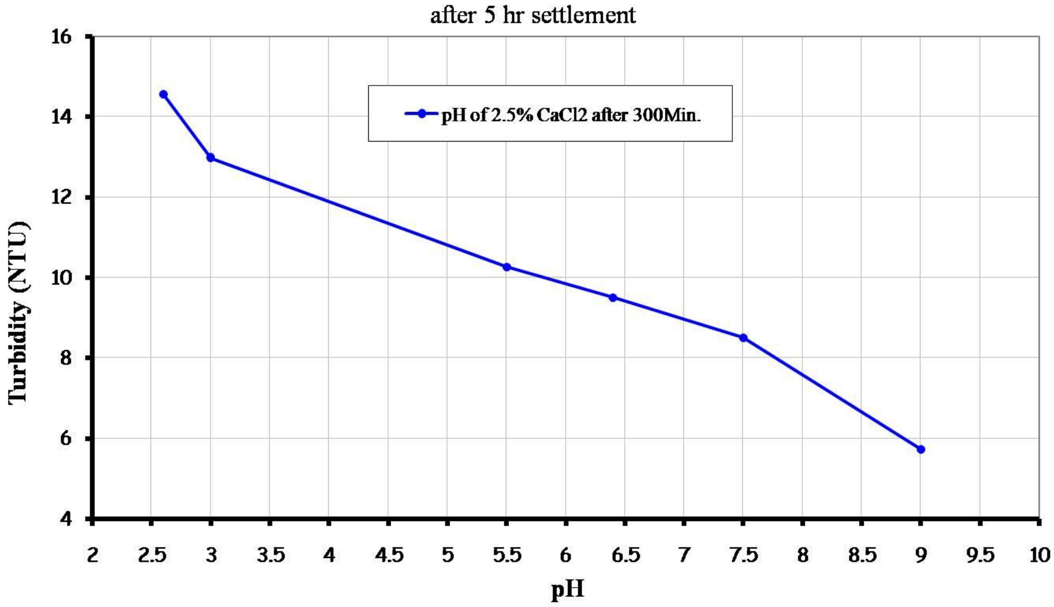


Fig. III.41 Supernatant Turbidity of Latex Flocculated with 28 ml ($2.5\% \ CaCl_2$) at different pHs

after 5 hr settlement



III.5.4 Effect of Agitation speed

Figures III.42 to III.44 show the affect of stirrer agitation on turbidity and settlement. The range of agitation speed is from 200 to 1000 rpm. It can be see that agitation speed has an affect on the turbidity. Figure III.43 shows that the turbidity decrease with agitation speed until it reaches a minimum at around 400 rpm and then increases. Figure III.44 shows that settlement height increased from 200-600 rpms then become constant at 170.

Fig. III.42 Supernatant Turbidity of Latex Flocculated with 28 ml (2.5% $CaCl_2$) and 5 ml (0.02%PE1) at different agitator speed

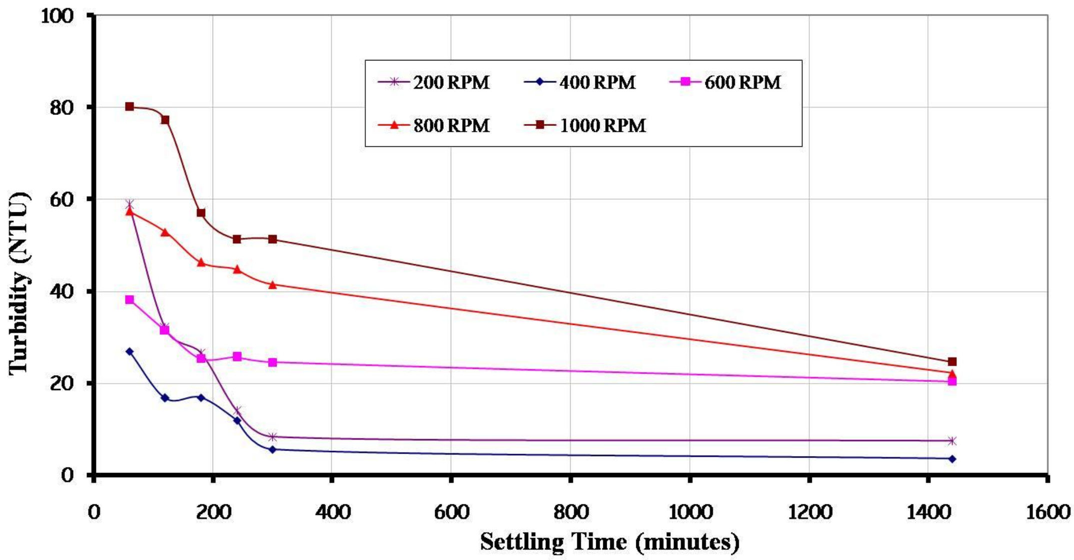


Fig. III.43 Supernatant Turbidity of Latex Flocculated with 28 ml (2.5% $CaCl_2$) and 5 ml (0.02% PE1) at different agitator speed
after 5 hr settlement

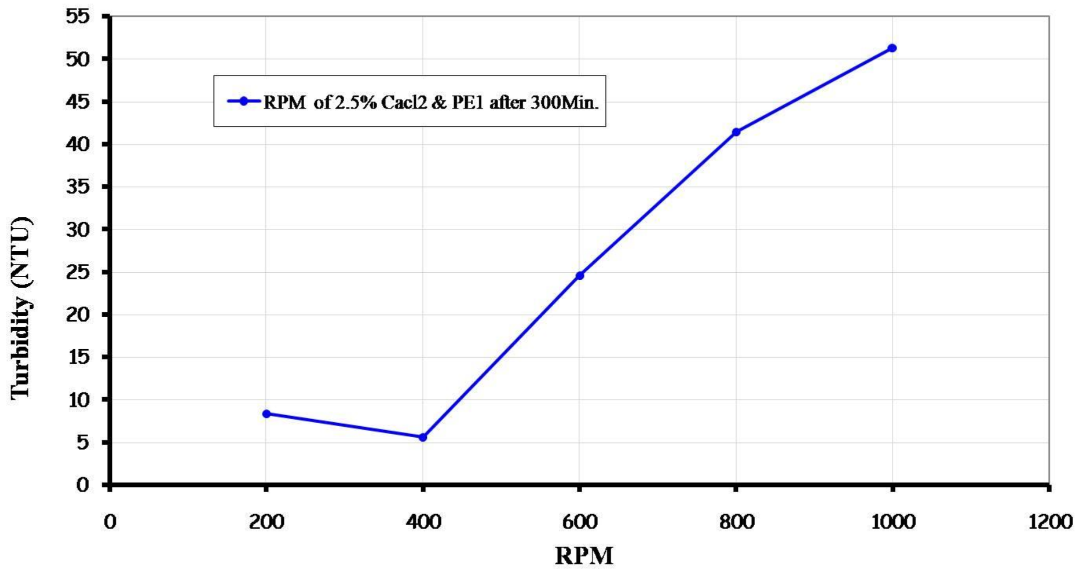
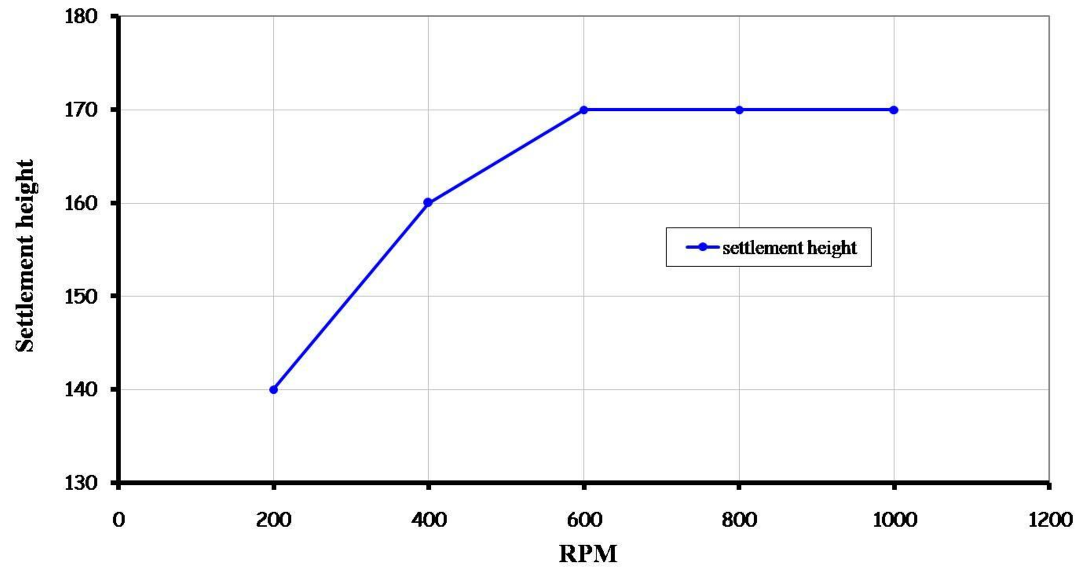


Fig. III.44 Supernatant Turbidity of Latex Flocculated with 28 ml (2.5% $CaCl_2$) and 5 ml (0.02% PE1) at different agitator speed



III.5.5 Effect of CIBA Polyelectrolyte (PE2)

The model wastewater is prepared with the addition of the calcium chloride solution at the optimum value of 28 ml that found early. Figure III.45 shows the effect of addition of CIBA poly-electrolyte (PE2) solution. The range of CIBA poly-electrolyte (PE2) solution is from 1 up to 9 ml . Figure III.46 shows that the best settlement and clearest supernated occurred at 5 ml of CIBA poly-electrolyte (PE2) solution. So the PE1 and PE2 give the same behavior with calcium chloride. Figure III.47 shows that the sedimentation height of 2.5% $CaCl_2$ with PE2 is lower (110) than with PE1 (140). (Figs. III.39,III.47)

Fig. III.45 Supernatant Turbidity of Latex Coagulated with 28 ml of (2.5% of $CaCl_2$) Solution with different amount of 0.02% PE2

