

Chapter 1

1 Introduction

One of the options in the treatment of industrial wastewater is flocculation. In this dissertation attention has been focused on understanding the flocculation process used in the treatment of paint wastewater. Wastewater is generated in the production of paint when reactors and filling lines are washed between batches. This results in a dilute paint-wash water stream. This wastewater stream can be further processed by flocculation to reduce waste disposal costs or in the case of white wash water, can be used in the production of lower quality paints (Jewell *et al*, 2004).

The purpose of this investigation was to determine the important parameters for the design and operation of a wastewater treatment process. Flocculation is not well understood. An empirical approach has been adopted so far in the literature. For instance, trial and error is used to determine when a particular system will flocculate.

This research adopted a macroscopic approach to flocculation, seeking to investigate the process using thermodynamic and kinetic principles. There is a need to understand the behaviour of wastewater generated from the new generation of low solvent paints, especially in the flocculation process, and to generate readily available data for use in applying flocculation to the new generation of paint wastewater.

Wastewater samples from Barloworld Plascon paints were used for the research. The contents of the water may include dissolved solids, particle suspensions and organic compounds.

The composition of wastewater from a paint production process, like most wastewater, varies according to which products are being washed out of the system at the time that the waste is generated. In the current process, the wastewater under consideration is coagulated and flocculated so that the water can be recovered and the sludge disposed of. The dosage of a flocculent is generally determined by trial and error and is known to depend on the solid concentration, the particular flocculent being used and the nature of the water being treated; Thomas *et al* (1999) have provided a thorough review of the factors that affect flocculation.

In general, the chemical nature of the particles to be removed and how these interact with the coagulant are neglected or dealt with simplistically (Thomas *et al*, 1999). The particles of a colloidal suspension are prevented from settling out under gravity due to the electrostatic charge on the surface of the particles; it is this surface chemistry which needs to be counteracted in order to achieve successful flocculation.

A unique opportunity to study the processes occurring during flocculation was identified in the case of paint wastewater, in that the interaction between the dispersant, which stabilises the colloidal suspension in paint, and the dispersant, itself, could be studied in isolation, without the presence of the other soluble and insoluble components.

The flocculation process has two products; the sludge and the wastewater. The experimental method for this work is defined in Chapter 3 and the results of these products are presented and analysed in Chapter 4. In Chapter 5 the conclusion and recommendation on findings are made.

Chapter 2

2 Literature Survey

2.1 Introduction to Flocculation

In wastewater treatment operations, 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. Knowing their differences can lead to a better understanding of the clarification and dewatering operations of wastewater treatment.

Flocculation can be described as the process in which destabilised particles are brought together to form aggregates called flocs. They are large enough to settle out under gravity. In this way separation of the water and the flocs formed is achieved (Faust and Aly, 1983). Coagulation is the process in which destabilisation of particles occurs by the neutralisation of the repulsive potential of double layer, followed by the agglomeration of particles in suspension to form a colloid structure (Faust and Aly, 1983). In this work the term ‘flocculation’ is used to describe both processes.

In literature there are two ways of looking at the flocculation process. One focuses on the microscopic aspects of the flocculation process. The other focuses on macroscopic aspects of flocculation; such as thermodynamics and kinetic factors, which are described using the crystallisation theory.

2.1.1 Microscopic approach

This approach focuses on the ionic interaction between the particles in solution. Flocculation occurs when a solution of multivalent metal, like aluminium sulphate or ferric chloride, is added to a colloidal suspension that has a higher pH than the solution of the metal salt. The metal cations undergo hydrolysis reactions with water and these reactions are sensitive to pH. When the pH of such a solution is raised the solubility limit of the metal, hydroxide is exceeded, so that the hydroxide forms a precipitate.

Stumm and Morgan (1962) presented evidence that confirmed the importance of chemical forces in the conventional treatment of natural waters by chemical coagulation. The authors emphasized that the effects of ferric and aluminium salts upon coagulation are not brought about by the simple aqua-metal ions themselves ($\text{Fe}(\text{H}_2\text{O})_6^{3+}$ and $\text{Al}(\text{H}_2\text{O})_6^{3+}$), but by their hydrolysis products.

These hydrolysed species are multinuclear hydroxo-metal complexes that may be highly charged. Complex formation of these ions can occur not only with OH^- , but also with other bases and with the ionised groups that occur on many colloids. Such specific chemical interactions between colloidal and dissolved substances and the hydrolysed metal ions must therefore be included in a consideration of the coagulation process.

Both the nature of the hydrolysis products and the charge of the colloidal particles can be governed by the pH. Stumm and Morgan (1962) demonstrated that it is possible to distinguish between the effects of coagulant dosage and pH on the flocculation process. This is accomplished by the use of an experimental technique which employs a pH-stat to control the pH and alkalinity of the solutions.

Particle destabilization is clearly a colloid-chemical process and is controlled by both chemical and physical parameters. The destabilization of colloidal dispersions can be accomplished by several different mechanisms. La Mer *et al*

(1964) divided these into two categories: (1) processes that affect reduction of the total potential energy of interaction between the electrical double layer of two similar particles and (2) processes that aggregate colloidal particles into a 3-dimensional floc network by the formation of chemical bridges. La Mer *et al* (1964) has defined the first group as coagulation and the second as flocculation.

Particles in solution acquire a surface electric charge when in contact with a polar medium. Ions of different charge in the medium are attracted towards the surface and ions of like charge are repelled. Therefore this process, together with the mixing inclination due to thermal motion, results in the formation of an electrical double layer (Coulson and Richardson, 1993). A colloid structure is a suspension of finely divided particles in a continuous medium from which the particles do not settle out quickly.

2.1.2 Macroscopic approach

Crystallization is the process of formation of solid crystals from a homogenous solution [1]. Crystallisation occurs by controlled cooling or evaporation when the solute exceeds its solubility. On the other hand; in precipitation, the product is formed by a chemical reaction and the precipitate is generally moderately soluble in the solvent (Swartbooi, 2005). The principles of crystallization and precipitation are similar, so crystallization theory can be used to understand precipitation.

Crystallization is very significant industrially as a method of purification (Coulson and Richardson 1996). It can also be used as a separation technique for chemical solid –liquid systems [1]. Crystallization technology allows the recovery of commercial salts in wastewater. Wastewater compositions usually contain a mixture of salts that vary considerably. These wastewaters are normally treated by using crystallisation [2].

One of the requirements for crystallization to occur is that the solution must be super-saturated. This basically means that the solution must have more solute than it would have in equilibrium [1]. This can be done in many different ways.

- Cooling the solution
- Addition of a second solvent to reduce the solute solubility
- Chemical reaction
- Changing pH
- Solvent evaporation
- Addition of another solute

Thermodynamic and kinetic factors play a major role in the crystallization of particles. Therefore they can be used to understand the precipitation of particles in a flocculation process.

(a) Thermodynamic factors

Conventional chemicals used for flocculation are mainly aluminium or iron-based salts. When adding water, to Al (III) or Fe(III) salts, the ions hydrolyse to form soluble monomeric and polymeric species and solid hydroxide precipitates. The solubility equilibria of Al³⁺ are listed below as reported by Jiang and Graham. (1998).

	Reaction	log K (25 °C)
•	$Al^{3+} + H_2O \longrightarrow Al(OH)^{2+} + H^+$	- 4.97
•	$Al(OH)^{2+} + H_2O \longrightarrow Al(OH)_2^+ + H^+$	- 4.3
•	$Al(OH)^{2+} + H_2O \longrightarrow Al(OH)_3^+ + H^+$	- 5.7
•	$Al(OH)_3 + H_2O \longrightarrow Al(OH)_4^- + H^+$	- 8.0
•	$2Al^{3+} + 2H_2O \longrightarrow Al_2(OH)_2^{4+} + 2H^+$	- 7.7
•	$3Al^{3+} + 4H_2O \longrightarrow Al_3(OH)_4^{5+} + 4H^+$	- 13.97
•	$13Al^{3+} + 28H_2O \longrightarrow Al_{13}O_4(OH)_{24}^{7+} + 32H^+$	- 98.73
•	$Al(OH)_3(am) \longrightarrow Al^{3+} + 3OH^-$	- 31.5
•	$Al(OH)_3(c) \longrightarrow Al^{3+} + 3OH^-$	- 33.5

The aqueous chemistry of Al in water can be explained by considering five monomers (Al^{3+} , $\text{Al}(\text{OH})^{2+}$, $\text{Al}(\text{OH})_2^+$, $\text{Al}(\text{OH})_3$ (molecule) and $\text{Al}(\text{OH})_4^-$) three polymer species $\text{Al}(\text{OH})_2^{4+}$, $\text{Al}_3(\text{OH})_4^{5+}$ and $\text{Al}_{13}\text{O}_4(\text{OH})_{24}^{7+}$ and an amorphous solid precipitate $\text{Al}(\text{OH})_3$ (s). Several other formulae for polymeric Al species can also be found in the literature, but it seems that $\text{Al}_{13}\text{O}_4(\text{OH})_{24}^{7+}$ is most common and stable polymeric Al species in water treatment (Bottero *et al*,1980).

Faust and Ally,1983 discuss the hydrolytic reactions of aluminium sulphate flocculent in solution. They use equilibrium conditions of these reactions to model the dissociation of the different species in water as a function of pH.

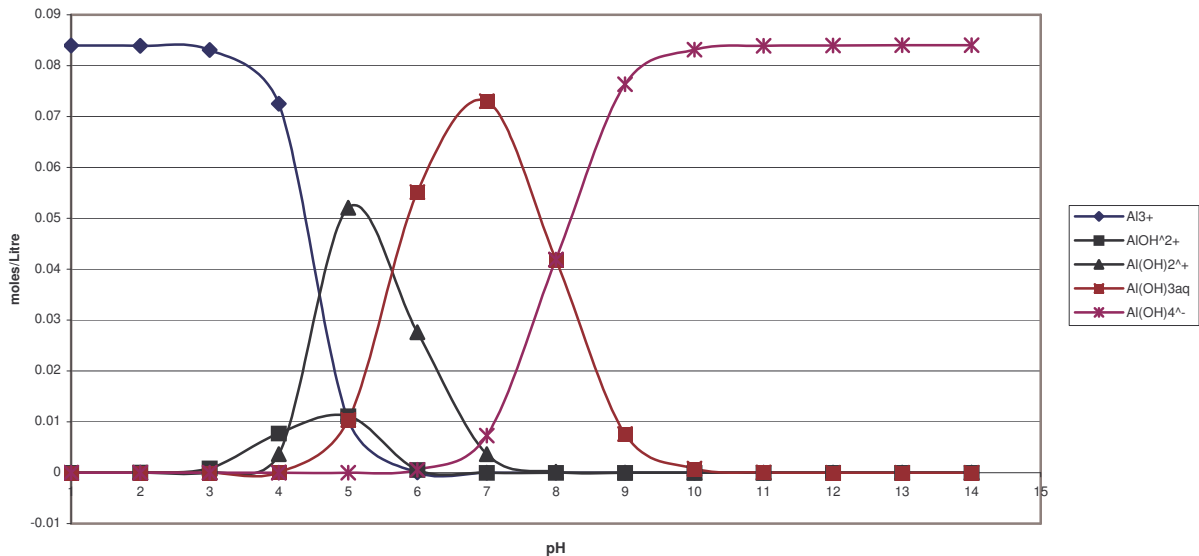


Figure 2.0 Aluminium hydroxide species distribution curve (adapted from Fosemore,2004)

The species distribution curve in Figure 2.0 as a result of the hydrolysis of aluminium in solution was plotted by Fosemore, 2004. The curve shows the dominant species as the aluminium ion dissociates into the different species at particular values of pH ranging from pH 1 to 14. From the plot it can be seen that aluminium hydroxide is dominant in the pH region between 5 and 8.

(b) Kinetics of crystallization

During coagulation, the suspended particles of the solution being flocculated may provide nucleation sites for the growth of the hydroxide crystals, with the metal hydroxide altering the nature of surface of the particles as this occurs; this is consistent with the observation that the higher the concentration of suspended particles present, the more effective coagulants are at reducing turbidity and this can usually be accomplished with a lower coagulant dosage (Fasemore, 2004).

In other words, at low particle concentrations coagulation does not occur because the hydroxide precipitates without interacting with the suspended particles. Alternatively, a monolayer of the hydroxide may neutralise the electrostatic repulsion and rather than providing nucleation sites per se. The particles may simply become enmeshed in the flocs as the hydroxide crystals grow. Sohnel and Garside, (1992) postulated that the crystallization of moderately soluble substances is usually the result of three processes:

- Crystal nucleation,
- Crystal growth,
- Crystal agglomeration and ageing.

Nucleation is defined as the kinetic step that 'allows' a solid to be formed from the bulk liquid (Swartbooi,2005). Nucleation can be associated with the formation of the new centres from which spontaneous growth can occur. The nucleation process determines the size and the size distribution of the crystals produced (Swartbooi, 2005).

When stable nuclei have been formed in a supersaturated system, they begin to grow into crystals of visible size (Mullin, 2001). Crystallization processes are usually dominated by nucleation (because of super saturation) and agglomeration (because of abundance of particles) (Swartbooi, 2005). Agglomeration is the formation of larger particles from the clustering of smaller

ones. The agglomeration rate depends on the frequency of collision and on the efficiency of particle contacts (Swartbooi,2005).

Currently, chemical flocculation is receiving improved attention for municipal and industrial waste treatment; in a number of existing facilities the process is used to aggregate sludge prior to cake filtration and disposal (Stumm *et al*, 1968). A question of theoretical interest and practical concern is the relationship between the quantity, or concentration, of the substance to be flocculated and the quantity of flocculent.

At low concentrations of flocculent, nucleation of particles is dominant, whereas at high feed concentration of flocculent, growth of particles is dominant. This creates a trade-off between particle nucleation *versus* growth, which is discussed in detail in Section 4.3. This phenomenon is similar to the behaviour exhibited by the continuous thickening of a uranium plant slurry studied by Turner and Glasser (1976).

Turner and Glasser (1976) investigated the flow patterns and density profiles within the thickener. They found out that there were two distinct stable modes of operation, which were named “settler” and “filter” modes. The settler mode coincided with the under-loaded operation, while the filter mode corresponded to a fully loaded thickener. The turbidity and visual appearance of these two states were found to be very different. Flow patterns were manipulated to yield a thicker sludge.

2.2 Factors Influencing flocculant dosage

In most water treatment plants, the minimum flocculent concentration and the residual turbidity of the water are determined by jar-test techniques. However, this often involves problems of excess or insufficient flocculent, particularly during periods of fast variations of water quality. Understanding these phenomena requires taking into account the physical and chemical nature of the water to be treated (Girou and Franceschi, 2002).

The significant specific surface area of particles and the existence of a surface charge on these colloids explain the prevalence of the surface forces over volume forces, which stabilise the system and remove any possibility of elimination by spontaneous settling (Girou and Franceschi *et al*, 2002). In some cases, the addition of mineral salts or organic compounds causes the agglomeration of these particles, allowing their elimination by decantation or filtration.

It is known that the characteristics of the water are important in the particle-coagulation interaction. The role of pH is particularly significant in so far as it determines the electrical charge of organic and inorganic colloids and at the same time it is a major factor in the hydrolysis of aluminium salts. According to Gregor *et al* (1997), pH control improves soluble matter removal; the pH adjustment was done during the flocculation phases by means of lime addition.

2.3 Pre-polymerised inorganic flocculants.

Pre-polymerised inorganic coagulants have been developed and used in water and wastewater treatment since the 1980's. Originally they were mainly polyaluminium chloride (PAC) and poly ferric chloride (PFC) (Jiang *et al*, 1997). Both PAC and PFC are made by partial hydrolysis of acidic aluminium chloride or ferric chloride solutions.