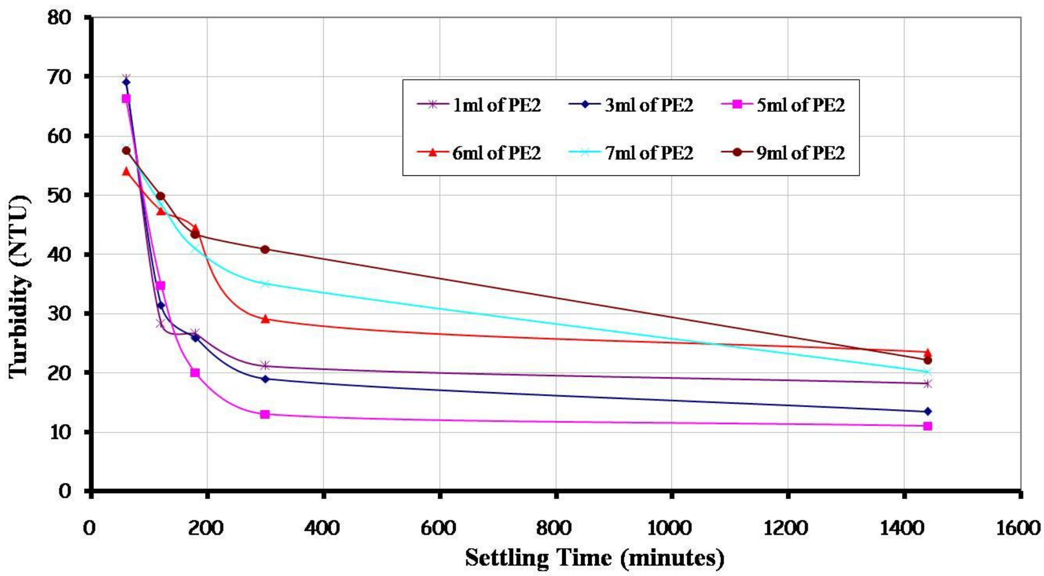


Fig. III.46 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE2 and 28 ml of (2.5% of $CaCl_2$) solution.
After 5 hr Settlement

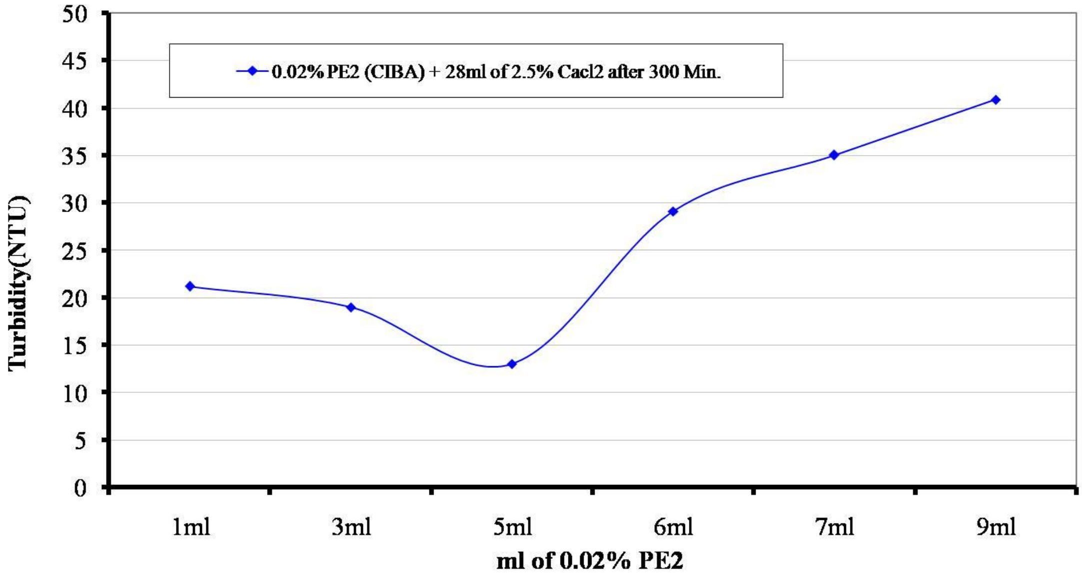
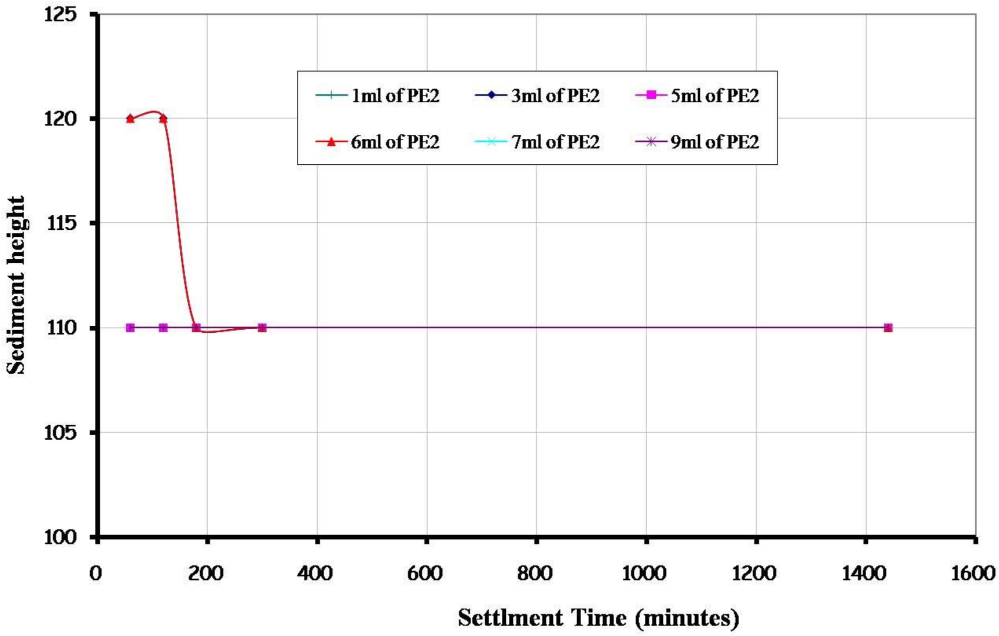


Fig. III.47 Sediment Height of Latex Coagulated with 2.5% of $CaCl_2$ Solution



III.5.6 Effect of CYTEC Polyelectrolyte (PE3)

The model wastewater is prepared with the addition of calcium chloride solution at the optimum value of 28 ml that found early. Figure III.48 shows the effect of addition of CYTEC poly-electrolyte (PE3) solution. The range of CYTEC poly-electrolyte (PE3) solution is from 1 up to 9 ml. From Fig.III.48 we noted that the minimum value for turbidity corresponds to the volume of CYTEC poly-electrolyte (PE3) solution is 3 ml. Figure III.49 shows that the best settlement and clearest supernated occurred at 3 ml of CYTEC poly-electrolyte (PE3) solution. Figure III.50 shows that the sedimentation height of 2.5% $CaCl_2$ with PE3 is lower (110) than with PE1 (140). (Figs. III.39, III.50).

Fig. III.48 Supernatant Turbidity of Latex Coagulated with 28 ml of (2.5% of $CaCl_2$) Solution with different amount of 0.02% PE3

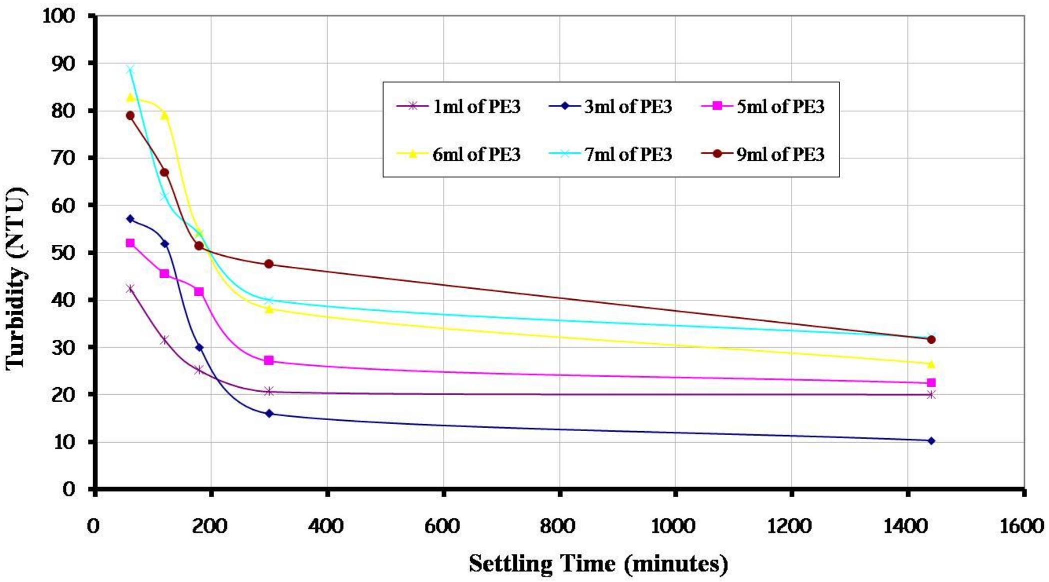


Fig. III.49 Supernatant Turbidity of Latex coagulated with different amount of 0.02% PE3 and 28 ml of (2.5% of $CaCl_2$) solution.
After 5 hr Settlement

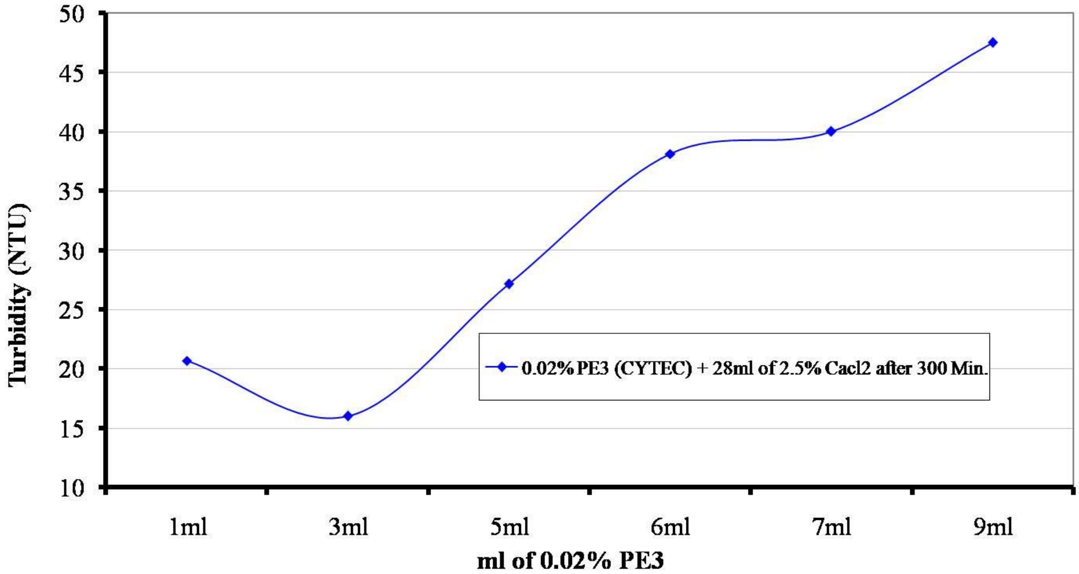
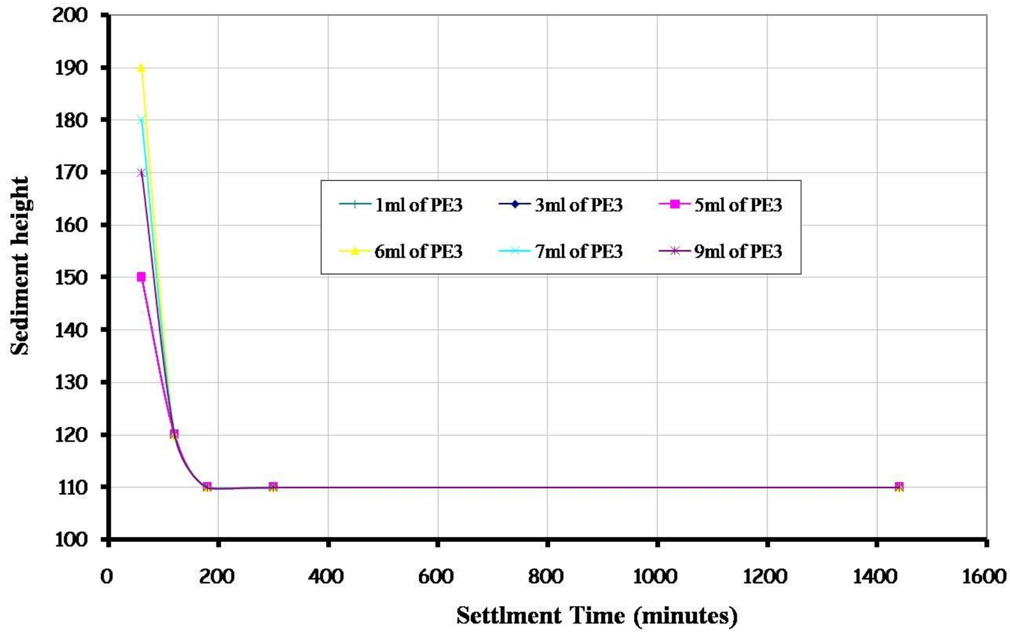


Fig. III.50 Sediment Height of Latex Coagulated with 2.5% of $CaCl_2$ Solution



III.5.7 Summary of Effect of Calcium Chloride

Table (III.6) shows a summary of the results associated with the effect of calcium chloride combined with different poly-electrolytes, pH and agitation speed. It can be seen from this table that PE3 gives the best performance. Therefore the optimum value of parameters are as follow;

- Calcium Chloride = 0.7 gm.
- PE3 = 0.0006 gm.
- pH = any value large than 7, but preferably smaller than 8.
- Agitation speed = 400 rpm.

Table III.6: Summary of performance of calcium chloride with other parameters

Parameters	Ca^{2+}(ml)	PE1(gm)	PE2(gm)	PE3(gm)	pH	Optimum rpm
Optimum Value	**28**	**0.001**	**0.001**	**0.0006**	**7-8**	**400**
Optimum Turbidity	**10**	**8.37**	**13**	**16**	**7-8**	**5.62**

Table IV.1 summarizes the results showing the parameters and their optimum values for the three metals ions. It should be noted that the optimization in this project was restricted to the effects on the coagulation/flocculation process and did not include an economic study. It can be seen from this table that, aluminum sulphate (0.5% $Al_2(SO_4)_3$) combined with poly-electrolyte (PE1) at the given pH and agitation speed gives the best results, because only 0.0375 gm is required to coagulate the model wastewater. Ferric chloride (2.5% $FeCl_3$) combined with PE3 at the shown optimum values is slightly less effective since it requires 0.1 gm and the optimum turbidity is slightly higher. As for calcium chloride (2.5% $CaCl_2$) combined with PE3 at shown optimum values, it is less effective since 0.7 gm (=19 times that of Al^{3+} ions) are needed to obtain the same coagulation as aluminum sulphate.

It can also be noted that the amount of poly-electrolyte (PE1) to be combined with aluminum sulphate is the least of all the other polyelectrolytes. The optimum speed was found to be 600 rpm, while the pH should be chosen above the 7 value, but preferably below 8 for corrosion considerations.

The issue to be investigated now is the order of adding the different chemicals. For the pH, it is adjusted in the plant before it reaches the concentrator.

Figure IV.1 shows a picture of the sample of model wastewater where the metal(Al^{3+}) was added first followed by polyelectrolyte (PE1), while figure IV.2 shows the effect of adding PE1 first followed by the metal. It is clear from the figure that metal should be added first since the figure shows a cloudy coagulation. The reason is that the PVC is already negatively charged (because of the effect of sodium lauryl sulphate, as discussed in section I.2.1). Adding the negatively charge of poly-electrolyte first will lead to repulsion between the particles.

Table IV.1 Results summary of coagulant metals ion with polyelectrolyte

Metals	Concentration of solution	ml solution for coagulation	gm of metal to coagulate wastewater	Type of Polyelectrolyte	ml of 0.02% PE solution to coagulate wastewater	g PE to coagulate wastewater	Turbidity	Optimum	
								rpm	pH
Al^{3+}	0.50%	7.5	0.0375	PE1	1.5	0.0003	14	600	7-8
Fe^{3+}	2.50%	4	0.1	PE3	5	0.001	16	600	7-8
Ca^{2+}	2.50%	28	0.7	PE3	3	0.0006	16	400	7-8

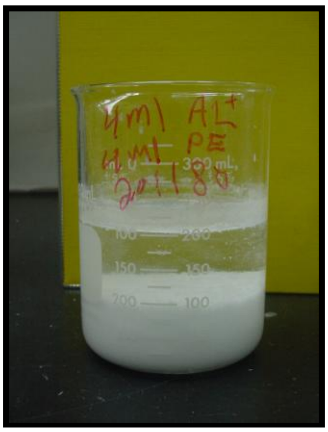


Figure IV.1:Adding metals ion then polyelectrolyte

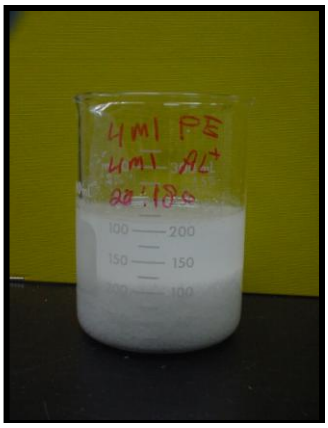


Figure IV. 2:Adding polyelectrolyte then metals ion

Chapter IV:
Conclusions

This research presented results of an experimental study of flocculation/coagulation process of wastewater generated from a polyvinyl chloride (PVC) plant. The wastewater contains chlorine based solid materials (i.e. latex). Experiments were carried out using a model wastewater which is chemically identical to the actual plant but is more consistent. Inorganic ions ($Al_2(SO_4)_3$, $FeCl_3$ and $CaCl_2$) and different water soluble commercial polyelectrolytes (PE1, PE2 and PE3) were added to the wastewater sample. Coagulation efficiency was determined by measuring both the turbidity of the supernatants and the relative settlement of the flocs in the Jar test. It was found that aluminum and ferric ions were more efficient than calcium ions as coagulants. The addition of polyelectrolyte improved the coagulation/flocculation process. It was found that that aluminum sulphate (0.5% $Al_2(SO_4)_3$) combined with polyelectrolyte (PE1) at pH in the range of 7 to 8, and agitation speed of 600 rpm give the best results. Ferric chloride (2.5% $FeCl_3$) combined with polyelectrolyte (PE3) is slightly less effective. As for calcium chloride (2.5% $CaCl_2$) combined with PE3 it is the least effective since 0.7 gm of the coagulant (=19 times that of Al^{3+} ions) are needed to obtain the same coagulation as aluminum sulphate. The coagulation/flocculation process was also found to be dependent on both the pH and the agitation speed.