The nature of the polymeric species formed depends on various factors such as the concentration of aluminium sulphate; the basic ratio (the ratio of moles of base added and/or bound to the moles of aluminium ($[OH]/[Al](III)$)); the hydrolysis duration of the Al(III) solution (ageing time); the anions in solution; the mixing mode of base with the Al(III) solution; and the nature and strength of the base (Jiang *et al*, 1997).

The most important parameters that govern the nature of the particle species are the concentration, pH, temperature and the ageing time. A variety of techniques such as nuclear magnetic resonance spectroscopy, X-ray radiation scattering and infrared spectroscopy have been used specifically to investigate the nature and structure of the pre-formed polymeric Al(III) species. This has given valuable information on the optimal conditions required during flocculation for the nucleation and growth of particles.

Aluminium sulphate was used as a flocculent in all our experiments. Fosemore (2004) compared ferric chloride to aluminium sulphate and showed that the latter produced clearer wastewater and thus, that it is the better flocculent to be used in the treatment of white wastewater (wastewater from the production of white paints).

2.4 Analysis of flocculation results

Thomas *et al* (1998) have done some work on flocculation modelling and this will be discussed below.

2.4.1 Flocculation modelling

The mathematical representation of flocculation has traditionally been based on considering the process as two distinct steps: transport and attachment (Thomas *et al*, 1998).

The transport, leading to the collision of two particles, is achieved by virtue of local variations in fluid/particle velocities arising through (a) the random thermal “Brownian motion” of particles (perikinetic flocculation), (b) imposed velocity gradient from mixing (orthokinetic flocculation) and (c) differences in the settling velocities of individual particles (differential sedimentation).

Attachment is then dependent upon a number of short range forces largely pertaining to the nature of the surfaces themselves. The two precepts are most succinctly expressed mathematically as a rate of successful collision between particles of size i and j :

$$\text{rate of flocculation} = \alpha\beta(i'j)n_i n_j$$

Where α = collision efficiency

β = collision frequency between particle i and j

i = particle size i

j = particle size j

n_i = particle size i concentration

n_j = particle size j concentration

The collision frequency, β , is a function of the mode of flocculation, which is perikinetic, orthokinetic or differential sedimentation. The collision efficiency, α (taking values from 0 to 1), is a function of the degree of particle destabilisation: the greater the degree of destabilisation, the greater the value of α . Thus, in effect, β is a measure of the transport efficiency leading to collision and, in turn, leading to attachment.

Most flocculation models are based upon this one fundamental equation. The values of parameters α and β are dependent upon a large number of factors

ranging from the nature of the particles to the method of destabilisation and the prevailing flow regime during flocculation. Much of the research done on flocculation modelling has focussed on establishing equations and specific values for these two parameters. The overall rate of flocculation always increases with the increase in particle concentration (Fasemore, 2004). It is very important to take the terms n_i and n_j into consideration when modelling flocculation.

The interpretation of the above model assumes that values of α and β are independent of one another (Thomas *et al*, 1998).

2.4.2 Particle settling rates

The motion of particles at very slow velocities (creeping flow) was modelled by Stokes. This work lead to the development of Stokes' law, a mathematical explanation of the force required to move a particle through a dormant, viscous fluid at very low values of particle Reynolds number (Coulson and Richardson, 1993). Navier-Stokes equation:

$$F_d = 6\pi\mu Vd$$

Where F_d = Is the drag force of the fluid on a particle

μ = is viscosity of the fluid

V = is the velocity of particle relative to the sphere

d = is particle diameter

This equation, along with principles of physics, can be used to derive an expression that describes the rate at which the sphere falls through a viscous fluid. From this law an equation that relates the terminal settling velocity of a smooth, rigid sphere in a viscous fluid of known density and viscosity to the diameter of the sphere when subjected to known forces can be derived. The

external forces acting on the particle are gravity, buoyancy and the drag force. In Section 4.3.2, Stoke's law is used to calculate the settling rates of the particles formed in flocculation.

Chapter 3

3 Flocculation: Experimental Method and Equipment

3.1 Flocculation: experimental method

Aluminium sulphate $[\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}]$ was used as a flocculant in these experiments supplied by Saarchem (99% purity). It was obtained in the form of very fine, white crystals, which dissolve completely in water to leave a clear solution.

3.1.1 Flocculent solution preparation

The flocculant solution was prepared by weighing the required mass and dissolving it in a 1 litre flask. The mass of sample measured ranged from 6 g to 109 g.

Previous work showed that the solid content of wastewater from different samples of waste varies between about 80 g in 1000 g of wastewater and 210 g of solids in 1000g of wastewater. This was done by drying a given mass of wastewater in an oven and measuring the mass of solid that remains after all liquids have evaporated. To limit the number of variables, the solid content of the wastewater had to be standardized for all experiments done. The standard level of solids in the wastewater samples was kept at 80 g in 1000 g of wastewater.

3.1.2 Flocculant jar test experiment

Extensive Jar testing was conducted to define the minimum amount of flocculent required to give the best flocculation of the wastewater. To ensure that the

solution of wastewater was homogenous the sample was thoroughly mixed with a curved bladed mixer.

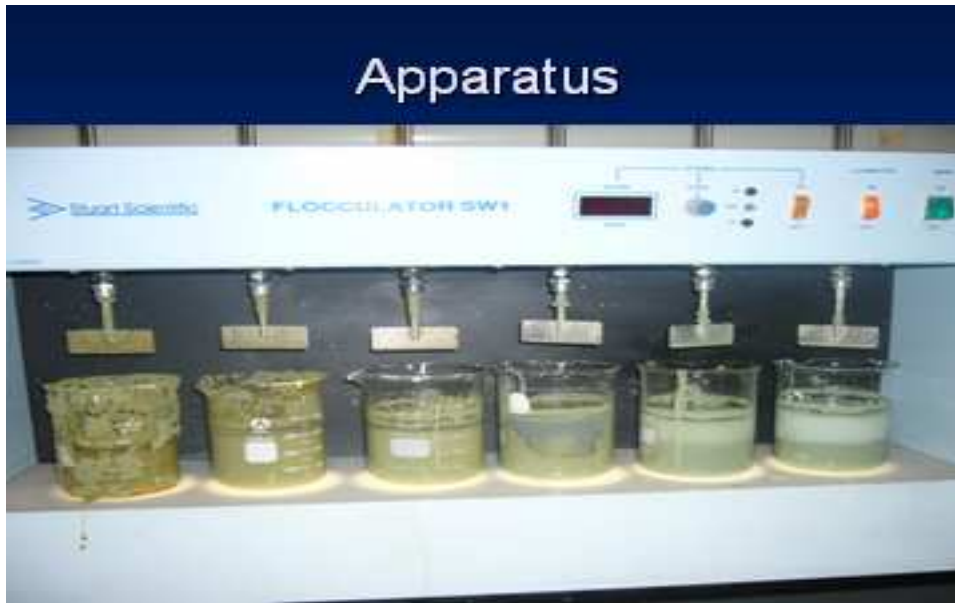


Figure 3.0 Flocculation experiment and apparatus

Figure 3.0 above shows the SW 1 model flocculator that was used to do the jar test experiments. The flocculator contains six stirrers with paddles. Equal volumes of wastewater were used in the experiment, each containing 400 ml. In each beaker 20, 40, 60, 80, 100 or 120 ml of flocculant was added (Jewell *et al*, 2004).

3.1.2.1 Procedure for wastewater flocculation

After the addition of the flocculant ,the solution is agitated at a speed of 240 rpm for 10 minutes. This allows the flocculent to quickly diffuse through the wastewater solution. The speed is then reduced to 10 rpm for 1 minute to allow floc formation to initiate. Finally the process is stopped and the solution is allowed to settle for 30 minutes.

3.1.2.2 Procedure for dispersant flocculation

The difference between the flocculation procedure for dispersant flocculation and that of wastewater flocculation is the time required to complete the process. For the flocculation of dispersants, the flocculator is maintained at a speed of 240 rpm for 5 minutes, rather than 10 minutes. After the 5 minutes the stirrer is stopped and the solution is allowed to settle for 24 hours, rather than 30 minutes. Analysis commences after the solution has settled completely.

3.1.2.3 Procedure for measuring dispersant particle size distribution

To measure particle size distribution a Malvern Master 2000, with Mastersizer Software, was used. Samples from the flocculation experiment were analyzed. The solution is first measured for calibration purposes to account for impurities. The sample solution is added into the measuring bath until the obscuration of measuring light is between 10-20 %. Ultrasonic sound is applied for 3 minutes, after which measurement commences.

3.1.3 Solution analysis

After completion of the experiment the extent of flocculation is analyzed by measuring the solid liquid interface. A thinner sludge indicates good flocculation. The pH and redox potential is measured using a Crison micro pH 2002 model meter. Turbidity is also measured, using an infra-red hanna portable micro processor turbidity meter. The unit of measurement is Formazin Turbidity Unit (FTU). The results are computed and plotted.

3.2 Flocculation Equipment

Owing to the ultimate intention of applying the results from this work in industry, tap water rather than distilled water was used to make all solutions. Analysis of

the water yielded the following results: pH 7.14, turbidity < 0 FTU and potential 45.1 mV. The dispersants (referred to as A and B) that are used in the production paint at Barloworld Plascon are supplied by CIBA SPECIALITY CHEMICALS PLC (Great Britain). Dispersant A is an anti-settling agent that helps to reduce interfacial tension between the hydrophilic pigments, or extenders, and the binders (4). In general, paint contains between 1 and 2% dispersant. For this study 1%, 2%, 3% and 4% dispersant solutions were prepared. Dispersant B is a high molecular weight compound that is suitable for wetting, dispersion and stabilization of inorganic pigment and fillers in solvent free systems (4).

To analyze the resulting solutions, a Cyberscan 500 E/pH meter, supplied by Eutech Cybernetics from Singapore, was used connected to A Metrohm 6.0234.110 and a high precision HI 93703 Turbidity meter was used. The meter covers a 0 -1000 FTU range in two scales: 0.00 to 50.00 FTU and 50 to 1000 FTU. The auto-ranging feature of the instrument sets the appropriate range for the measurement. It has been designed according to the ISO 7027 International Standard. Consequently, the turbidity measurement unit is the FTU (Formazine Turbidity Unit). The FTU is equivalent to the other internationally recognized unit for measuring turbidity, the Nephelometric Turbidity Unit (NTU). The sample's particle size distribution is measured using the Malvern Mastersizer.

Chapter 4

4 Results and discussion

The results obtained from the flocculation of Barloworld Plascon paint wastewater are presented in this chapter, which is divided into three sections.

In the first section consideration is given to aluminium sulphate as a flocculent. In particular, optimum aluminium sulphate dosage is investigated. Previous research on iron chloride (Fosemore, 2004) as a flocculant looked at factors affecting the flocculent dosage. Among other things, the effects of mixing in flocculation, and of resting time on flocculated water properties are also considered.

The second section presents a much more specific aspect of flocculation. Instead of flocculating wastewater, dispersants are flocculated. Dispersants are used in the production of paints, to stabilize the suspension of paint particles. Two dispersants, A and B, are compared. The study investigates the optimum amount of aluminium sulphate required to flocculate Dispersant A.

Fosemore (2004) postulated that a relationship exists between redox potential and good flocculation. To verify this, evaluation of redox potential as an indicator for effective flocculation was done. pH was also evaluated as an indication of good flocculation. Previous work has shown that it is very important to analyze the solid content of wastewater before flocculation. In Section 4.2 the effect of dispersant concentration on flocculation is investigated.

The last section presents results on the evaluation of the relationship between flocculant quantity and the nucleation *versus* growth of particles at different concentrations of aluminium sulphate. How different flocculent quantities at a

fixed dosage affect floc particle size is investigated. This is done for three different flocculent dosages (7 g/l, 52 g/l and 109 g/l). These concentrations were chosen to make comparison with previous literature data simple. Then the settling rates of these dispersants were further investigated, using Stoke's law.

Results from the experiments are evaluated using measured properties such as pH, redox potential and turbidity, where turbidity is used as a measure of flocculation efficiency. The particle size distribution of the solution after flocculation is also measured using a Malvern. To aid in the understanding of this section some terminology is introduced below.

- Flocculent Feed concentration: the concentration of inorganic flocculent before adding it to the wastewater
- Good flocculation: turbidity is less than 100 FTU.
- Recovered water: water that is left on top of the sludge after flocculation.
- Sludge: floc aggregates that settle to form a thick paste after the flocculation process.
- Effective concentration: is the bulk concentration of the solution after flocculent has been added.

4.1 Wastewater Flocculation

In this section experimental results on the flocculation process on white wastewater, using aluminium sulphate, are presented. The major focus is to investigate the dosage of aluminium sulphate required. The effect of mixing and

scale upon flocculation efficiency is tested. Finally this study looks at the resting required for various dosages before readings can be measured.

4.1.1 Investigating the optimum aluminium sulphate dosage

To investigate the optimum flocculent dosage the pH, turbidity and redox potential after flocculation were measured for different feed concentrations and volumes. Figure 4.0 below is a plot of pH of flocculent against volume of flocculant at various feed concentration. It illustrates the change of pH with flocculent quantity at different flocculent feed concentrations.

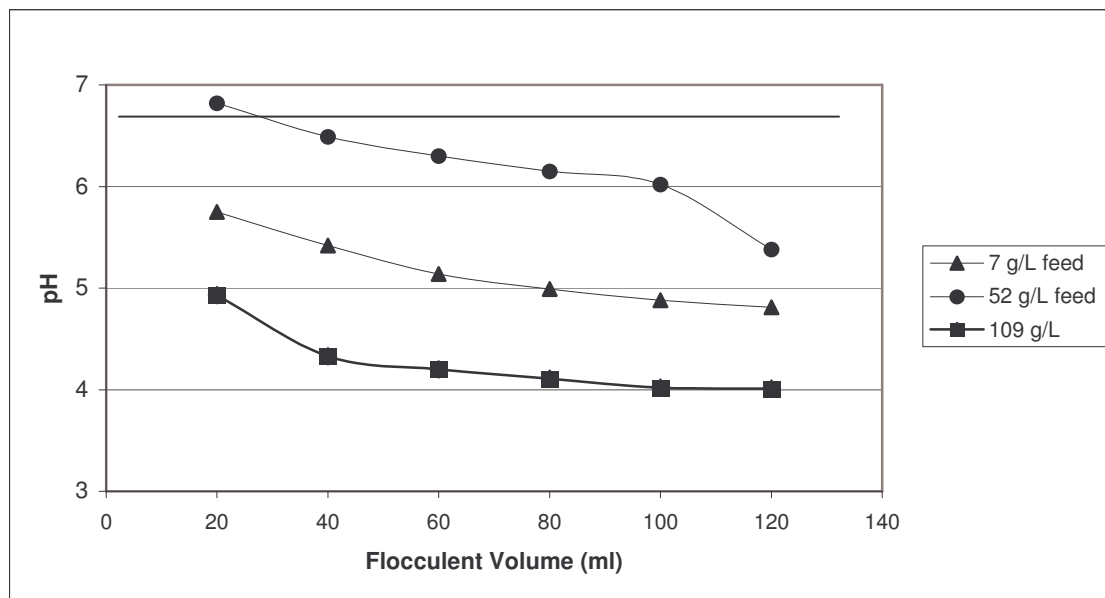


Figure 4.0 Effect of volume of flocculent added on pH for different flocculent feed concentrations

It can be seen that for the 7g/l feed concentration the pH drops from 5.8 to 4.8 as the quantity of flocculent is increased. The same decrease behaviour is observed for the 52 g/l and 109 g/l feed concentrations. The 52 g/l decreases from 6.9 to 5.4 and the 109 g/l from 5 to 4.