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Appendix A: Tables and Pictures of Results

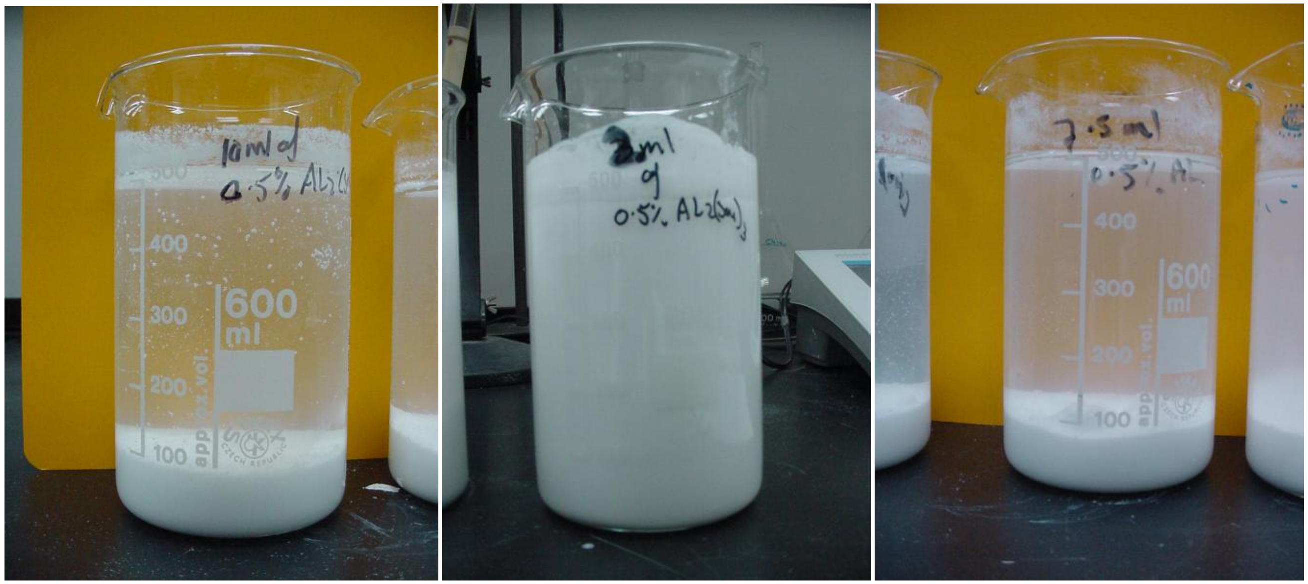
A1 Experimental Results

A1.1 Table showing coagulation of model waste latex using aluminum sulphate

Dosage	10ml		8ml		7ml		6ml		4ml		3ml		2ml	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
10	198.3	190	67.2	185	62.85	170	185.7	150	200	Cloudy	136	Cloudy	135.7	Cloudy
60	187.6	170	60.49	140	60.95	140	97.84	120	192	Cloudy	134	Cloudy	129.1	Cloudy
120	148.4	150	56.45	130	52.7	110	87.8	105	156.3	Cloudy	129.2	Cloudy	117.9	Cloudy
300	85.1	140	55	110	51.99	110	81.19	110	105.3	Cloudy	109.3	Cloudy	112.7	Cloudy
1440	58.3	110	20.17	100	30.5	100	50.01	105	62.4	Cloudy	78.2	Cloudy	81.7	Cloudy

Dosage	6.5ml		7.5ml		8.5ml	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
10	200	160	81.83	170	149.4	180
60	110	140	61.11	150	84.24	150
160	68.7	130	56.08	120	77.63	120
250	61.34	120	39.85	115	57.17	115
300	60	115	20	110	57.75	105
370	59.32	110	18.96	105	51.88	100
1440	52.15	100	18.05	80	33.93	95

A1.2 Digital pictures showing coagulation of model waste latex using aluminum sulphate



A1.3 Coagulation of Model Waste Latex using Aluminum sulphate with polyelectrolyte (PE1)

Dosage	10ml of PE1		9ml of PE1		7ml of PE1		5ml of PE1		3ml of PE1		1ml of PE1	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	313.5	120	374.4	120	252.2	125	342	160	50.93	100	63.82	170
70	82.79	100	58.57	100	157.5	110	168.3	118	58.97	120	37.39	165
110	81.6	100	59.7	100	163.2	105	47.98	100	39.9	120	24.4	150
160	78.12	100	49.37	100	143.1	100	45.66	100	37.95	120	41.91	145
210	57.85	100	47.75	100	95.31	95	39.77	100	25.97	120	24	145
300	47.92	100	45.35	100	44.5	95	36.24	105	22.66	125	20	145

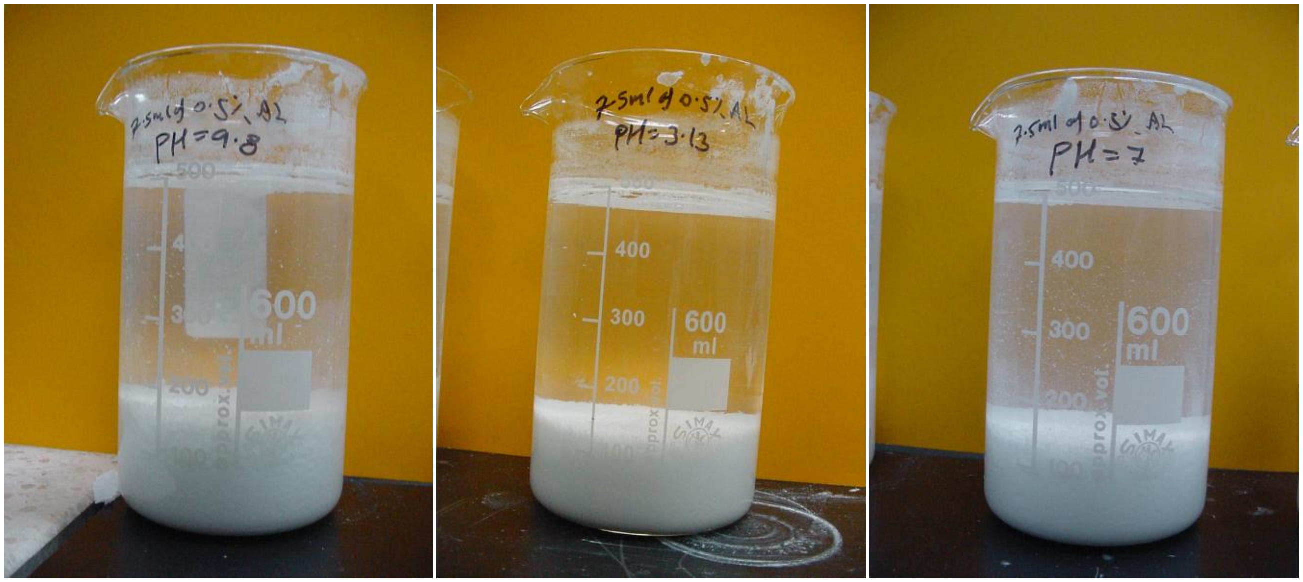
Dosage	2ml of PE1		1.5ml of PE1		0.5ml of PE1	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
10	432.2	190	326.9	170	549.8	200
30	159.1	190	32.25	120	58.06	150
60	111.6	150	22.12	110	27.49	130
100	116	130	22	110	35.77	125
180	46.95	120	15.08	110	23.2	115
300	22.8	120	14	110	22.56	110

A1.4 Digital pictures showing coagulation of model waste latex using aluminum sulphate with polyelectrolyte (PE1)

A1.5 Coagulation of Model Waste Latex using Aluminum sulphate with different pH

Dosage settling Time(min.)	pH9.8 with 7.5ml of 0.5%Al	pH7 with 7.5ml of 0.5%Al	pH6.6 with 7.5ml of 0.5%Al	pH5 with 7.5ml of 0.5%Al	pH3.13 with 7.5ml of 0.5%Al	pH2.7 with 7.5ml of 0.5%Al
30	1100	1093	1100	1100	1100	903.3
60	807.7	362.9	496.4	364.1	1100	849
90	272.6	127.2	208.3	104	174.6	671.4
120	119.2	37.43	54.5	44.36	116.5	569.1
180	38.05	24.43	20.12	28.05	57.18	257.2
240	43.2	20.58	16.89	17.42	50.34	84.2
300	15.39	14.53	13.7	16.3	17.4	18.97
1440	13.75	20.06	17.9	13.4	11.93	14.3

A1.6 Digital pictures showing Coagulation of Model Waste Latex using Aluminum sulphate with different pH



A1.7 Coagulation of Model Waste Latex using Aluminum sulphate with polyelectrolyte (PE1) at different speeds

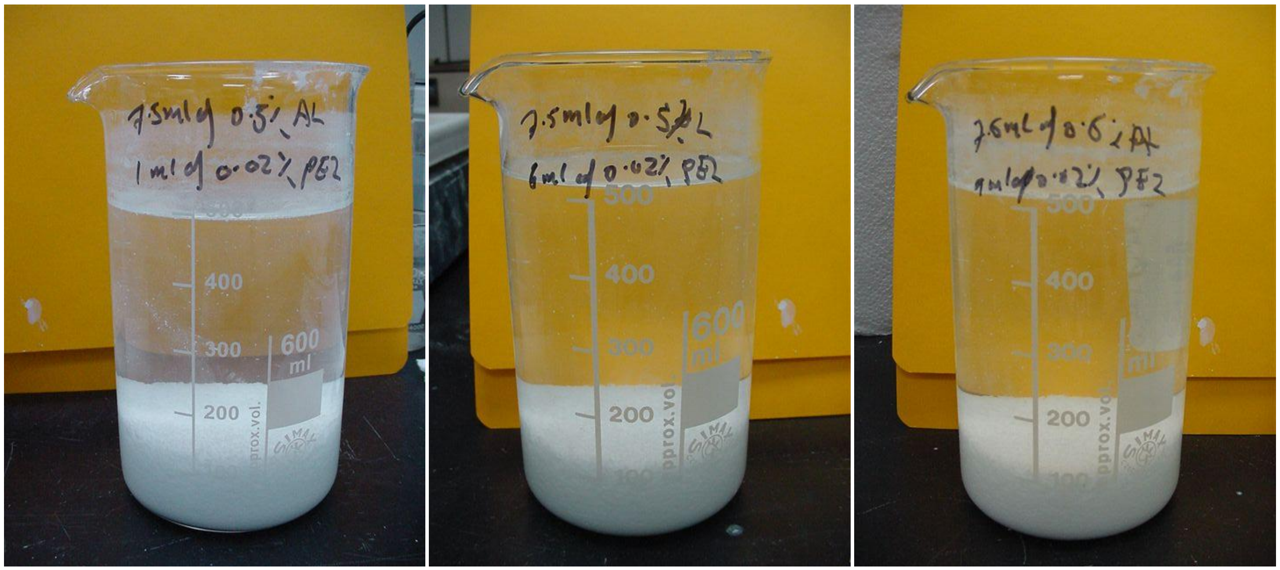
settling Time(min.)	200 RPM @ 7.5ml of 0.5%Al and 1.5ml of 0.02%PE1		400 RPM @ 7.5ml of 0.5%Al and 1.5ml of 0.02%PE1		600 RPM @ 7.5ml of 0.5%Al and 1.5ml of 0.02%PE1		800 RPM @ 7.5ml of 0.5%Al and 1.5ml of 0.02%PE1		1000 RPM @ 7.5ml of 0.5%Al and 1.5ml of 0.02%PE1	
	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	22.12	110	38.75	95	45.76	100	41.42	110	134.7	125
120	21.4	110	36.2	95	36.79	100	8.47	110	119.2	125
180	15.08	110	24.05	95	25	100	5.04	110	71.19	125
240	15	110	21.21	95	21.18	100	12	110	65.7	125
300	14	110	13	95	12.46	100	19	110	25	125
360	32	90	11.77	95	16.39	100	4.97	110	29.97	125
1440	40	90	41.45	95	6.55	100	10.55	110	18.52	125