Jar test showed that flocculation occurred in all experiments in the given bulk range. However the experiment with a 7g/l feed concentration gave the best flocculation in terms of producing clear wastewater. This point corresponds with the point where low turbidity starts at 40 ml (20 FTU) as compared to 20 ml (320 FTU).

For all flocculation experiments done at 7g/l flocculent feed concentration, it was observed that at the extremes (low and high flocculent quantity) the results of flocculation process were not as good as those performed in the intermediate flocculent feed quantities. A possible explanation could be the competition between particle nucleation and growth. At very low effective flocculent volumes the nucleation of particles is dominant (small particles are made, that do not settle easily). Therefore, there is not enough flocculent to enable the growth of floccs. At high flocculent volumes, growth is dominant, so that particles grow rapidly and are porous because there is excess flocculent. This is explained in Section 4.3, where the same hypothesis is further investigated, using dispersants.

Fasemore (2004) shows that there is a relationship between the redox potential and flocculation. This, too, was observed in this work and it was noticed that at points where good flocculation occurs there is a change in the slope of the potential for all curves.

The Figure 4.1 illustrates the change in potential for different flocculent volumes. Three runs were done for the each sample and the averages are plotted in the figure below.

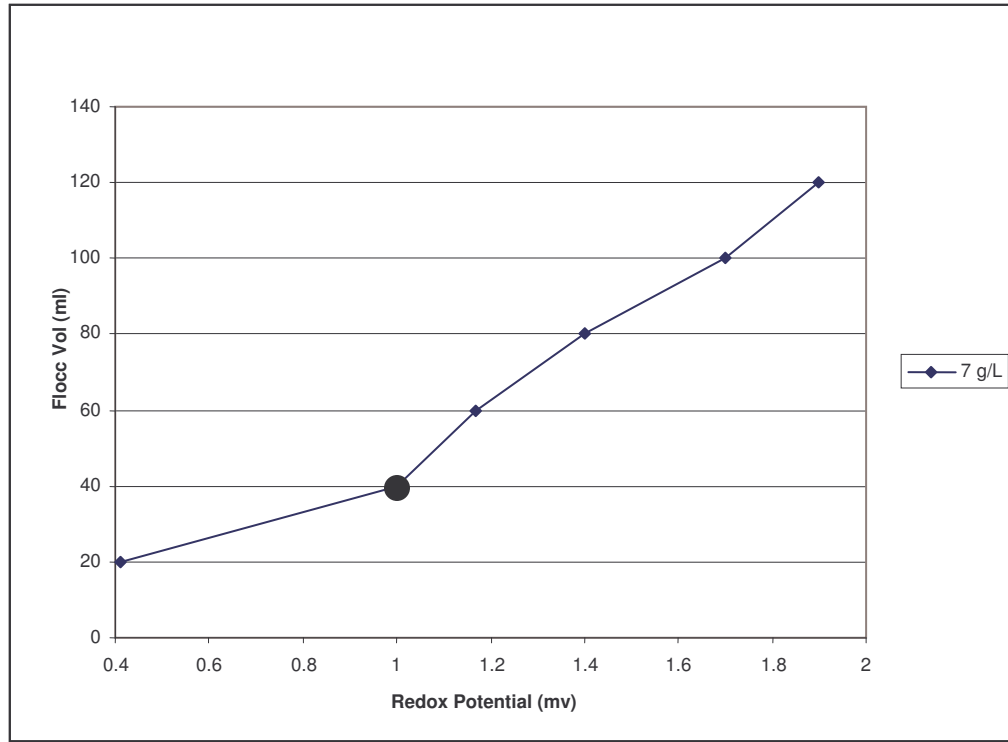


Figure 4.1 Graph of redox potential versus flocculent volume; ● is the point where good flocculation happens. Note the change of slope in region of good flocculation.

From the experimental results it can be seen that there is a roughly linear relationship between the volume of flocculent added and the potential of the solution after flocculation. From the jar test observation it was noted that the optimal quantity of flocculent to give good flocculation results corresponds to the part where the slope of Figure 4.1 changes.

It was postulated that this point separates the region where nucleation is dominant, from the region where growth is dominant. In the nucleation dominant region there is a deficiency of aluminium ion to hydrolyze the wastewater. If higher volumes of flocculent are added (that is, more than 120 mL), the turbidity would increase. On the basis of work done in Section 4.2 on dispersants it was postulated that at higher concentrations of flocculent there are insufficient hydroxide ions to be precipitated. Therefore the excess flocculent contributes to

the turbidity of the water once the flocculation process is completed. A nucleation-dominant region would again exist.

4.1.2 Effect of mixing

The paint production process consists of paint, a series of mixing vessels where different chemical species in powder form are mixed at high speed to produce a wide range of paint products. Therefore mixing plays a very significant role in the paint production industry.

Mixing increases the interaction between different chemical substances. It allows crystals grow together to form flocculi at the highest rate of shear to which the system is exposed (Hunter and Van de Van, 1977). Once this stage is complete, slower mixing allows flocculi to become intertwined, forming flocs. Finally the flocs aggregate and settle

This section investigates the effect of mixing in the flocculation of paint wastewater at a fixed flocculent concentration (7 g/l) and impeller speed (240 rpm). To evaluate this, samples of equal volume were flocculated with the same quantity of aluminium sulphate. In each run the procedures were done as follows:

- Run 1: Aluminium sulphate was added and after this the impeller was switched on to start mixing.
- Run 2: Aluminium sulphate added quickly at once (by turning the beaker over) while mixing (the impeller was already switched on).
- Run 3: Aluminium sulphate added slowly while the wastewater was mixed (the impeller was already switched on)

The table below show results obtained from these experiments.

Table 4.0 Interface measurements and turbidity of clear water after flocculation

<u>Run</u>	<u>Procedure</u>	<u>pH</u>	<u>Potential</u>	<u>Turbidity</u>	<u>Interface measurements</u>	
					<u>Sludge (Volume)</u>	<u>Clear water (Volume)</u>
1	Add flocculent before mixing	4.83	132.9	607 FTU	475 ml	165 ml
2	Add flocculent during mixing	4.47	152.6	637 FTU	328 ml	312 ml
3	Add flocculent slowly during mixing	4.56	149.7	184 FTU	559 ml	81.2 ml

In Run 1, where the flocculent is mixed with wastewater before flocculation, the resultant solution after flocculation has a high turbidity (637 FTU and 165 ml of clear water). This study proposes that this practice encourages the nucleation of particles. In contrast, in Run 3, the flocculent is injected slowly during mixing. This results in a minimum turbidity, although the sludge formed is very porous. The study further proposes that Run 3 encourages the growth of particles. On the other hand, in Run 2 flocculent was quickly introduced during flocculation. The resultant solution had a very high turbidity but the highest volume of recovered water was achieved. Therefore, it was observed that the best results in terms of lowest turbidity are obtained when flocculent was injected slowly into the waste system during mixing.

4.1.3 Effect of resting time on flocculated water properties

Previous work shows that there is a pH drift in the water that occurs after flocculation. It is postulated that during flocculation, certain components in the solution itself play a role in the buffering equilibrium. A buffer is a solution which resists changes in pH when small quantities of acid or an alkali are added to it. Once that has happened the buffer re-establishes equilibrium by reacting to

consume H^+ or release OH^- and reverse the pH back to the initial value (Fasemore, 2005, Thomas, *et al*, 1998).

To do this, four samples of wastewater were flocculated with the same concentration of aluminium sulphate (7 g/l) but different quantities. Figure 4.2 below shows how pH changes with time after flocculating, so as to give different effective bulk concentration of aluminium sulphate in the wastewater.

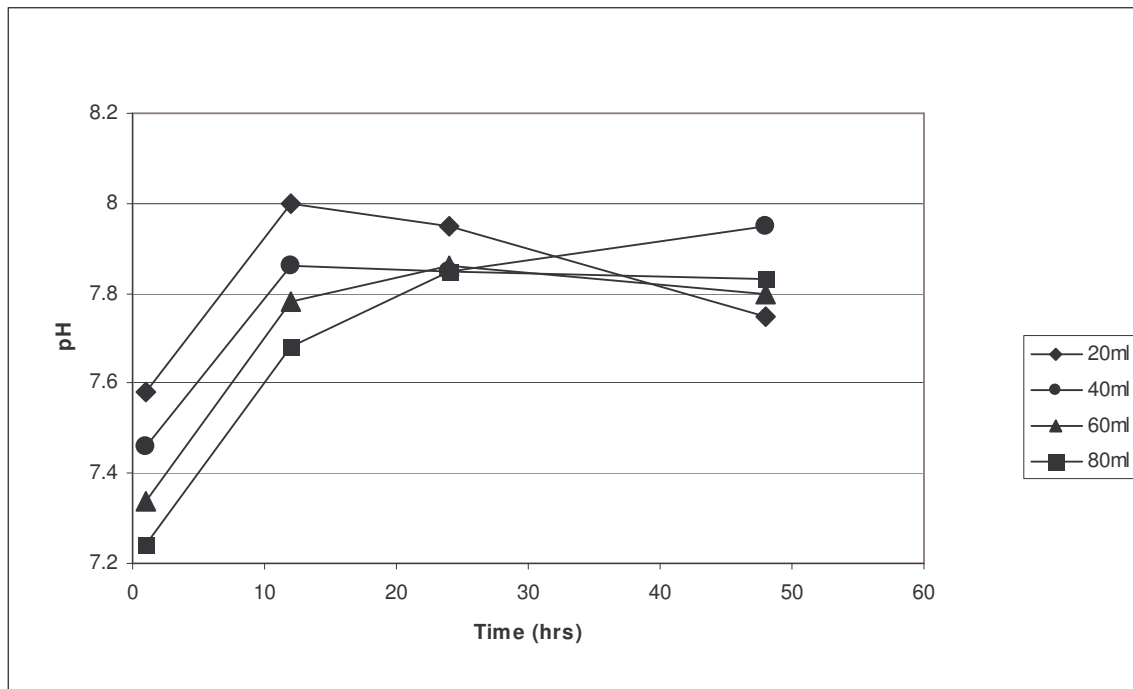


Figure 4.2 The effect of time on pH in the flocculation process

From the experiment it can be seen that pH increases for twelve hours after the flocculation experiment for all the runs. It is postulated that during this period the buffer solution in the paint wastewater counteracts the change in pH that was brought about by the precipitation reaction which lowered the pH of the solution. Aluminium ions react with the hydroxide ions (OH^-) leaving a solution that is highly concentrated with hydrogen ions (H^+), resulting in an acidic solution. After about twelve hours a majority of the samples reach a maximum pH. There is

approximately a 0.2 increase in pH as the quantity of flocculent is increased in 20 ml steps from 20ml to 80 ml.

All solutions showed that there is no, or very little, change in pH values after 12 hours. This change in pH with time is in line with the hypothesis about the buffers existing in paint wastewater. During the first 12 hours after flocculation pH changes relatively rapidly. Hence, it is important to be consistent during the experimental program and always measure pH at roughly the same time after flocculation.

4.2 Dispersant Flocculation

To narrow up the flocculation problem, more specificity in the approach was needed, as was focus on the particular components of the paint that are responsible for the stabilization of the particles suspended in solution. Dispersants were used to stabilize the suspension of particles in paint. In coagulation, the effect of the dispersants must be counteracted in order to allow particles to settle out. Previous work by Fasemore (2004) showed that the flocculation of wastewater often varies from batch to batch. The different dispersants used in different paints were postulated to be the cause of this variability.

Therefore, the dispersants used in the production of paint were investigated, to determine the effect of the dispersant on the flocculation behaviour of water. This enabled measurement of the particle size distribution of the flocculated sample, which could not be done with paint wastewater because of its sticky texture. Particle size distribution results are presented in Section 4.3.

This section, among other things covers the effect of flocculant feed concentration in the destabilization of the dispersants used in the production of paint. Changes in redox potential have been found to be associated with good flocculation (Fasemore, 2004) and whether this would be used as a measure of flocculation effectiveness was investigated. Turbidity was used to evaluate the degree of destabilization of the dispersants.

4.2.1 Flocculation of 2 % Dispersants (A and B) using aluminium sulphate

Two proprietary dispersants, denoted A and B respectively, were investigated. It was observed that a much higher flocculant dosage is required to flocculate an equal volume of dispersant solution than that required for wastewater. In Section 4.1.1, 7g/l was the optimum dosage of aluminium sulphate required to flocculate wastewater. For dispersants, on the other hand, 52 g/l was the optimum dosage of aluminium sulphate. The experiments in this section were conducted using the mixing technique denoted 'Run 3' in Section 4.1.2.

A 2% solution of each dispersant was flocculated with various different volumes of a 52g/l flocculent feed solution and results are shown in Figure 4.3. For Dispersant A good flocculation is obtained with addition of as little as 10ml of flocculent, with the turbidity of the recovered water being less than 20 FTUs in every case. For the Dispersant B on the other hand turbidity drops to 7 FTUs when 40 mL of flocculent feed solution is added. However, as the volume of the flocculent added is increased, the turbidity increases slowly again between 40 ml to about 160 ml of flocculent added and then steadily from 160ml onwards. The turbidity increases relatively rapidly after 160 ml of flocculent has been added.

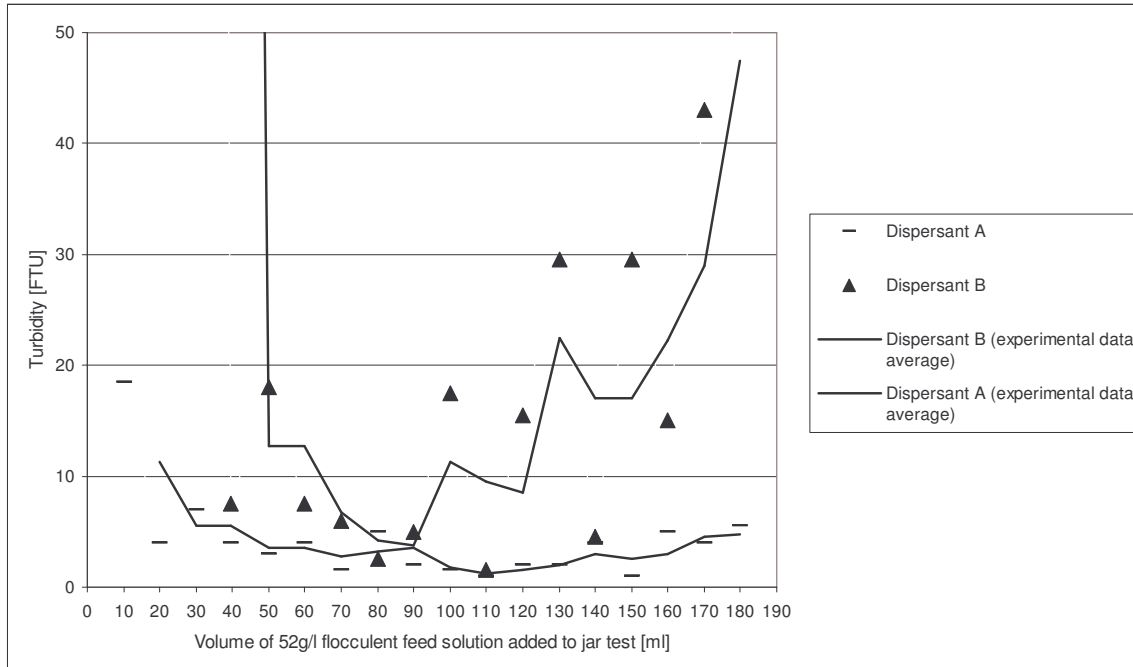


Figure 4.3 Comparison of turbidity at various volumes of flocculent added for Dispersants A and B.

This increase in turbidity with increasing flocculent volume for Dispersant B may be due to some kind of re-stabilisation phenomenon, possibly similar to what is observed for flocculation with high concentrations of polyelectrolyte coagulants (Nozaic *et al*, 2001). This behaviour can also be explained by the growth of particles at high flocculent volumes. Owing to the ultra-sensitive behaviour of Dispersant B to dosage, the remainder of the work was done using a 2% solution of Dispersant A unless otherwise specified.

4.2.2 Appropriate aluminium sulphate dosage required to flocculate Dispersant A

As discussed in the introduction, one of the key aspects of coagulation and flocculation is the interaction between the coagulant and the material to be removed from the wastewater. By changing the feed concentration of

wastewater, the amount of time that the coagulant has to interact with the suspended material relative to its interactions with itself can be changed, which leads to irreversible precipitation. A graph of the turbidity obtained when different volumes of the feed solutions of concentrations 8, 52 and 109 g/l are dosed into a 2% solution of Dispersant A is presented in Figure 4.4.

For the 8 g/l feed solution of aluminium sulphate the turbidity of the recovered water decreases steadily as the volume of solution dosed increases. The lowest value of turbidity attained is still relatively high at 301 FTUs. For the 52 g/l solution, for all jar test in which 40ml or more aluminium sulphate added the turbidity of the recovered water is 17 FTUs or less. For the 109 g/l solution the turbidity decreased initially as the volume of flocculent dosed was increased, reached a minimum of 341 FTUs and then began to increase again. The best flocculation was obtained for the 52 g/l with the low (8 g/l) and high (109 g/l) feed concentrations performing equally badly. A possible explanation for this behaviour is that at low concentrations, there is simply not enough flocculent present to interact with the dispersant molecules and remove them from the solution. Therefore nucleation is dominant but there is not sufficient flocculent for growth.

At the intermediate concentration good interactions between the flocculant and the dispersant lead to effective removal of the dispersant molecules (nucleation occurs followed by growth). At the high flocculent feed concentration, the flocculent precipitates out very rapidly, not allowing for sufficient interaction with the dispersant molecules for removal of suspended material.

The sludge formed for the 109 g/l feed solutions at low and high flocculent quantities is quite different, although the turbidity readings are similar. At low volumes, the sludge has a fine texture, but the solution remains milky. A possible explanation for this it that nucleation of the hydroxide crystals occurs in preference to growth, resulting in lots of aluminium hydroxide particles that are

too small to settle out under gravity. In other words, the flocculent itself contributes to the turbidity of the recovered water.

At high dosages of flocculant on the other hand the sludge floats on the surface of the water initially and eventually sinks to the bottom of the beaker. This indicates that the sludge has a low density and may be due to very high crystal growth rates leading to crystal morphology that is not compact. The matrix of these crystals is too open to enmesh and remove the dispersant molecules as the cake settles.

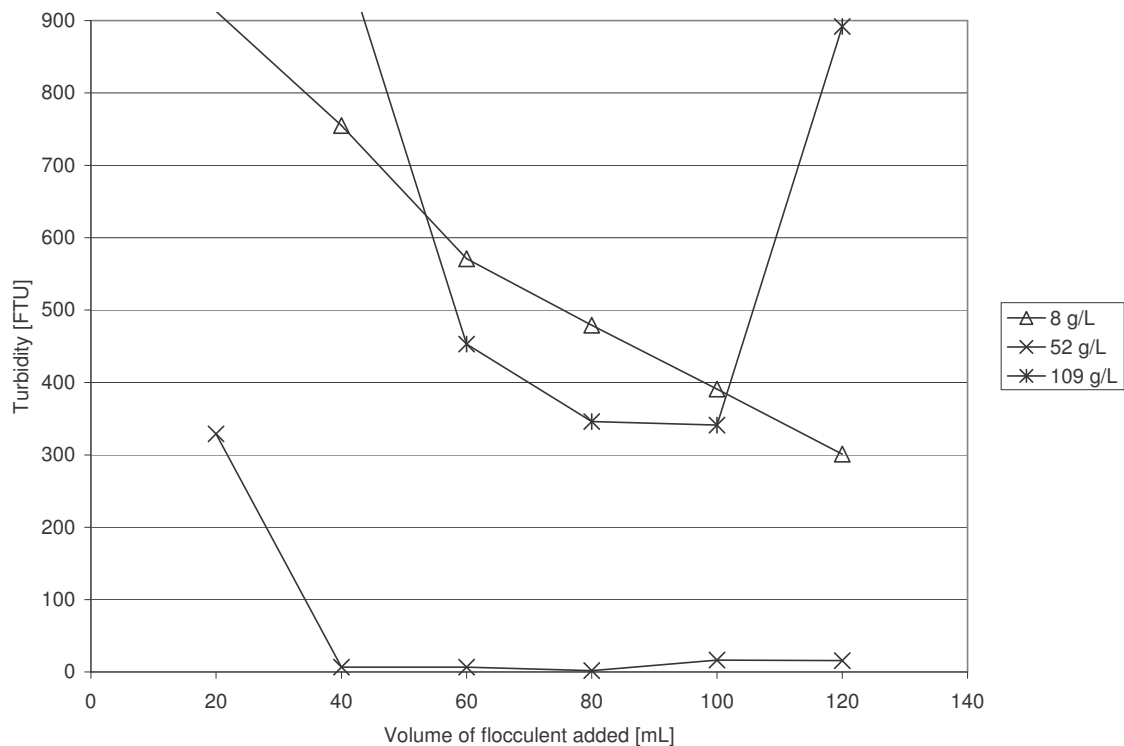


Figure 4.4 Effect of changing the volume of flocculent added for different feed concentrations

4.2.3 Evaluation of redox potential as an indicator for effective flocculation.

It has been suggested previously that redox potential can be used an indicator for flocculation (Fasmore, 2005). A graph of turbidity against redox potential for the three different feed concentrations is given in Figure 4.5. For the 8 g/l feed

solution, the turbidity decreases with increase in flocculent volume. In contrast for the 109 g/l feed solution, the turbidity attains a minimum and then increases again as a function of potential. In neither case does the turbidity drop below 300 FTU nor the potential go above 100 mV. However for the 52 g/l solution, the turbidity drops to below 20 FTU only for points with very high redox potential readings, namely 200 mV and above. In other words for the jar tests which exhibited good flocculation, the potential readings exceeded 200mV.

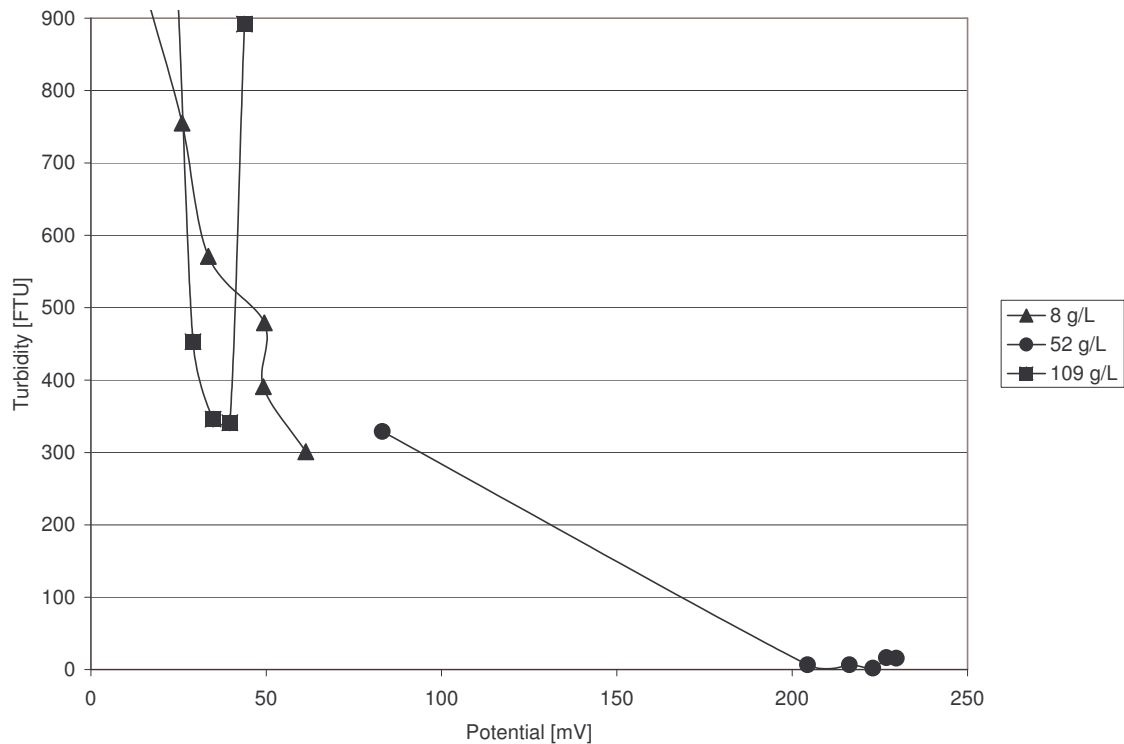


Figure 4.5 Evaluation of redox potential as an indicator for effective flocculation

The significance of the redox potential measurements is as follows: as the concentration of hydronium ions (H_3O^+) increases or the concentration of hydroxide ions (OH^-) decreases, the measured potential will increase. Since flocculation involves the formation a hydroxide precipitate, it would lead to the removal of hydroxide ions from solution and an increase in redox potential.

The more hydroxide ions are removed from the solution, the greater the increase in the redox potential. This implies when 40mL or more of the 52 g/l feed

flocculent solution is dosed into the dispersant solution, a large amount of hydroxide ions are removed from the solution (i.e. lots of hydroxide precipitate forms) leading to very effective flocculation and turbidity reduction. Similarly for the 8 g/l feed solution, the more aluminium sulphate is added, the more hydroxide precipitate is formed and the more turbidity reduction occurs. In the case of 109 g/l feed solution, the potential increases by about the same amount as for the 8 g/l.

This is not what one would expect due to the large amounts of aluminium sulphate being added. The small increase in potential implies that the aluminium ions do not hydrolyse completely before the precipitate is formed, suggesting that the precipitate has a different composition and possibly contains sulphate. This means that for good flocculation to occur, the metal salt must hydrolyse before it can interact effectively with the suspended particles to be removed. This is in agreement with the work of Jiang and Graham (1998) who used ferric and polyferric sulphate.

4.2.4 The Evaluation of pH as an indication of good flocculation

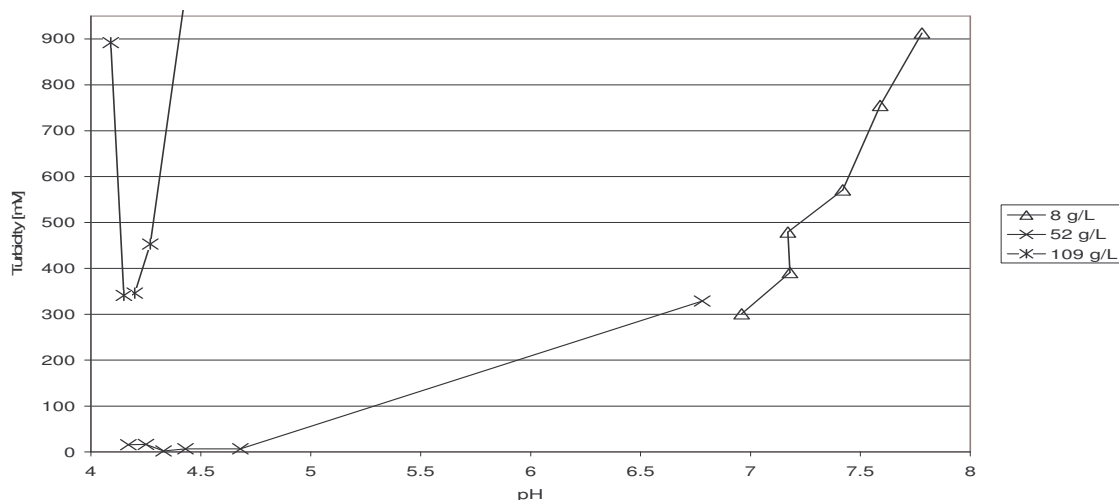
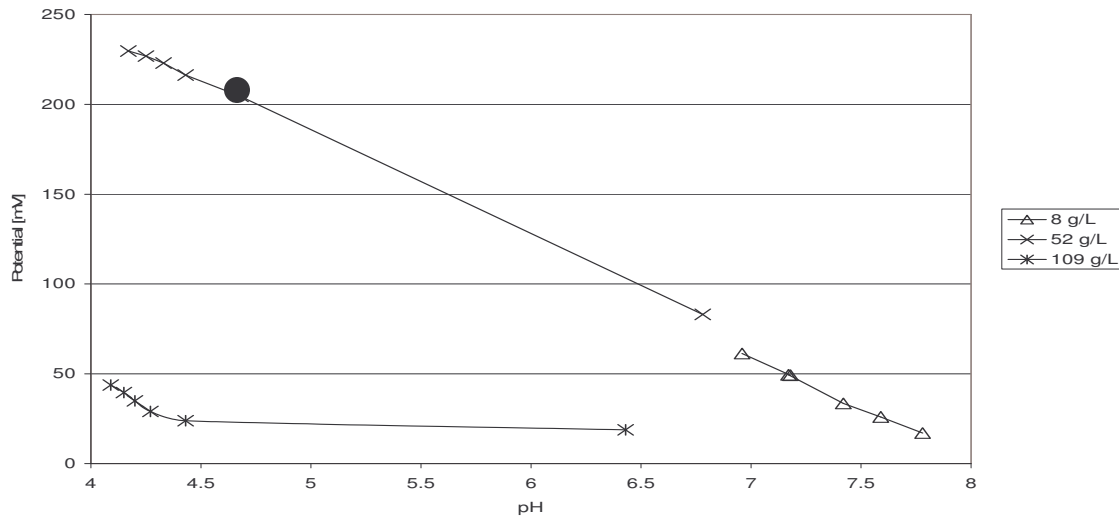


Figure 4.6 Evaluation of pH as an indicator of effective flocculation

Due to the importance of the hydrolysis reactions of Al^{3+} in flocculation which are affected by pH, it was decided to explore whether changes in pH can be used to

indicate when effective flocculation will occur. A graph of turbidity against pH for different feed concentrations is shown in Figure 4.6. For the 8 g/l and 52 g/l feed solutions, the turbidity decreases as the pH decreases. The pH measured for the 109 g/l feed solution jar tests is in the same range as the pH for which very effective flocculation was achieved using the 52 g/l solution, yet the turbidity for these experiments is above 300 FTUs. Thus a low pH (between 4 and 5) is probably a necessary, but not a sufficient, condition for effective flocculation. Figure 4.7 shows a plot of redox potential against pH for the three flocculent feed concentrations: 8 g/l , 52 g/l and 109 g/l. The flocculent volume is increased from 20 ml to 120 ml, while pH and redox potential are monitored for each concentration.



4.7 Redox potential as a function of pH; ● is the point where good flocculation occurs. Note the drop in potential at this point.

It can be seen from the above plot that the relationship between redox potential and pH is linear at low feed concentration and non-linear at high flocculent feed concentration. The 8 g/l plot has the same slope as the 52 g/l. There is a drastic drop in potential at the point where good flocculation occurs (there is a 140 mv drop in potential after good flocculation, as compared to a 10 mv potential drop at points in lower volumes of flocculant).