A1.8 Digital pictures showing Coagulation of Model Waste Latex using Aluminum sulphate with polyelectrolyte (PE1) at different speeds

A1.9 Coagulation of Model Waste Latex using Aluminum sulphate with CIBA polyelectrolyte (PE2)

Dosage	1ml of PE2		3ml of PE2		5ml of PE2		6ml of PE2		7ml of PE2		9ml of PE2	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	114.2	150	21.9	150	30.71	150	12.08	150	13.5	150	16.89	150
90	65.32	120	20.27	120	23.69	120	10.64	120	14.72	120	13.28	120
150	36.02	110	18.17	110	16.32	110	6.56	110	15.67	110	13.95	110
300	27.65	110	12.35	110	7	110	4	110	6.1	110	11.32	110
1440	13.87	110	6.01	110	5.73	105	2	105	10	108	7.61	110

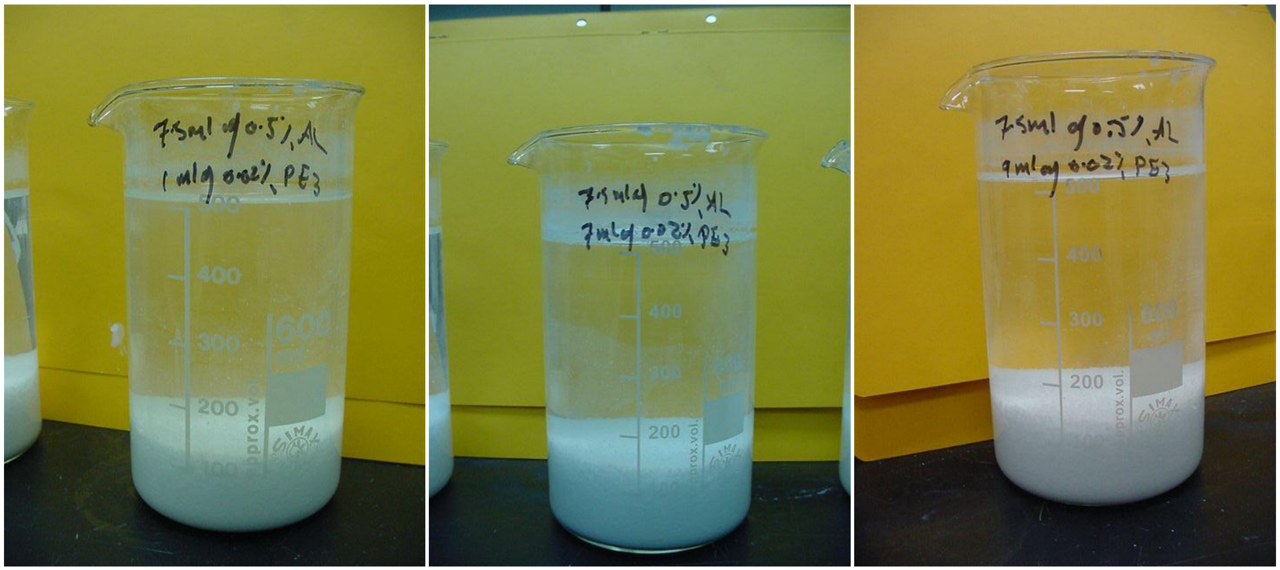
A1.10 Digital pictures showing Coagulation of Model Waste Latex using Aluminum sulphate with CIBA polyelectrolyte (PE2)



A1.11 Coagulation of Model Waste Latex using Aluminum sulphate with CYTEC polyelectrolyte (PE3)

Dosage	1ml of PE3		3ml of PE3		5ml of PE3		6ml of PE3		7ml of PE3		9ml of PE3	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	107.3	150	39.16	150	52.55	150	112	190	36.76	180	42.25	170
120	67.11	120	35.31	120	18.53	120	37.38	120	25.12	120	36.33	120
180	46.54	110	28.34	110	19.05	110	24.95	110	17.95	110	26.12	110
300	33.55	110	26.33	110	21.45	110	19.49	110	13.02	110	21.9	110
1440	19.63	110	16.2	110	12.08	110	14.85	110	8.21	110	14.41	110

A1.12 Digital pictures showing Coagulation of Model Waste Latex using Aluminum sulphate with CYTEC polyelectrolyte (PE3)

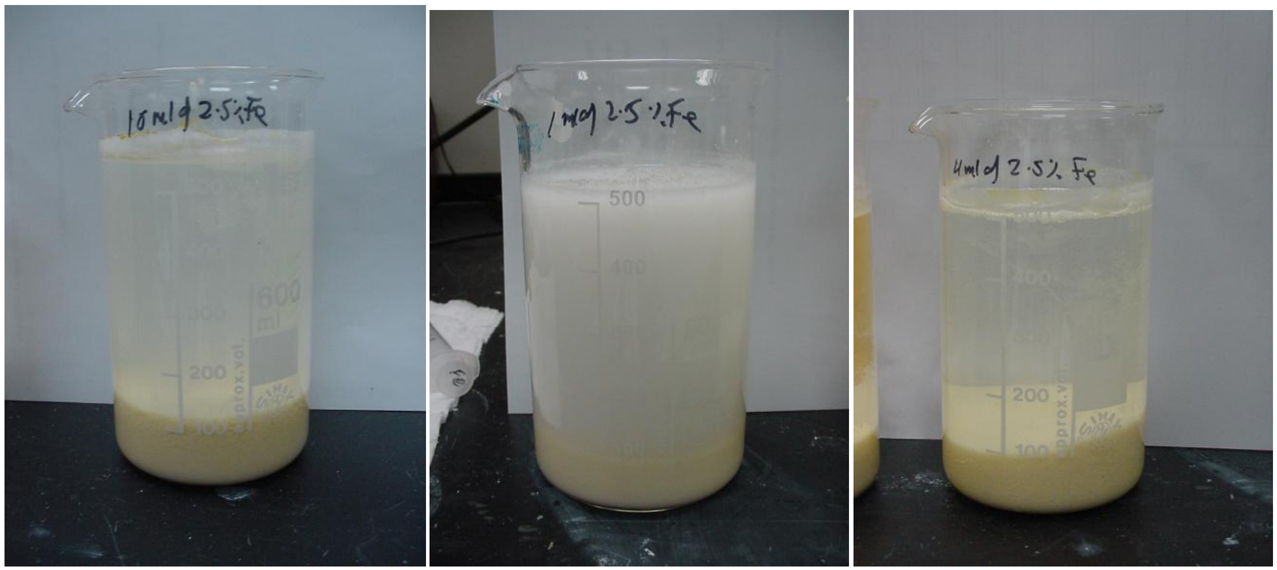


A1.13 Coagulation of Model Waste Latex using Ferric Chloride

Dosage	10ml		9ml		7ml		5ml		3ml		1ml	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	82.92	190	98.2	160	95.93	190	42.03	190	128.6	190	182.6	cloudy
60	76.3	190	87.6	160	73.24	190	33.54	190	37.61	190	167.3	cloudy
90	68.76	150	82.78	150	83.24	150	30.07	180	29.48	180	157.6	cloudy
300	65.82	150	72.32	150	65.95	150	25.68	160	27.01	160	133.8	cloudy
420	58.76	140	68.04	148	71	150	23.08	145	23.41	160	126	cloudy
1440	30.44	135	25.88	130	24.5	137	12.48	125	10.37	134	63.87	cloudy

Dosage	4ml		6ml	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	38	180	49.2	180
60	24.18	180	36.52	180
120	20.77	150	35.24	150
180	21.46	150	33.94	150
300	21	150	30.02	150
1440	7.65	120	17.51	125

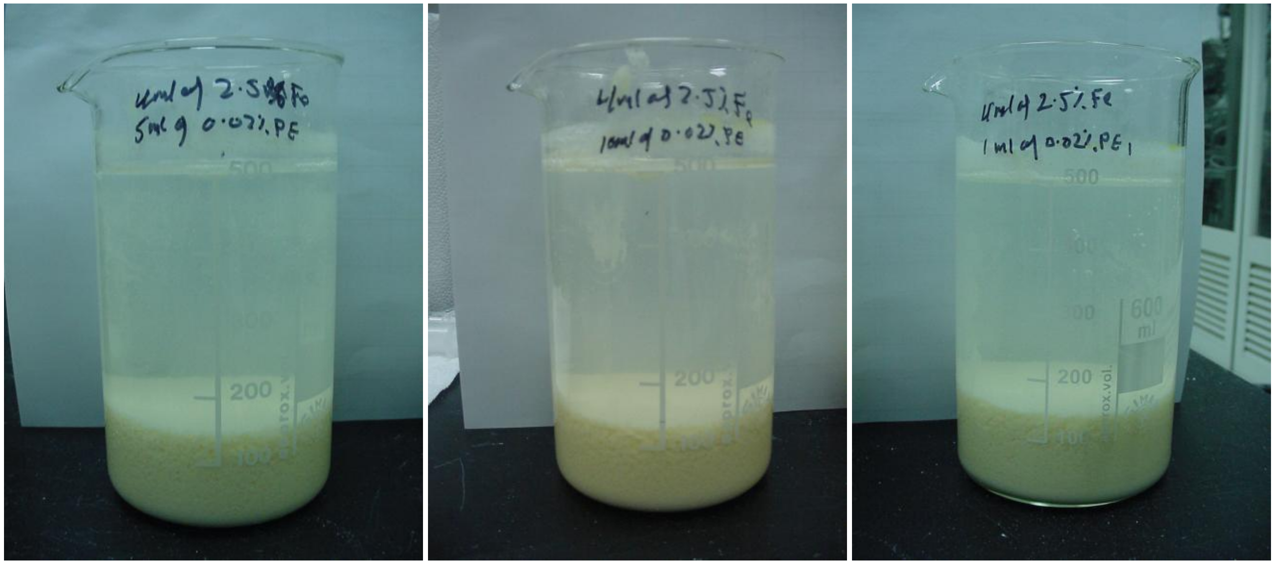
A1.14 Digital pictures showing Coagulation of Model Waste Latex using Ferric Chloride