4.2.5 The effect of dispersant concentration on flocculation

Further experiments were performed to examine the effect of dispersant concentration on flocculation with a 52 g/l feed solution of aluminium sulphate. The results are presented in Figures 4.8 and 4.9.

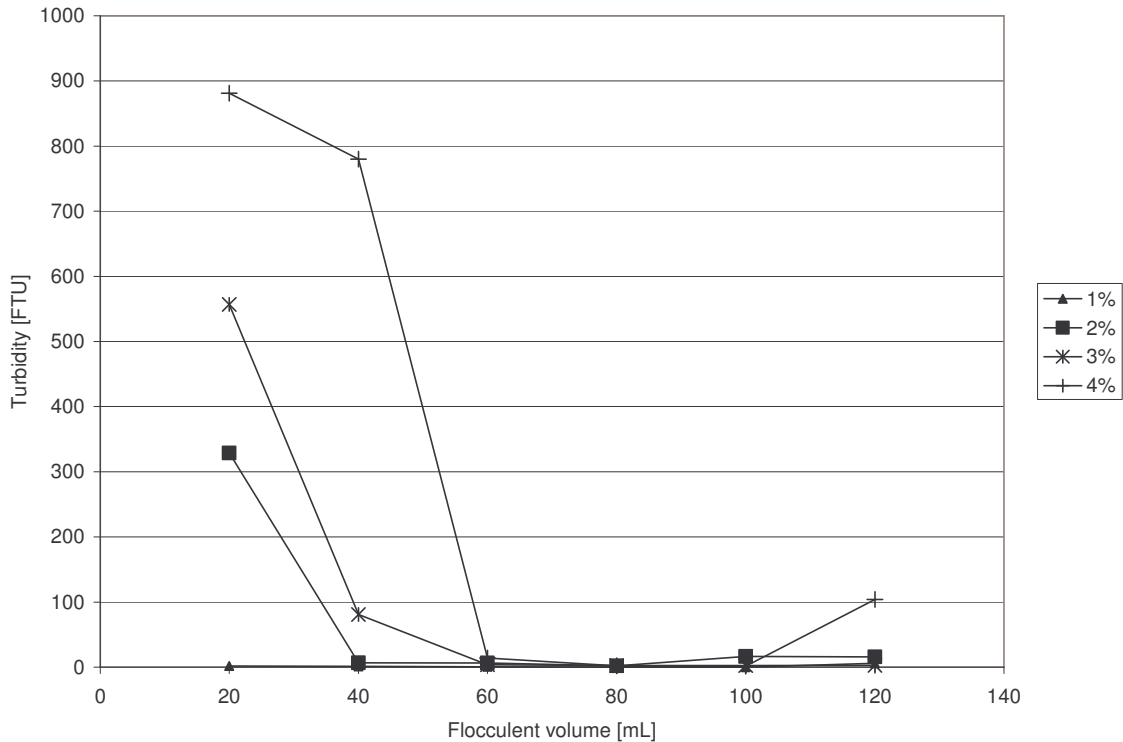


Figure 4.8 Turbidity as a function of volume of 52 g/l flocculent feed solution added for 1, 2, 3 and 4% solutions of Dispersant A

From the results it can be observed that the 1% solution can be flocculated using any volume from 20 to 120 ml. As the dispersant concentration increases a greater volume of flocculent is required; a minimum of 40 mL and 60 mL for the 2% and 3% solutions respectively. In the case of the 4% solution, the turbidity drops down to 3 FTUs when 60 ml of flocculent is added, but increases again when 120 ml of flocculent is added. This is similar to the restabilisation phenomenon observed for Dispersant B in 2 % solutions.

4.2.6 The evaluation of turbidity as a function of redox potential for different volumes of a 52 g/l flocculent feed solution added for 1%, 2%, 3% and 4 % solutions of Dispersant A

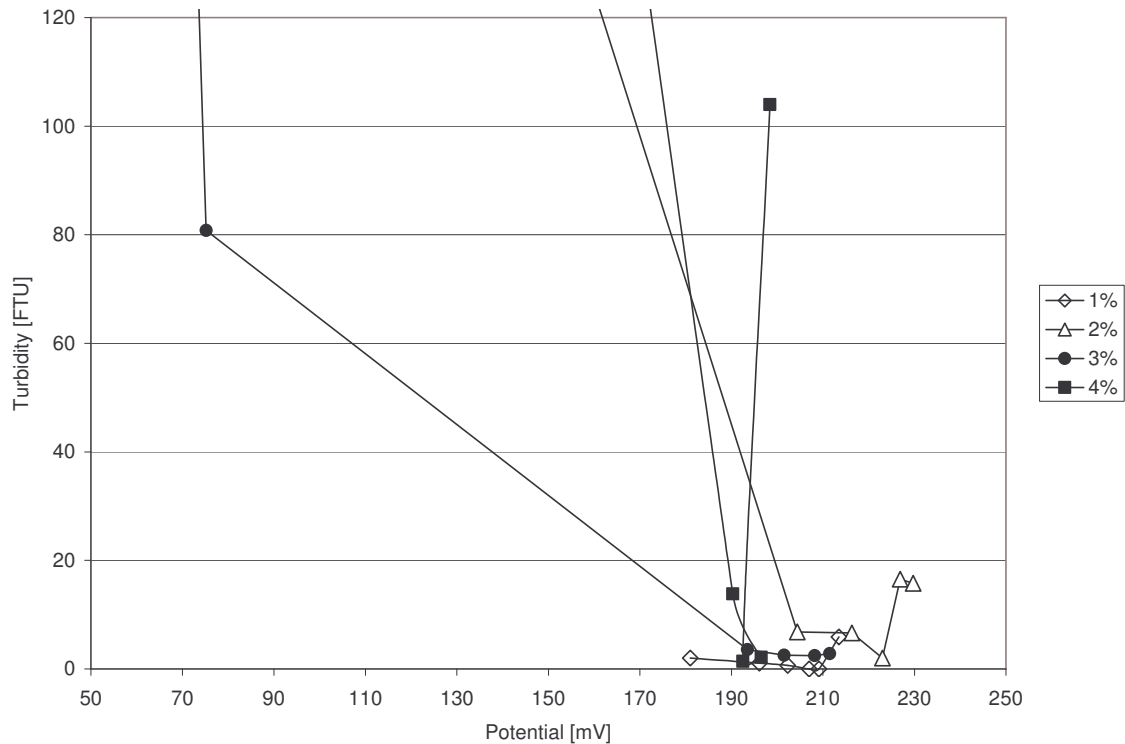


Figure 4.9 Turbidity as a function of potential for different volumes of a 52 g/l flocculent feed solution added for 1%, 2%, 3% and 4% solutions of Dispersant A

To substantiate the fact that these results confirm the earlier observation regarding increases in potential as an indication of good flocculation, turbidity has been shown as a function of potential in Figure 4.9. The 1% dispersant solution yielded high redox potential measurements and good flocculation in all cases. For the 2% and 3% solutions the potential increases to about 200mV as the turbidity decreases below 100FTUs.

For the 4% dispersant solution the redox potential increases as the turbidity decreases initially and then the turbidity increases again to 104 FTUs (for the jar

test, to which 120 mL of flocculent was added), while the potential remains high, at 198 mV. Even though the turbidity for this experiment is not very high, this still represents a point for which the flocculation has not been fully effective in spite of the increase in redox potential. More work would need to be done to investigate whether the addition of a greater volume of flocculent would result in a smaller potential and a higher turbidity, in line with the hypothesis offered above for the connection between redox potential and turbidity reduction.

4.2.7 Comparison of flocculation between Dispersant A and paint wastewater produced from Dispersant A at 52g/l

This section compares the degree of flocculation obtained for Dispersant A and paint wastewater of paint produced from Dispersant A. The paint used is manufactured from 2% by mass of Dispersant A. The dispersant solution is also prepared so as to be 2% by mass.

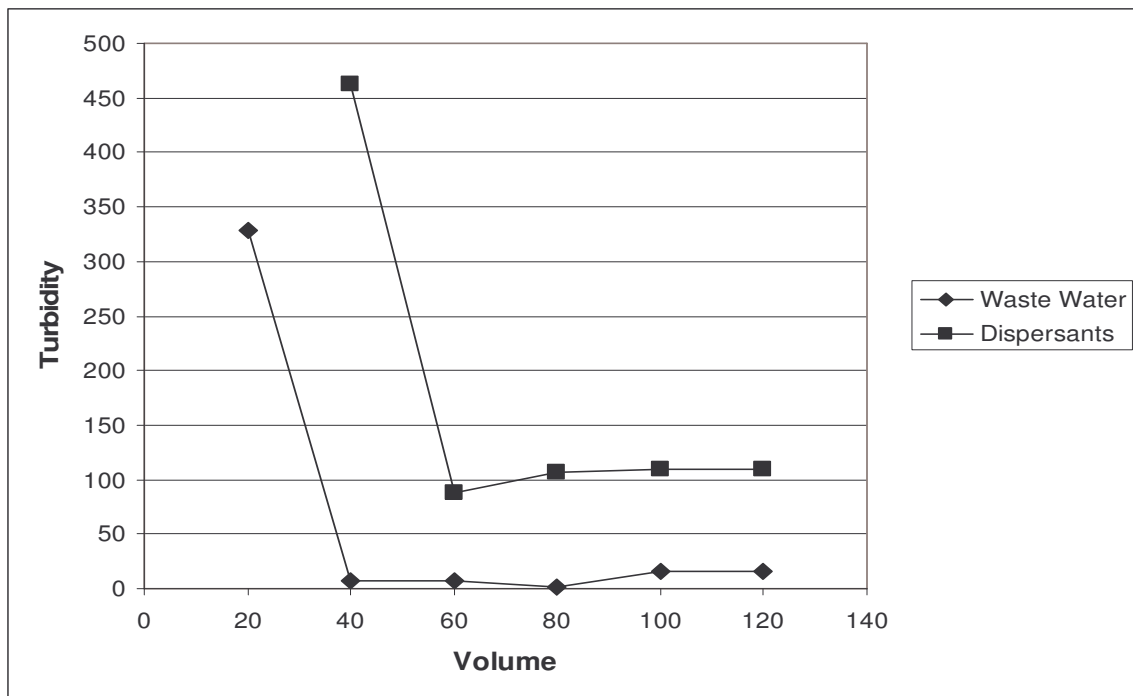


Figure 4.10 Comparison of turbidity for the same % composition of Dispersant A and wastewater

Results in Figure 4.10 show that less flocculent is required to flocculate the same amount of wastewater than is required for flocculating pure Dispersant A. This emphasizes the observation mentioned earlier: **that there is a strong correlation between the extent of flocculation and the solid content of the wastewater**. It can be seen that a lower dosage is required to flocculate wastewater than for dispersants. This is because wastewater flocs are much heavier than dispersant flocs so they settle much faster, owing to gravity.

It can also be observed that the results obtained from the wastewater and dispersant flocculation experiments are similar. This confirms the initial assumption that the dispersants are responsible for keeping the particles in suspension. **Therefore, when flocculating wastewater, the flocculent attacks the dispersant. This causes the destabilization of the colloid matrix and thus, flocculation.**

4.3 Particle Nucleation Versus growth

In previous sections the focus was on the analysis and discussion of experimental results of water recovered from the flocculation process. This section shifts the focus towards particles that formed from the hydrolysis of aluminium sulphate.

To evaluate the relationship between particle nucleation versus growth and the degree of flocculation, samples of Dispersant A were flocculated and analyzed for particle size in a Malvern, as per the procedure in Section 3.1.2.3. The results are presented in Section 4.3.1, for samples flocculated using 7g/l, 52 g/l and 109 g/l of aluminium sulphate. Section 4.3.2 covers the settling rate of the different size of particles that form when the dispersants are precipitated.

4.3.1 The effect of flocculent on particle size distribution.

4.3.1.1 Particle size distribution as a result of flocculation with 7g/l initial flocculent.

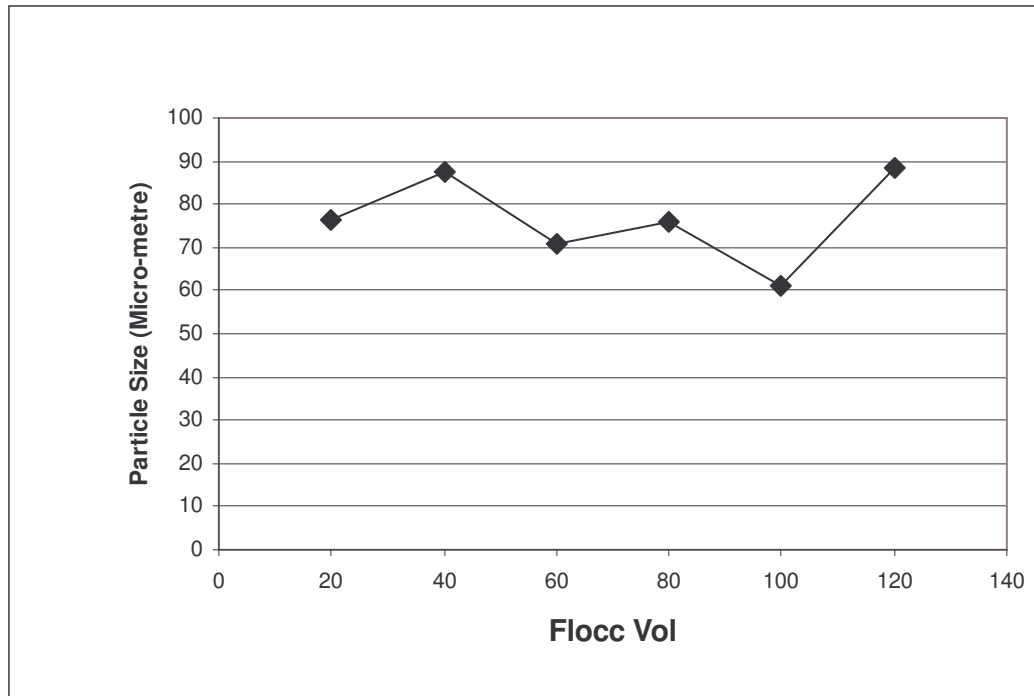


Figure 4.11 The relationship between flocculent volume and particle size. The flocculated feed concentration is 7 g/l in all experiments.

The results in Figure 4.11 show that particle size is between 60 μm and 90 μm . It can be interpreted that at low flocculent concentration (7g/l) nucleation of particles is dominant. It is postulated that this is caused by an insufficiency of aluminium sulphate to precipitate all the particles out of solution. This results in a few particles of more or less the same size. The above plot shows that 90 % of the particles that were flocculated range from 60 to 90 micro-meters. To test this hypothesis, the concentration of aluminium sulphate was increased to 52 g/l and the results are discussed in the following section.

4.3.1.2 Particle size distribution as a result of flocculating with 52g/l feed flocculent

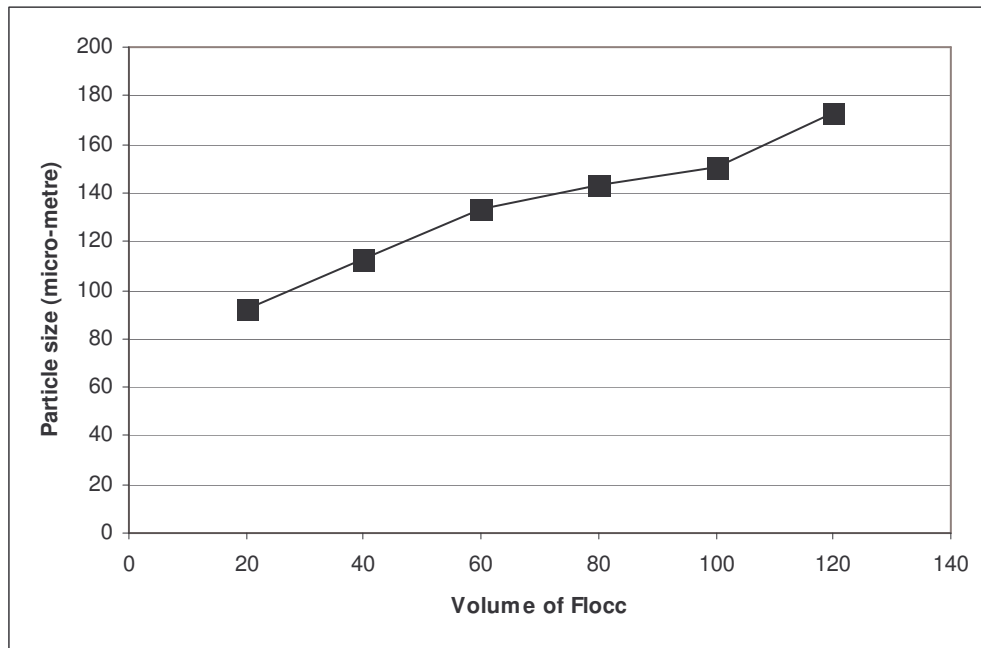


Figure 4.12 Graph of volume of flocculent added versus particle size

The fluid concentration was 52 g/l in all these experiments.

Results show a strong relationship between flocculent dosage and particle size measured. In this case it is postulated that for flocculation to start there must be enough flocculation in solution to precipitate all the particles. Once all particles have been nucleated' the excess flocculent is used in the growth of existing particles. Figure 4.12 shows that particle size increases proportionally with flocculent volume.

It was observed that as the particle size increases, the density of the flocs decreases. This is because each particle has an electronic charge which repels neighbouring particles, depending on their orientation and charge. Thus, these low-density flocs are light and fluffy. They float on top of the flocculated water. It is very difficult to recover the wastewater from them.

To substantiate the observation, the results of the particle distribution for the 109g/l experiments are presented below.

4.3.1.3 Particle size distribution as a result of flocculating with 109g/l feed concentration

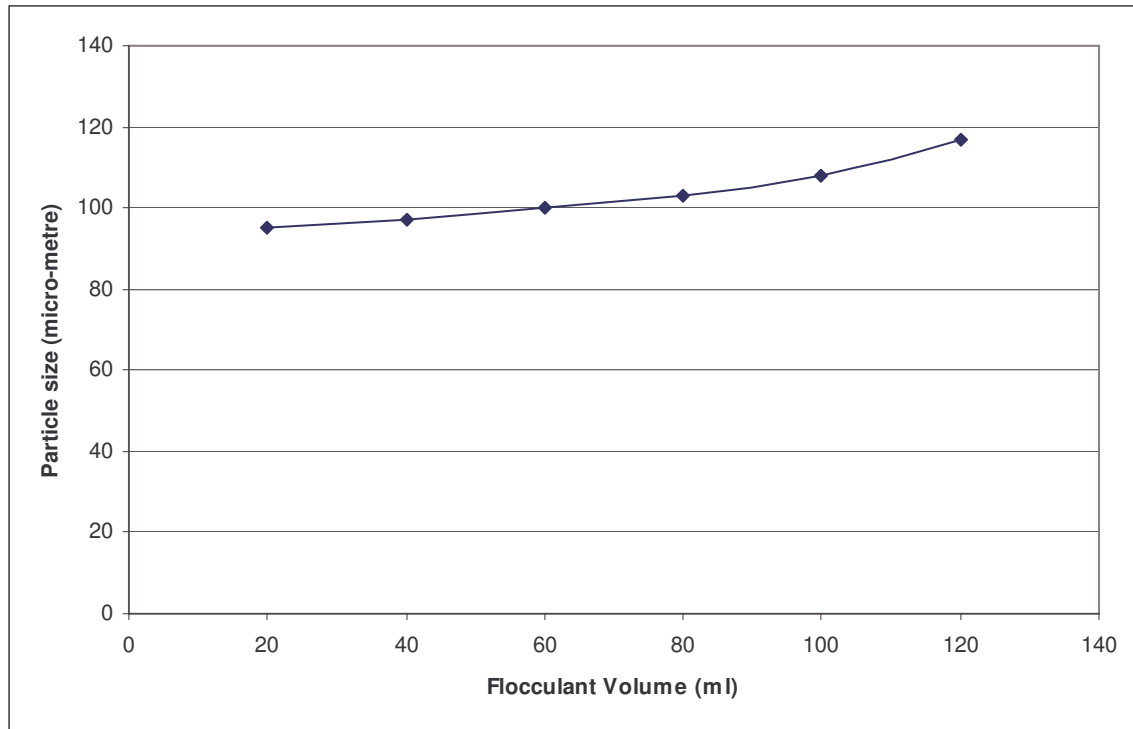


Figure 4.13 Graph of volume of flocculent added versus particle size

The fluid concentration was 109 g/l in all these experiments.

The plot in Figure 4.13 again shows us a linear relationship between flocculent volume and particle size at 109 g/l. Although the dependence (slope) is not as strong as for 52g/l, at a flocculant dosage of 109g/l growth of particles is still dominant. This is in accordance with the postulate mentioned in Section 4.12, about particle nucleation versus growth.

4.3.2 Investigation of particle (dispersants) settling rates

Section 4.3.1 observes how the quantity of aluminium sulphate at different concentrations affected the size particles formed. It was observed that at low concentrations (7g/l), nucleation was dominant and when the concentration of aluminium sulphate was increased to 52 g/l, particle size was proportional to the quantity of flocculent added. When the concentration was further increased to 109 g/l, the particles decreased in size. In Section 4.2.7 the turbidity of recovered water from the flocculation of dispersants and white wastewater is compared. Results showed that for 52g/l feed concentration of aluminium sulphate, minimum turbidity was obtained at 40ml of the flocculent.

In this section the settling velocities of the particles discussed in Section 4.3.1 are investigated. Figure 4.14 presents results obtained when settling rates calculated from Stokes' law were plotted against volume of flocculant at different feed concentrations of aluminium sulphate.

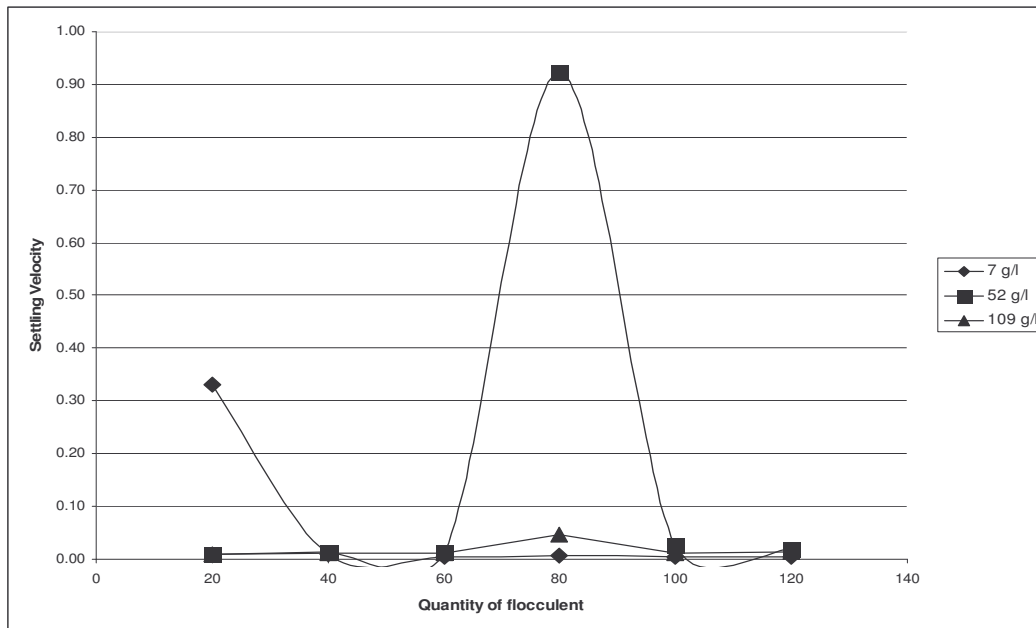


Figure 4.14 Settling rates for three concentrations

From the results it can be seen that at a concentration of 7 g/l, the settling rates decrease from 0.32 m/s to 0.02 m/s as the quantity of flocculent is increased from 20 mL to 40 mL. When the flocculent quantity is increased further, the rates stay the same. This can be associated with the fact that at low concentrations of flocculent there is no growth of particles.

On the other hand, the plot of the 52g/l flocculent feed concentration shows that the settling rates increase from 0.01 m/s to 0.02 m/s when the quantity of flocculent is increased from 20ml to 120 ml. It can be observed that at this concentration there is a drastic increase in settling velocity at 80 ml of flocculent. This is also observed in the 109g/l concentration. This comparison can be observed much better in a reduced scale (Figure 4.15).

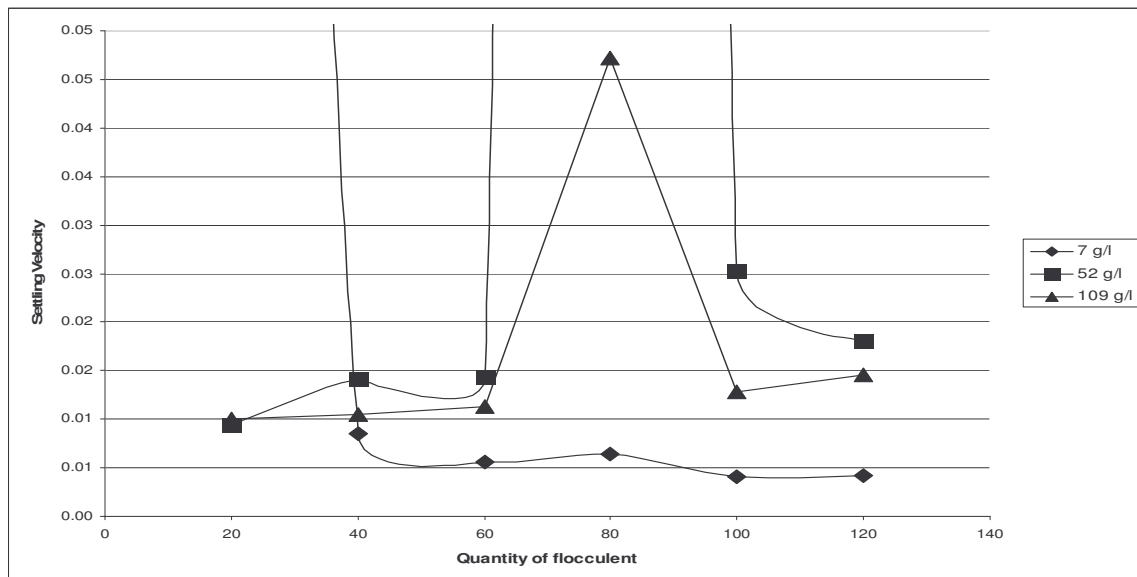


Figure 4.15 Settling rate is a function of quantity of flocculent added.

Three different feed flocculents are considered.

In general, when the settling velocities of the three concentrations are compared it can be seen that 52g/l remains high besides 7g/l initial high rates.

The results show that there is a relationship between high settling rates and particle size. This can be interpreted by Stokes' law for spherical particles:

$$V = \frac{1}{18\mu} (\rho_s - \rho_f)gd^2$$

Where V = settling velocity
 g = gravitational acceleration
 ρ_s = density of solid particles
 ρ_f = density of fluid
 μ = viscosity of fluid

This expression is derived from balancing the forces that act on a particle moving in a fluid at very low speed. From the expression above it can be seen that the settling velocity of a particle is directly proportional to its diameter. Therefore, big particles settle faster than small particles.

Section 4.3.1 showed that particle size is proportional to the concentration of flocculent in the regions where growth is dominant. Therefore, it can be said that at a dispersant concentration of 52 g/l, particles formed settle much faster than at other concentrations. Thus, flocculent dosage is directly proportional to settling velocities at the region where growth is dominant.

CHAPTER 5

5 Conclusions and Recommendations

From work done on the treatment of wastewater used in the production of paint, the conclusions given below could be made.

There is a correlation between the flocculant dosage and the solid content of the wastewater that is being flocculated. Less flocculent is required to flocculate a solution with more solids in it. Therefore, a proper analysis of the wastewater is required before the flocculation process is started. It might be advantageous to control the amount of solids in wastewater by mixing wastewater of different concentrations if these are available.

Good flocculation is accompanied by a considerable change in redox potential. It is postulated that this occurs because, at the point where good flocculation happens, there is a transfer of electrons. Therefore potential can be used to predict good flocculation at low dispersant concentrations.

It was found that good mixing improved the kinetics of the paint wastewater flocculation process. Since the hydrolysis reaction of Al^{3+} is very significant in flocculation, the reaction is affected by pH. The possibility that changes in pH can be used to indicate when effective flocculation in dispersants will occur was explored. Results show that the best flocculation occurred between pH 4 and 5.

Both dispersants used in these experiments were easy to flocculate, compared to wastewater. It was observed that more flocculent is required to flocculate Dispersant A than B, to generate similar flocculation results. It was found that in order to flocculate paint wastewater, the effect of the dispersants needs to be

counteracted, and this destabilizes the colloidal suspension, enabling flocculation and settling to occur.

Another finding was that particle size increases with flocculent volume added. During flocculation the balance between particle nucleation and growth plays a significant role. At low flocculent concentrations nucleation is dominant. The particles formed under these conditions are not dense or large enough to settle down due to gravity. Conversely, at high flocculent concentrations, growth becomes dominant and this results in the formation of large low-density particles. These are very porous, so they do not settle. It is very important to monitor the growth of particles, to yield the best results.

In this work important means of optimizing the flocculation process and minimizing the amount of wastewater from the paint production process have been identified. Future research modelling the correlation between the solid content of wastewater and the flocculent feed concentration might prove worthwhile. This study found that the flocculent feed concentration decreased with increasing solid content of wastewater. It also found that, at low dispersant concentration, redox potential can be used to predict the flocculent feed concentration that will result in good flocculation. Future research might be done to determine why redox potential does not give a good prediction at high dispersant concentration.

CHAPTER 6

References

Bottero J.Y., Cases J.M., Fiessenger F and Poirier JE (1980) *J.Phys.Chem.*(84) 2933-2939.

Coulson J.M.and Richardson J.F. *Chemical Engineering (Particle Technology and Separation Processes)* (1993).University of Newcastle-upon-Tyne, Vol2, 95-98.

Fasemore O.A., (2004): *The flocculation of paint wastewater using inorganic salts*, Msc Dissertation University of the Witwatersrand, Johannesburg. South Africa 20-28 and 52-85.

Faust S.D. and Aly O.M. (1983) *Chemistry Of Water Treatment*, Butterworth publishers, Stoneham, .277-363.

Flynn C.M. (1984) *Hydrolysis of inorganic iron (III) salts*, Chemical Review, vol.84, no.1, 31 to 41.

Girou A. and Franceschi M. (2002).*Optimisation of coagulation-flocculation process of raw water by optimal design method*, Universite P. Sabatier, France,3562 -3571.

Gregor J.E., *Optimising organic nature removal from low turbidity waters by controlled pH adjustment of aluminium coagulation* (1997): Water Research (31), 2949-2958.