A1.15 Coagulation of Model Waste Latex using Ferric Chloride with polyelectrolyte (PE1)

Dosage	10ml of PE1		9ml of PE1		7ml of PE1		6ml of PE1		5ml of PE1		4ml of PE1		3ml of PE1		1ml of PE1	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	115.4	190	132.3	190	73.89	190	49.38	190	32.79	190	42.2	200	110	200	60.8	200
60	70.72	150	95.24	170	35.22	190	29.24	190	30.56	160	38.59	170	32.98	170	55.67	180
120	58.31	150	44.06	160	38.05	165	26.26	150	25	155	30.69	155	27.56	170	52.52	165
300	40.22	150	39.6	155	33.08	150	23.36	150	20	150	26.81	150	30.2	150	43.57	150
1440	29.39	100	31.29	110	15.24	125	18.7	125	10	90	23.85	125	20.43	120	19.29	120

A1.16 Digital pictures showing Coagulation of Model Waste Latex using Ferric Chloride with polyelectrolyte (PE1)



A1.17 Coagulation of Model Waste Latex using Ferric Chloride with different pH

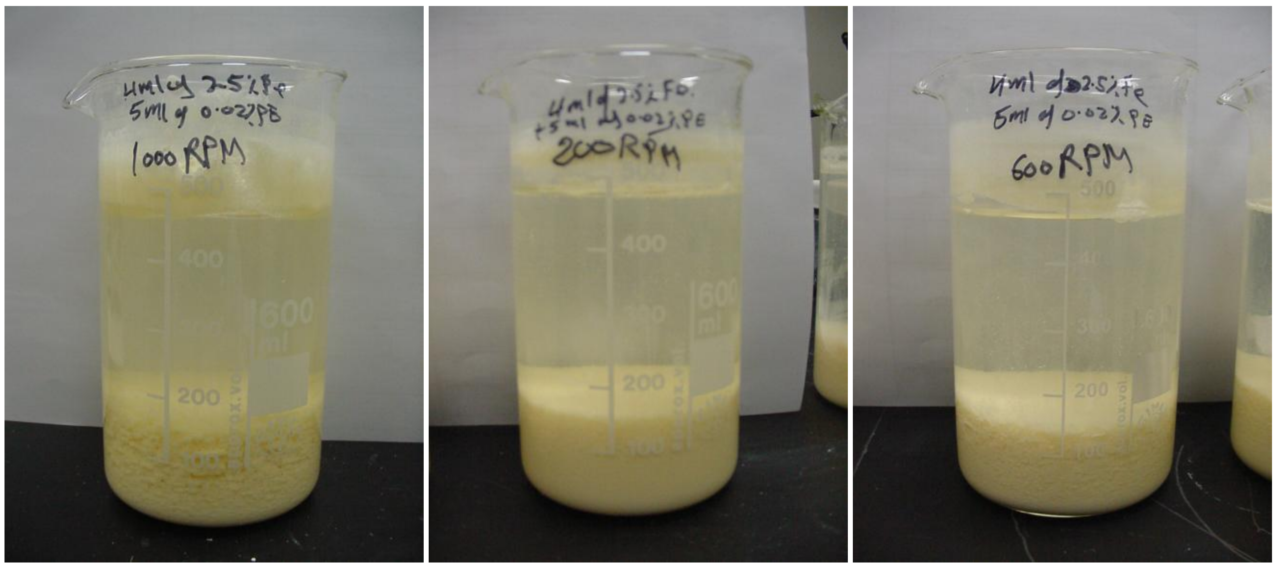
settling Time(min.)	pH2.6 with 4ml of 2.5%Fe	pH3.5 with 4ml of 2.5%Fe	pH5 with 4ml of 2.5%Fe	pH6.21 with 4ml of 2.5%Fe	pH7.2 with 4ml of 2.5%Fe	pH9.5 with 4ml of 2.5%Fe
30	140.9	124.8	66.92	51.1	90.34	45.38
60	89.47	42.84	41.35	39.23	48.38	34.4
90	61.73	32.79	33.65	29.29	32.8	26.28
120	45.04	32.22	30.95	29.5	28.69	24.47
300	32.08	30.07	25.17	21.2	20.59	21.19
1440	12.93	12.86	15.3	13.25	14.282	12.86

A1.18 Digital pictures showing Coagulation of Model Waste Latex using Ferric Chloride with different pH

A1.19 Coagulation of Model Waste Latex using Ferric Chloride with polyelectrolyte (PE1) at different speeds

settling Time(min.)	200 RPM @ 4ml of 2.5%Fe and 5ml of 0.02%PE1		400 RPM @ 4ml of 2.5%Fe and 5ml of 0.02%PE1		600 RPM @ 4ml of 2.5%Fe and 5ml of 0.02%PE1		800 RPM @ 4ml of 2.5%Fe and 5ml of 0.02%PE1		1000 RPM @ 4ml of 2.5%Fe and 5ml of 0.02%PE1	
	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	32.02	190	17.64	150	12.86	150	18.86	160	83.79	190
60	30.59	160	12.08	150	11.7	150	18.23	160	60.64	190
90	23.65	160	11.77	150	11.02	150	17.44	160	51.87	190
300	20	150	9.88	140	8.62	130	19.05	160	45.37	190
500	10.61	150	8.39	120	10.68	120	15.34	110	43.22	150

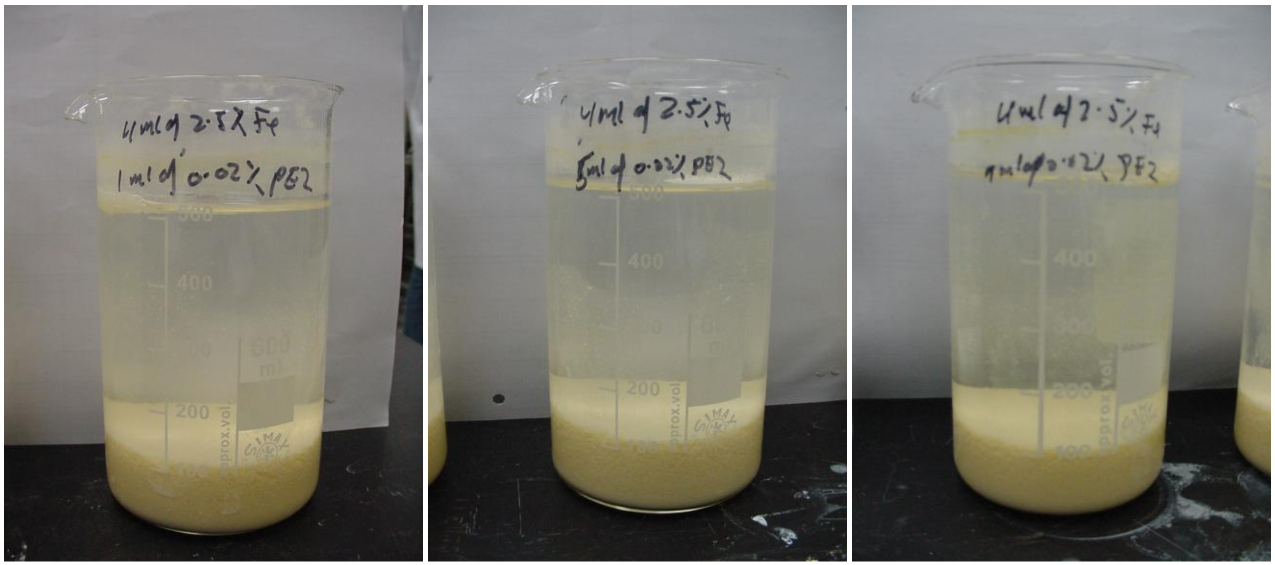
A1.20 Digital pictures showing Coagulation of Model Waste Latex using Ferric Chloride with polyelectrolyte (PE1) at different speeds



A1.21 Coagulation of Model Waste Latex using Ferric Chloride with CIBA polyelectrolyte (PE2)

Dosage	1ml of PE2		3ml of PE2		5ml of PE2		6ml of PE2		7ml of PE2		9ml of PE2	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	49.77	120	45.25	110	32.58	110	45.25	110	38.67	110	34.07	110
120	41.23	110	37.34	105	24.45	110	36.24	105	26.67	110	30.37	110
180	35.27	110	31.95	105	21.92	110	25.99	105	27.04	105	27.09	110
300	31.28	110	27.3	105	20	110	22.31	105	23.7	105	24.61	110
1440	17.52	100	15.89	100	11.1	100	20.8	100	15.38	100	16.76	100

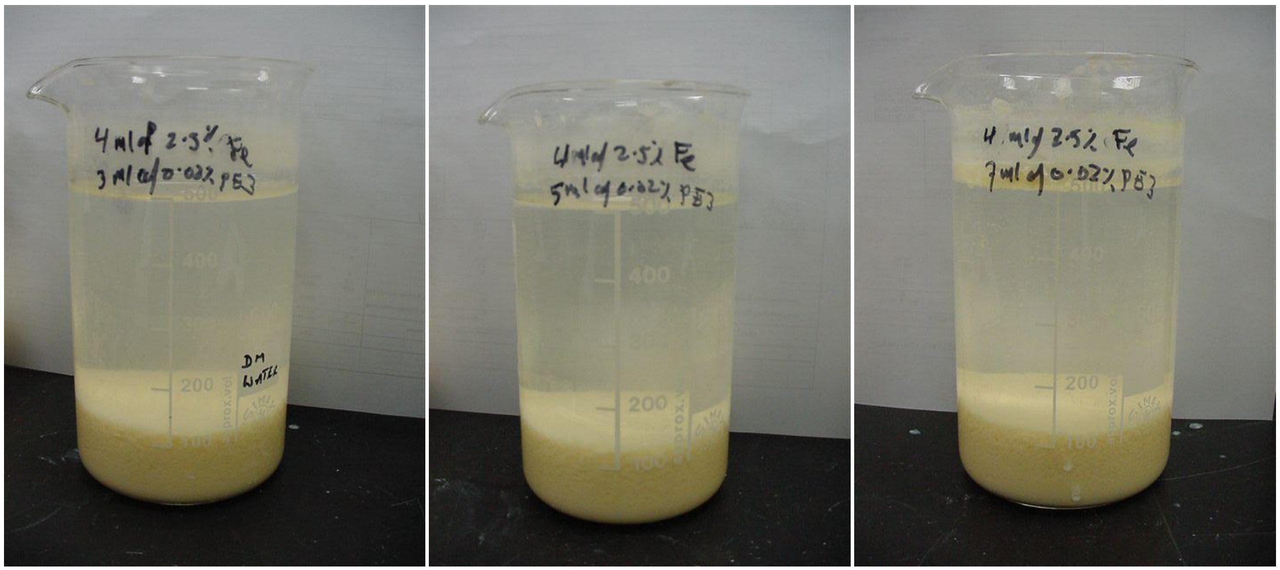
A1.22 Digital pictures showing Coagulation of Model Waste Latex using Ferric Chloride with CIBA polyelectrolyte (PE2)