Hunter R.J.and Van deVan T.G. (1977) *Rheologica Acta*, 16, 534-543.

Jewell L.L, Fasemore O.A., Glasser D., Hildebrandt D., Heron L., Van Wyk N., Cooray B.,(2004) *Towards zero waste production in the paint industry*: Water SA, Vol 30, No 5 (special edition) 95-99.

Jiang J.Q. and Graham N.J.D. (1998) *Water Research*, 32 (3) 930-935.

La Mer V.K., *Coagulation Symposium Introduction* (1964): *J. Colloid Science*, 19 - 291.

MSDSs for Dispersants A and B (2004) P.O. Box 571, 8440 an Heerenveen, The Netherlands.

Nozaic D.J., Freese S.D. and Thompson P. (2001) *Water Science and Technology: Water Supply*, 1 (1) 43-50.

Stumm W. and Morgan J.J., (1962) *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibrium in Natural Water*, John Wiley and Sons, New York, USA, 130 -140, 230 – 399, 418-490.

Swartbooi (2005) A.M. Precipitation of Nickel and Cobalt Sulphides, Msc Dissertation, University of Cape Town, 5 – 24.

Thomas D.N, Judd S.J. and Fawcett N., *Flocculation Modeling*, School of Water Sciences, Cranfield University, 1579 – 1591.

Thomas D.N., Judd S.J. and Fawcett N. (1999) *Water Research*, 33 (7) 1579-1592.

Turner P.S. and Glasser D., *Continuous Thickening in a Pilot Plant*, University of the Witwatersrand, Johannesburg. South Africa. *Ind. Eng., Fundam.*, Vol 15, No.1, 1976. 23 –30.

[1] *Crystallization*, <http://en.wikipedia.org/wiki/Crystallization>, 01.07.2006

[2] *Crystallization Theory*, <http://us.mt.com/mt/resources/contactUs.jsp>, 01.07.2006

[3] *Handbook for Organic Chemistry Lab*, <http://orgchem.colorado.edu/hndbksupport/cryst/cryst.html>, 01.07.2006

CHAPTER 7

Appendices

Appendix A (Preliminary experimental work)

A.1 Calibration of E/pH Equipment

To Calibrate the E /pH meter 2 Potassium Chloride standard solutions were used; one at a pH of 4 and the other at 7. These solutions were used to calibrate the E/pH meter and the probe. To set optimum operating temperature of the meter and ensure consistency of results, solutions at different temperatures were investigated. Results obtained are tabulated and plotted below.

Table A.1 Results of change in pH as concentration is increased at different temperatures

Plotting Concentration Versus pH		
Exp 1	pH Old	Conc
	2.6	0.064982 m/l
	3.33	0.032491 m/l
	5.52	0.0162455 m/l
	7.09	0.00812127 m/l
Exp 2	pH (temp 22)	Conc
	2.93	0.064982 m/l
	3.43	0.032491 m/l
	5.45	0.0162455 m/l
	6.7	0.00812127 m/l
Exp3	pH (temp 30.1)	Conc
	2.15	0.064982 m/l
	2.67	0.032491 m/l
	4.17	0.0162455 m/l
	5.23	0.00812127 m/l

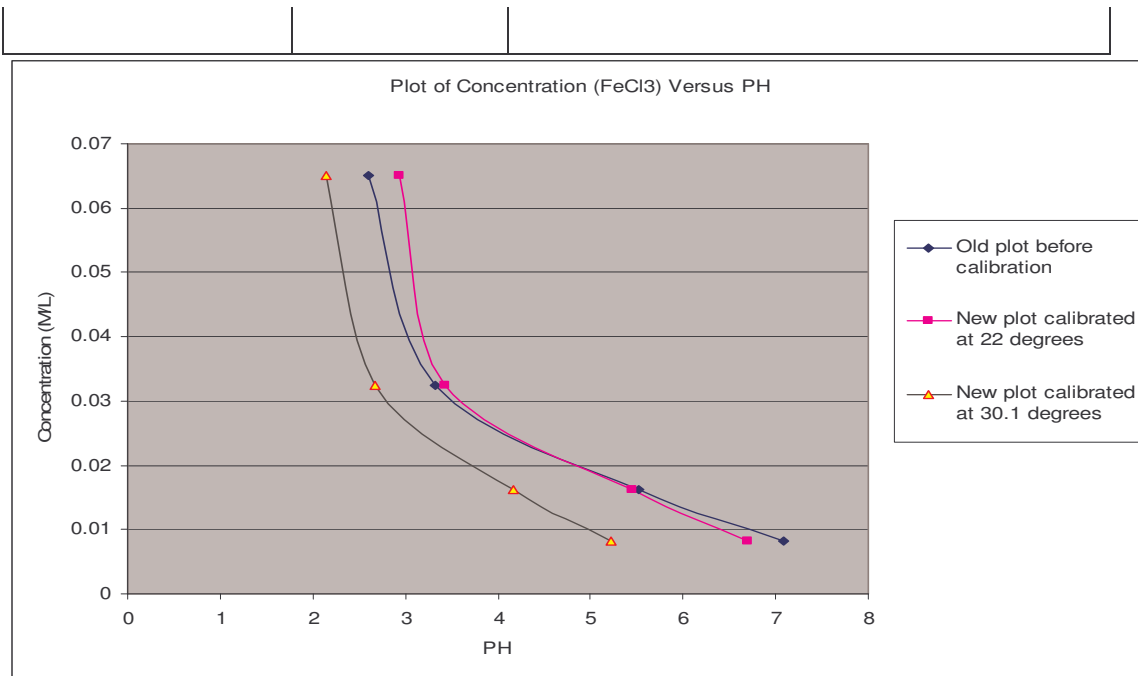


Figure A.1 A plot of change in pH as concentration is increased at different temperatures

A.2 Time Investigation

To find out the time at which samples can be analyzed for pH and potential, experimental work was done at different flocculent feed concentrations: 6g/l, 7g/l, 8g/l. These results were tabulated and are plotted below.

A.2.1 Time Investigation for 6g/l

Table A.2.1 Results obtained after different periods

1hr			
Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.88
2	400 ml	40 ml	7.68
3	400 ml	60 ml	7.43
4	400 ml	80 ml	7.02
5	400 ml	100 ml	6.42
6	400 ml	120 ml	6.08

12 hrs

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.82
2	400 ml	40 ml	7.57
3	400 ml	60 ml	7.37
4	400 ml	80 ml	6.96
5	400 ml	100 ml	6.26
6	400 ml	120 ml	5.95

2 days

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.49
2	400 ml	40 ml	7.35
3	400 ml	60 ml	7.12
4	400 ml	80 ml	6.17
5	400 ml	100 ml	5.95
6	400 ml	120 ml	5.7

4 days

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.87
2	400 ml	40 ml	7.67
3	400 ml	60 ml	7.46
4	400 ml	80 ml	7.09
5	400 ml	100 ml	7.3
6	400 ml	120 ml	5.88

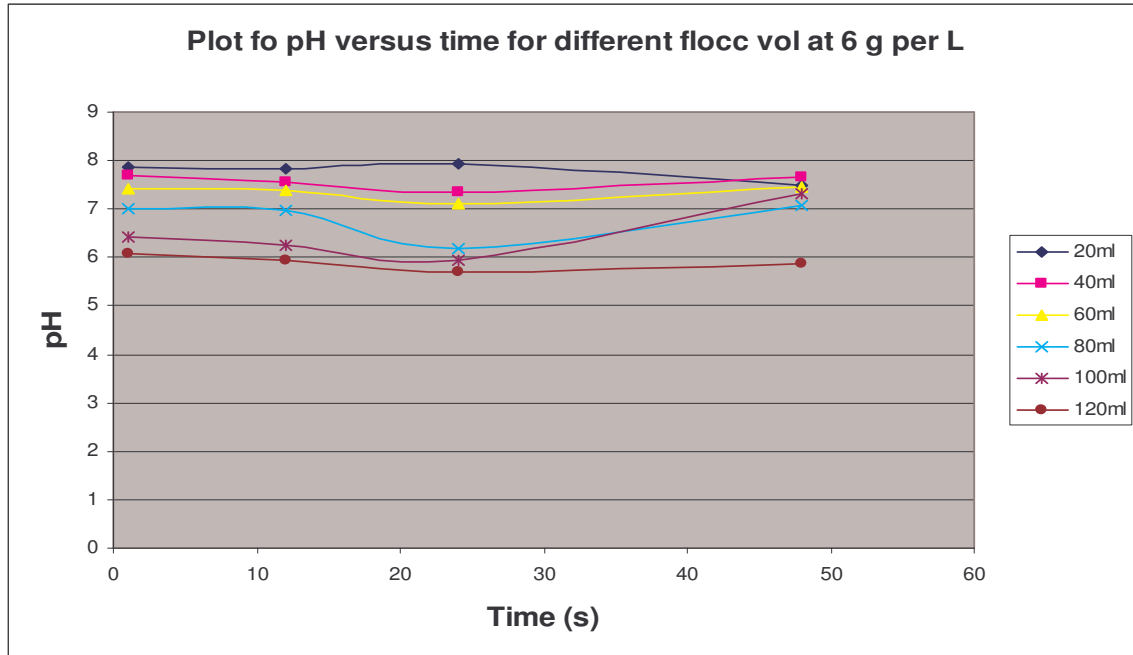


Figure A.2.1 Results obtained after different periods

A.2.2 Time Investigation for 7g/l

Table A.2.2 shows results obtained after different periods.

1hr			
Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.58
2	400 ml	40 ml	7.46
3	400 ml	60 ml	7.34
4	400 ml	80 ml	7.24
5	400 ml	100 ml	7.23
6	400 ml	120 ml	7.2

12 hrs

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	8.09
2	400 ml	40 ml	7.86

3	400 ml	60 ml	7.78
4	400 ml	80 ml	7.68
5	400 ml	100 ml	7.62
6	400 ml	120 ml	7.53

2 days

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.95
2	400 ml	40 ml	7.85
3	400 ml	60 ml	7.86
4	400 ml	80 ml	7.85
5	400 ml	100 ml	7.84
6	400 ml	120 ml	7.86

4 days

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.71
2	400 ml	40 ml	7.95
3	400 ml	60 ml	7.8
4	400 ml	80 ml	7.83
5	400 ml	100 ml	7.87
6	400 ml	120 ml	7.83

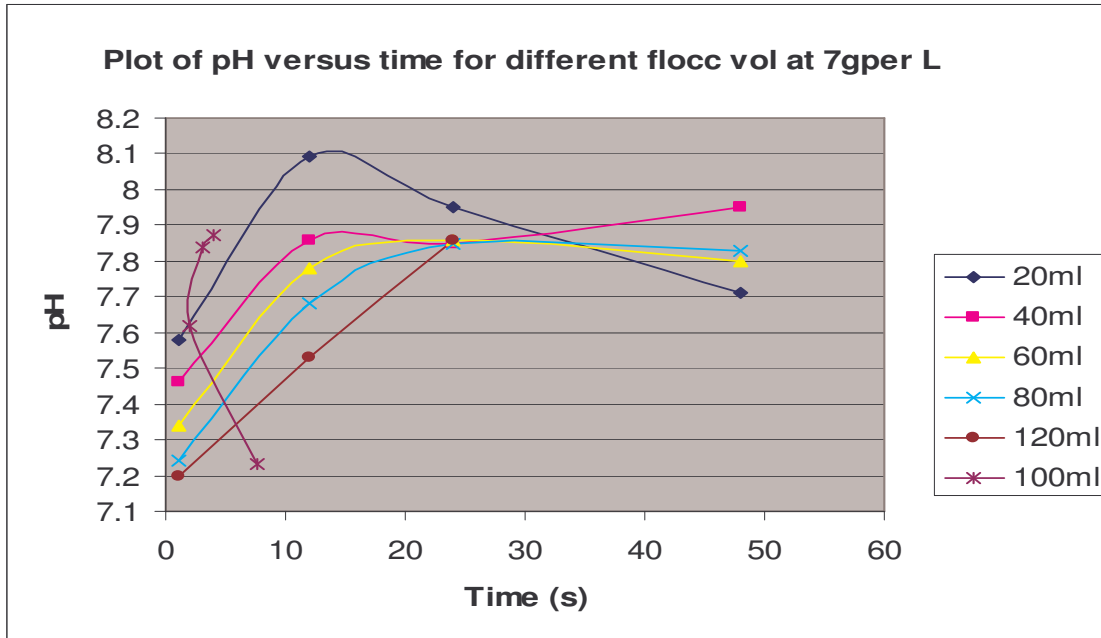


Figure A.2.2 Results obtained after different periods

A.2.3 Time Investigation for 8g/l

Table A.2.3 Shows results obtained after different periods.

1 hr

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.82
2	400 ml	40 ml	7.67
3	400 ml	60 ml	7.55
4	400 ml	80 ml	7.5
5	400 ml	100 ml	7.48

12 hrs

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.75
2	400 ml	40 ml	7.65
3	400 ml	60 ml	7.54
4	400 ml	80 ml	7.42

5	400 ml	100 ml	7.16
---	--------	--------	------

2 days

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.47
2	400 ml	40 ml	7.42
3	400 ml	60 ml	7.26
4	400 ml	80 ml	7.27
5	400 ml	100 ml	7.16

4 days

Sample	Vol w w	Vol flocc	pH
1	400 ml	20 ml	7.83
2	400 ml	40 ml	7.74
3	400 ml	60 ml	7.71
4	400 ml	80 ml	7.54
5	400 ml	100 ml	7.62

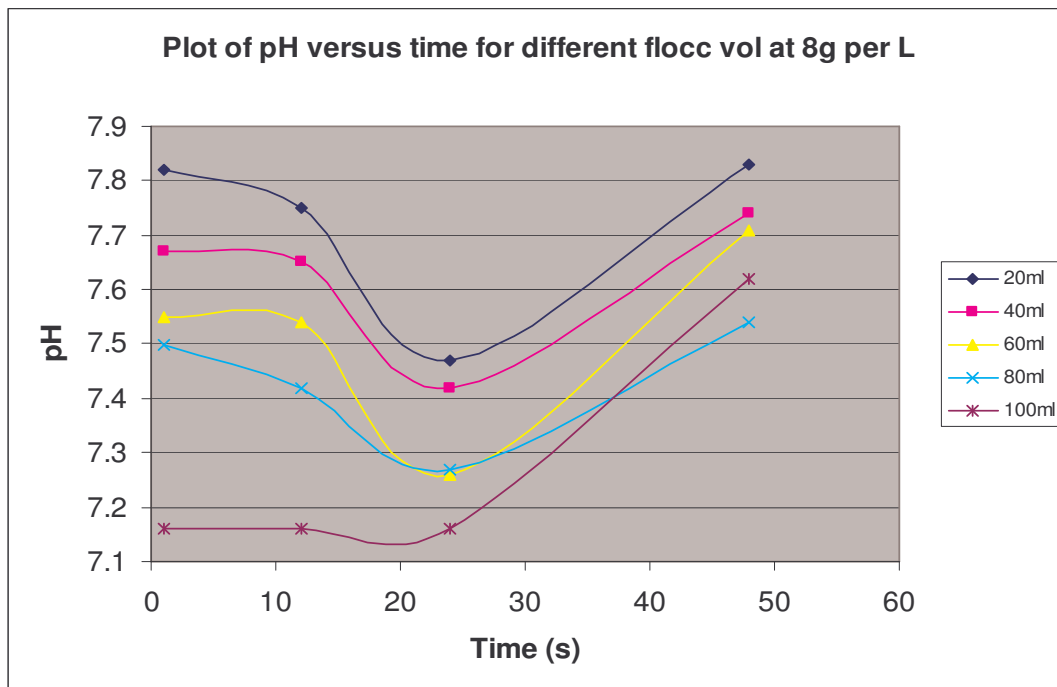


Figure A.2.3 Results obtained after different periods

A.3. Scaling up Investigation

To ensure that the process under investigation could be implemented in an industrial scale, scale-up experiments were conducted and results are presented below.