A1.23 Coagulation of Model Waste Latex using Ferric Chloride with CYTEC polyelectrolyte (PE3)

Dosage	1ml of PE3		3ml of PE3		5ml of PE3		6ml of PE3		7ml of PE3		9ml of PE3	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	58.84	140	61.19	130	45.25	130	56.14	130	36.83	120	39.97	120
120	33.46	140	33.67	120	30.28	120	30.19	120	27.25	120	30.25	120
180	32.25	120	30.2	120	20.45	120	27.64	120	19.68	120	27.99	120
300	27.71	120	25.11	120	16	120	19.39	120	20.21	120	24.35	120
1440	20.73	110	19.93	110	10.91	110	17.25	110	13.01	110	19.45	110

A1.24 Digital pictures showing Coagulation of Model Waste Latex using Ferric Chloride with CYTEC polyelectrolyte (PE3)



A1.25 Coagulation of Model Waste Latex using Calcium Chloride

Dosage	5ml		10ml		15ml		20ml	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	117.7	Cloudy	112.6	Cloudy	110.2	200	193.5	190
60	121	Cloudy	95.4	Cloudy	74.39	200	39.14	185
150	116	Cloudy	70.1	Cloudy	57.81	195	39.53	175
300	116.1	Cloudy	62.9	Cloudy	40.77	175	29.57	165
1440	60.5	Cloudy	58.9	Cloudy	23.48	155	21.61	155

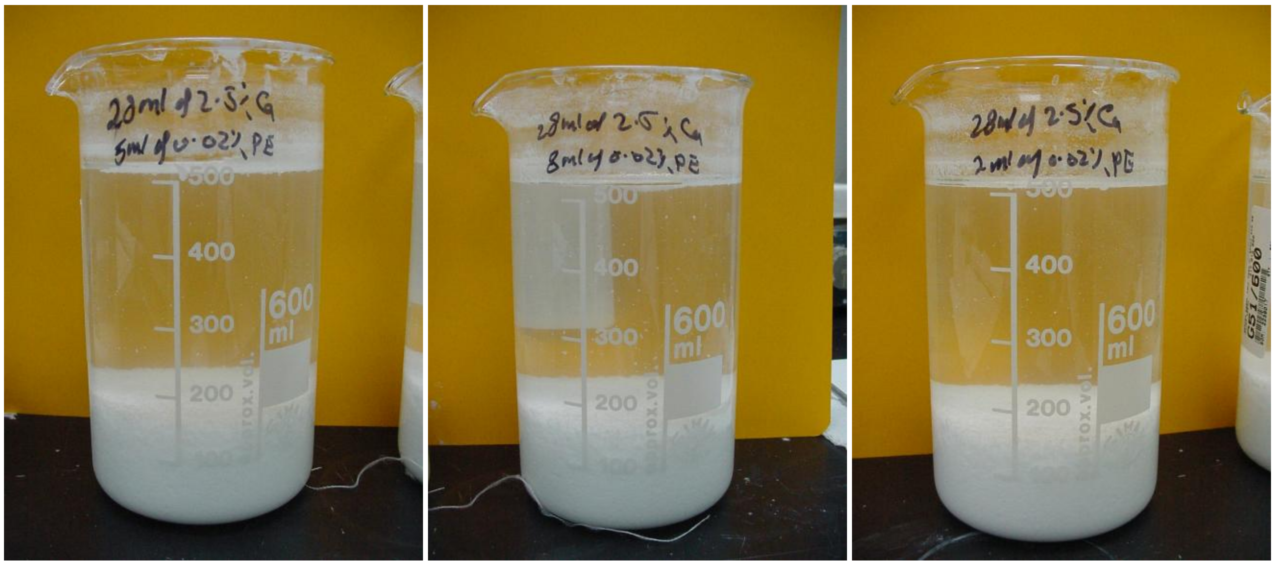
Dosage	22ml		24ml		25ml		26ml		28ml		30ml	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	98.63	Cloudy	129.6	200	224	190	292.5	200	128.1	200	327.1	200
60	37.38	190	29.99	200	45.57	185	37.54	200	37.35	200	68.33	200
150	19.46	180	35.97	190	16.42	180	17.65	180	20.54	170	19.59	190
180	34.12	180	27.81	190	20.4	170	30.42	180	11.38	150	13.71	180
300	27.38	180	17.51	180	16.36	170	14.46	170	10	135	15.72	175
1440	18.73	160	13.29	160	15.09	160	13.56	150	7	130	13.54	170

A1.26 Digital pictures showing Coagulation of Model Waste Latex using Calcium Chloride

A1.27 Coagulation of Model Waste Latex using Calcium Chloride with polyelectrolyte (PE1)

Dosage	1ml of PE1		2ml of PE1		4ml of PE1		5ml of PE1		7ml of PE1		8ml of PE1		10ml of PE1	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
30	298	220	305.3	210	347	200	237.4	210	259.2	210	343.5	210	248	200
60	149	210	84.79	190	87	195	58.78	210	74	200	85.34	200	74.2	190
90	82	199	51.62	190	64.8	190	31.91	180	68.2	190	61.93	195	53.9	185
180	50	185	35.45	176	41.3	170	26.64	160	47.35	185	52.71	190	46.32	180
300	38.41	180	33.92	154	19.48	160	8.37	140	26.8	170	37.37	180	40.71	170
1440	36.3	180	25.32	140	17	160	7.52	130	24	165	30	145	35.65	160

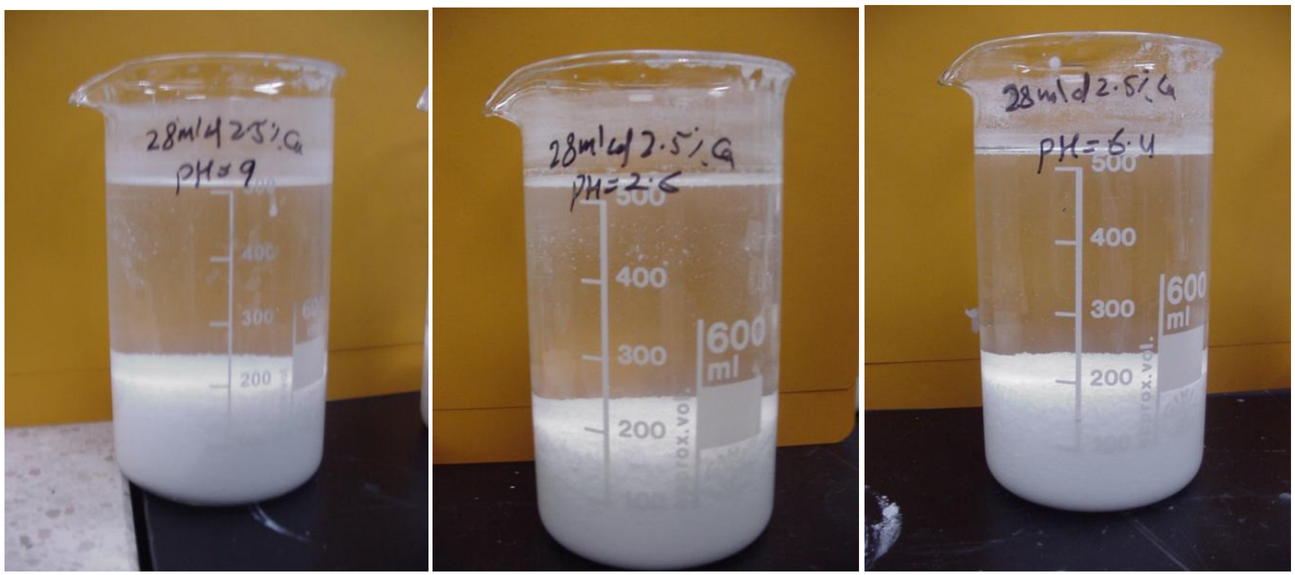
A1.28 Digital pictures showing Coagulation of Model Waste Latex using Calcium Chloride with polyelectrolyte (PE1)



A1.29 Coagulation of Model Waste Latex using Calcium Chloride with different pHs

settling Time(min.)	pH2.6 with 28ml of 2.5%Ca	pH3 with 28ml of 2.5%Ca	pH5.5 with 28ml of 2.5%Ca	pH6.4 with 28ml of 2.5%Ca	pH7.5 with 28ml of 2.5%Ca	pH9 with 28ml of 2.5%Ca
60	37.08	29.59	24.73	38.33	29.5	27.9
120	23.74	19.07	23.21	18.87	24.19	20.29
300	14.56	12.97	10.26	9.5	8.5	5.73
1440	11.84	11.45	11.56	10.34	7.44	3.72

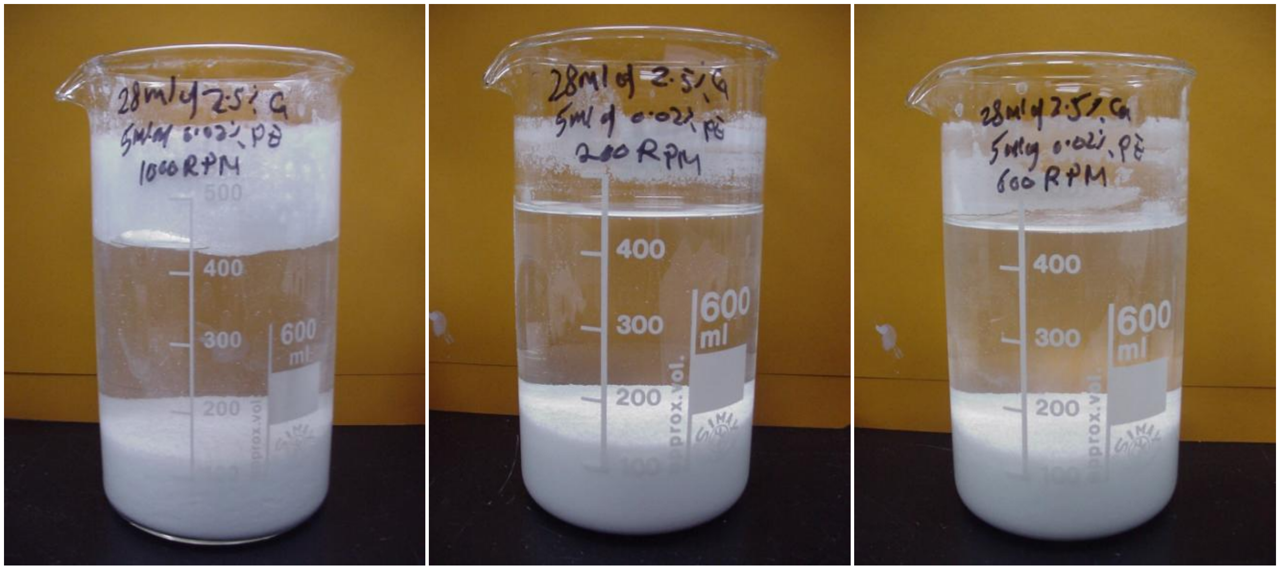
A1.30 Digital pictures showing Coagulation of Model Waste Latex using Calcium Chloride with different pHs



A1.31 Coagulation of Model Waste Latex using Calcium Chloride with polyelectrolyte (PE1) at different speeds

settling Time(min.)	200 RPM @ 28ml of 2.5%Ca and 5ml of 0.02%PE1		400 RPM @ 28ml of 2.5%Ca and 5ml of 0.02%PE1		600 RPM @ 28ml of 2.5%Ca and 5ml of 0.02%PE1		800 RPM @ 28ml of 2.5%Ca and 5ml of 0.02%PE1		1000 RPM @ 28ml of 2.5%Ca and 5ml of 0.02%PE1	
	Supernatant Turbidity	Level	SupernatantT urbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	58.78	210	27	160	38.28	170	57.42	170	80.2	170
120	32.04	190	16.79	160	31.54	170	52.92	170	77.3	170
180	26.64	160	16.94	160	25.39	170	46.36	170	57.1	170
240	14.13	150	11.95	160	25.71	170	44.82	170	51.33	170
300	8.37	140	5.62	160	24.61	170	41.46	170	51.33	170
1440	7.52	130	3.56	150	20.45	150	22.19	130	24.71	140

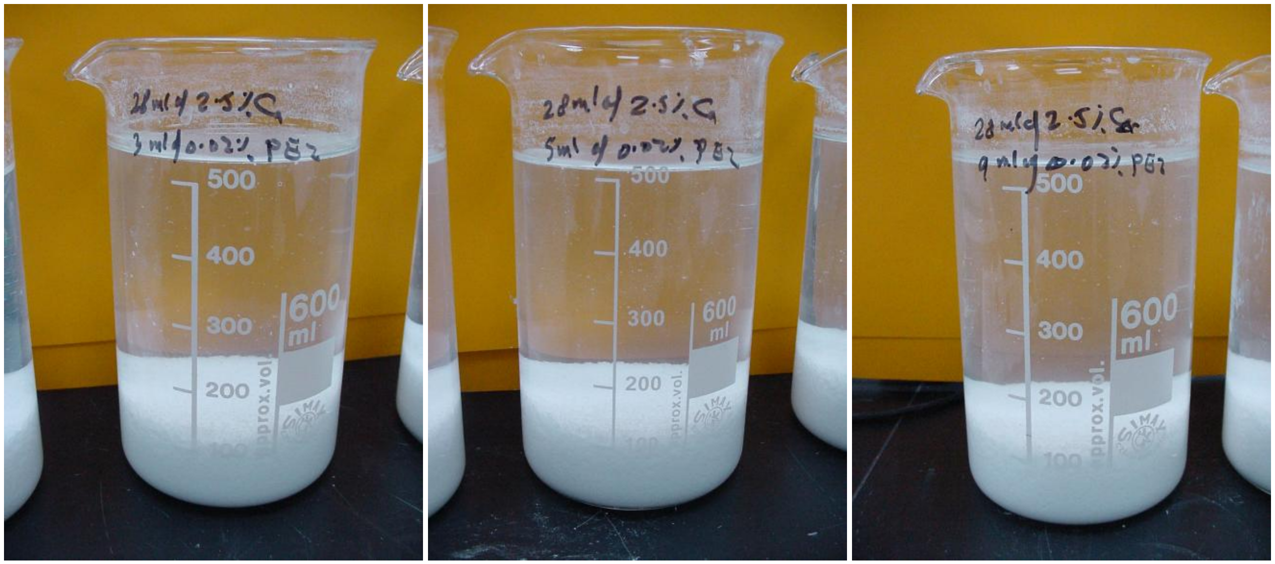
A1.32 Digital pictures showing Coagulation of Model Waste Latex using Calcium Chloride with polyelectrolyte (PE1) at different speeds



A1.33 Coagulation of Model Waste Latex using Calcium Chloride with CIBA polyelectrolyte (PE2)

Dosage	1ml of PE2		3ml of PE2		5ml of PE2		6ml of PE2		7ml of PE2		9ml of PE2	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	69.59	120	69.14	120	66.32	110	54.07	120	57.96	110	57.58	110
120	28.36	120	31.41	120	34.77	110	47.37	120	48.45	110	49.86	110
180	26.62	110	25.87	110	20	110	44.37	110	40.9	110	43.36	110
300	21.17	110	19	110	13	110	29.12	110	35.01	110	40.87	110
1440	18.19	110	13.48	110	11	110	23.48	110	20.17	110	22.17	110

A1.34 Digital pictures showing Coagulation of Model Waste Latex using Calcium Chloride with CIBA polyelectrolyte (PE2)



A1.35 Coagulation of Model Waste Latex using Calcium Chloride with CYTEC polyelectrolyte (PE3)

Dosage	1ml of PE3		3ml of PE3		5ml of PE3		6ml of PE3		7ml of PE3		9ml of PE3	
settling Time(min.)	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level	Supernatant Turbidity	Level
60	42.48	130	57.1	120	52.07	130	82.8	130	88.6	130	78.82	130
120	31.45	120	51.9	120	45.56	120	79.01	120	61.9	120	67	120
180	25.14	110	30	110	41.78	110	54.34	110	53.94	110	51.34	110
300	20.68	110	16	110	27.15	110	38.12	110	40	110	47.52	110
1440	20.05	110	10.3	110	22.52	110	26.55	110	32.08	110	31.68	110

A1.36 Digital pictures showing Coagulation of Model Waste Latex using Calcium Chloride with CYTEC polyelectrolyte (PE3)

Appendix B: Some Definitions

Agglomeration – The bringing together of visibly sized flocs into large masses of randomly arranged (i.e., non-crystalline) particles, mainly through the action of slow mixing and bridging mechanisms.

Aggregation – In general, the bringing together of small particles into larger ones. Applies to coagulation, flocculation and agglomeration, as well as the orderly growth arrangement of crystalline structures.

Agitation – In waste rand wastewater treatment; the general act of forcing the liquid into a state of hydraulic turbulence.

Clarification – The general process of removing suspended solids by sedimentation, in water and wastewater, usually following a coagulation-flocculation step.

Coagulation – In water and wastewater treatment; the process of adding dissolved substances (such as charged to destabilize particulate suspension ions) or colloids (such as macromolecules).

Coagulant – A substance added during water or wastewater treatment to bring about destabilization of primary particles.

Consolidation – The reduction in volume of the solid phase of a suspension during the hindered settling and compression stages of gravity sedimentation.

Destabilization – The neutralization or destruction of the physical and/or chemical forces holding a solid phase suspended in a liquid.

Flocculants – A chemical agent added to a suspension of solids in a liquid to flocculate the small particles into larger ones.

Flocculation – The growth of unstable, microscopic particles in water, into small visible amorphous masses (of indefinite shape and arrangement) brought about by a low degree of turbulent agitation.

Flocculent – The characteristic physical and chemical properties of amorphous, gelatinous, hydrous (i.e., floc-like) solid particles.

Mixing – General term for the bringing together of different substances into a uniform combination forming a blend where the original substances are not easily distinguishable from each other. In water and wastewater this can apply to the uniform distribution of solids within a liquid or of liquids within a liquid.

Precipitation – In water and wastewater treatment; the chemical formation of solid masses, separable from the liquid, out of dissolved or ionic species in water. An example is removal of calcium ion by softening processes. This can also be referred to as coagulatin, but it is not the destabilization of colloidal or molecular particles, which is also called coagulation.

Sedimentation – The removal of particles, that are heavier than the suspending liquid, by gravity settling, usually under quiescent or laminar flow conditions.

Stirring – This term is commonly used, in water and wastewater treatment, to indicate the action of putting the water in motion so as to "mix" all the constituents or components within the liquid.

Subsidence – A general term used to indicate the sinking of a solid phase within a liquid phase. In settling operations, it is commonly used to denote the state of volume or height reduction of the solid phase during hindered settling and compression as opposed to the free settling of individual particles.

Thickening – In water and wastewater sedimentation; the process of making concentrated solid slurries (in a state of hindered settling) more dense by providing proper conditions for gravity to drag the solids down into an increasingly smaller volume while liquid is forced up and out.

Turbulence – The state of fluid motion in which the flow of individual shear planes are not in a laminar condition as defined by Reynolds' correlations. Rather the movement of individual shear planes is in a state of disarray with respect to each other.