Table A.3 How different scales affect pH

Sample	Vol w w	Vol floc	pH	E
1	100	5	7.4	-12.1
2	200	10	7.13	2.8
3	300	15	7.18	1.1
4	400	20	7.11	4.5
5	500	25	7.04	8.4

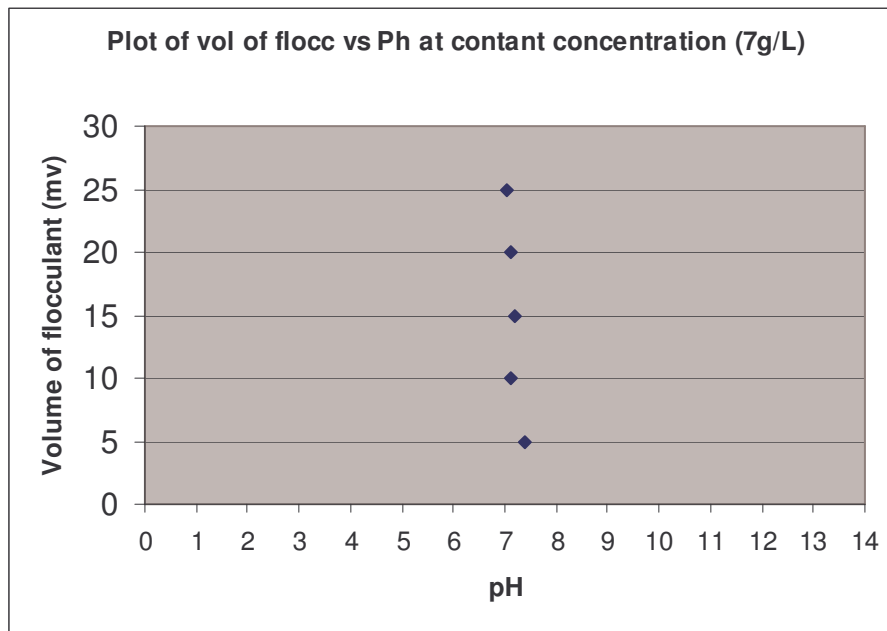


Figure A.3 How different scales affect pH

Appendix B (Wastewater flocculation experimental work)

To investigate the optimum flocculent dosage, the pH turbidity and potential after flocculation were measured for different feed concentrations and volumes.

B.1.1 White Wastewater Flocculation for (7g, 52g, 109g)

Table B.1.1 illustrates the change in pH with flocculent volume at different feeds.

7g/l

5.75	0.411764706
5.42	0.777777778
5.14	1.105263158
4.99	1.4
4.88	1.666666667
4.81	1.909090909

52g/l

6.82	0.411764706
6.49	0.777777778
6.3	1.105263158
6.15	1.4
6.02	1.666666667
5.38	1.909090909

109 g/l

4.93	0.411764706
4.33	0.777777778
4.2	1.105263158
4.11	1.4
4.02	1.666666667
4.01	1.909090909

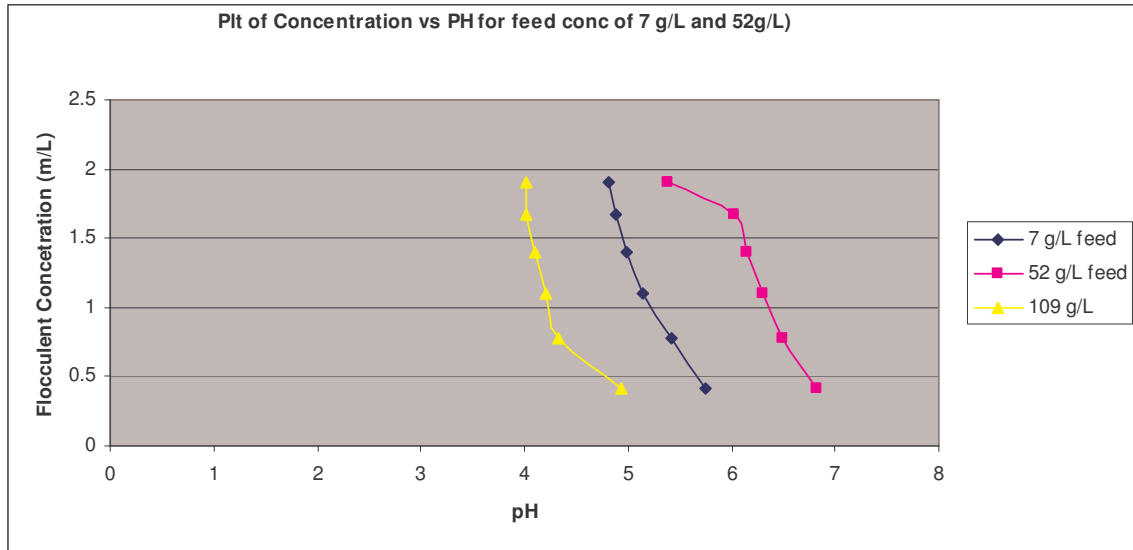


Figure B.1.1 illustrates the change in pH with flocculent volume at different feeds.

B.1.2 White Wastewater Flocculation for (6g, 7g, 8g) Optimisation

B.1.2.1 White Wastewater Flocculation for 6g

Table B.1.2 illustrates the change in pH with flocculent volume.

Sample	Vol w w	Vol flocc	pH	redox potential
1	400 ml	20 ml	6.37	60.1
2	400 ml	40 ml	6.03	61.5
3	400 ml	60 ml	6.02	69.1
4	400 ml	80 ml	5.88	70.8
5	400 ml	100 ml	5.87	74.7
6	400 ml	120 ml	5.85	75.9

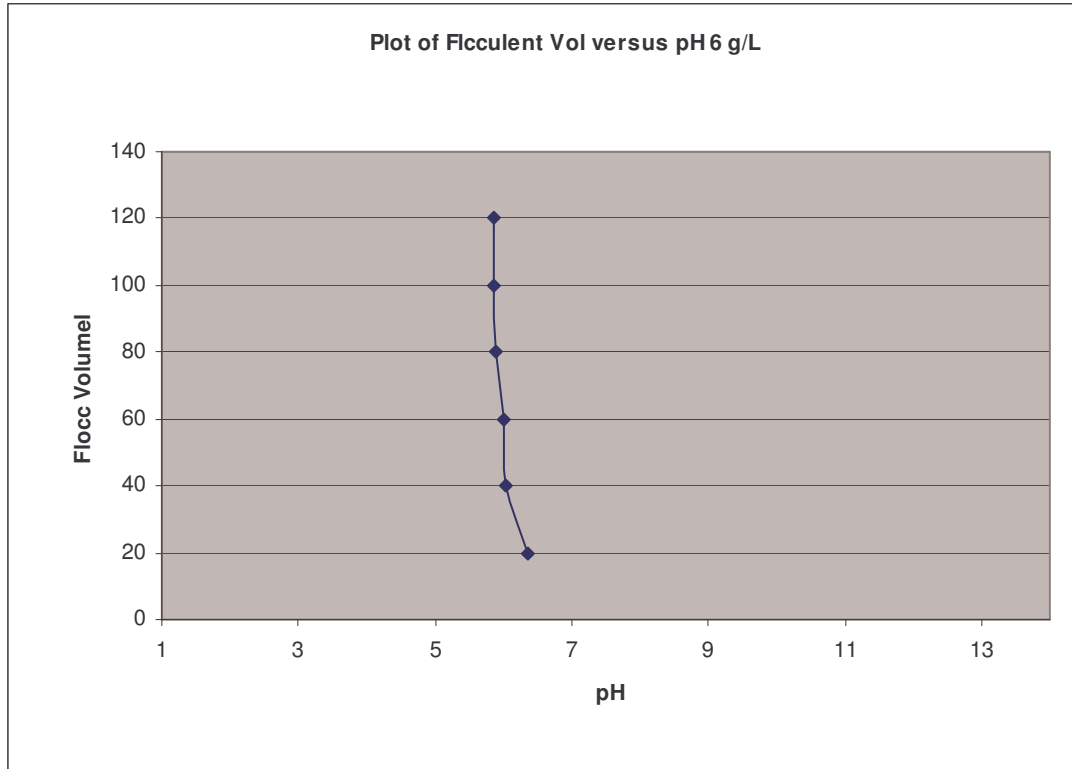


Figure B.1.2 illustrates the change in pH with flocculent volume

B.1.2.2 White Wastewater Flocculation for 7g

Table B.1.2.2 illustrates the change in pH with flocculent volume.

Sample	Vol w w	Vol flocc	pH	redox potential
1	400 ml	20 ml	6.6	35.9
2	400 ml	40 ml	6.44	40.3
3	400 ml	60 ml	6.6	45.3
4	400 ml	80 ml	6.58	39.7

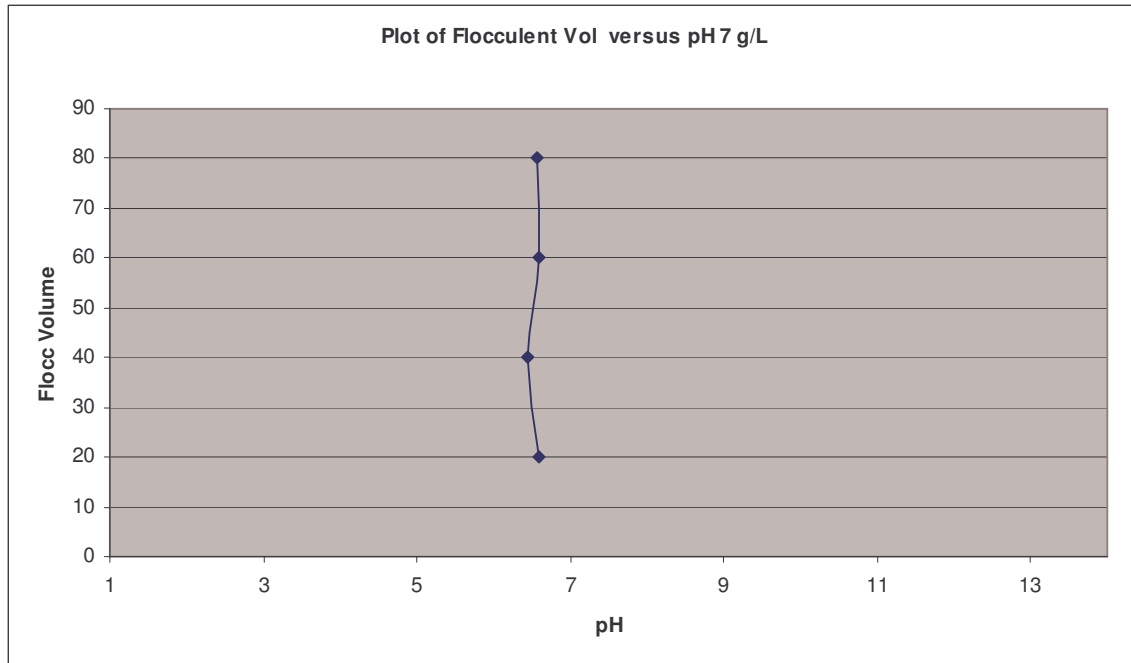
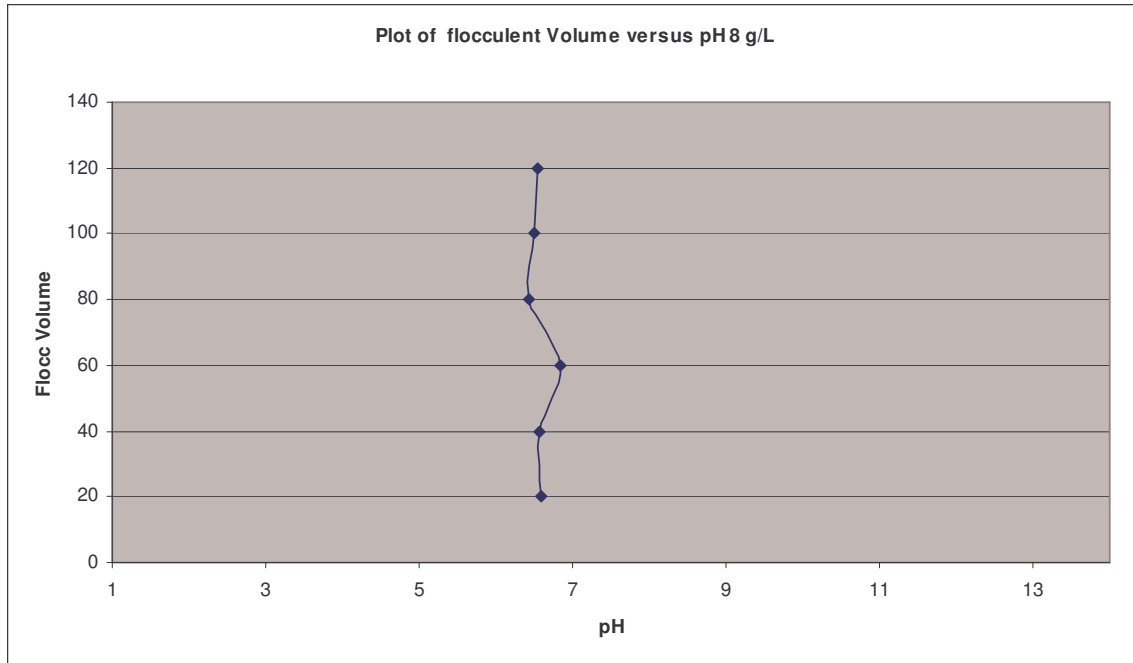


Figure B.1.2.2 illustrates the change in pH with flocculent volume.

B.1.2.3 White Wastewater Flocculation for 8g

Table B.1.2.3 illustrates the change in pH with flocculent volume.

Sample	Vol w w	Vol flocc	pH	redox potential
1	400 ml	20 ml	6.6	37.6
2	400 ml	40 ml	6.56	39.9
3	400 ml	60 ml	6.83	20.9
4	400 ml	80 ml	6.44	45.1
5	400 ml	100 ml	6.5	40.4
6	400 ml	120 ml	6.54	40.2



FigureB.1.2.3 illustrates the change in pH with flocculent volume.

Appendix C(Dispersants flocculation experimental work)

The results obtained in the dispersant flocculation experiments using aluminium sulphate are evaluated, using measured properties of the recovered water such as pH, redox potential and turbidity, where turbidity is used as a measure of flocculation efficiency.

C.1 Comparing Dispersants A and White Waste at different Concentrations

C.1.1 Flocculent Concentration 6g/l

Table C.1.1 Results obtained when flocculating dispersants and paint wastewater

Dispersants					
	Sample	dispersant vol	Vol flocc	pH	Potential
	1	400	20	7.72	18.8
	2	400	40	7.6	23.9
	3	400	60	7.5	29.1
	4	400	80	7.41	34.9
	5	400	100	7.33	39.6
	6	400	120	7.25	43.8
Paint					
	Sample	Vol w w	Vol flocc	pH	potential
	1	400	20	6.37	60.1
	2	400	40	6.03	61.5
	3	400	60	6.02	69.1
	4	400	80	5.88	70.8
	5	400	100	5.87	74.7
	6	400	120	5.85	75.9

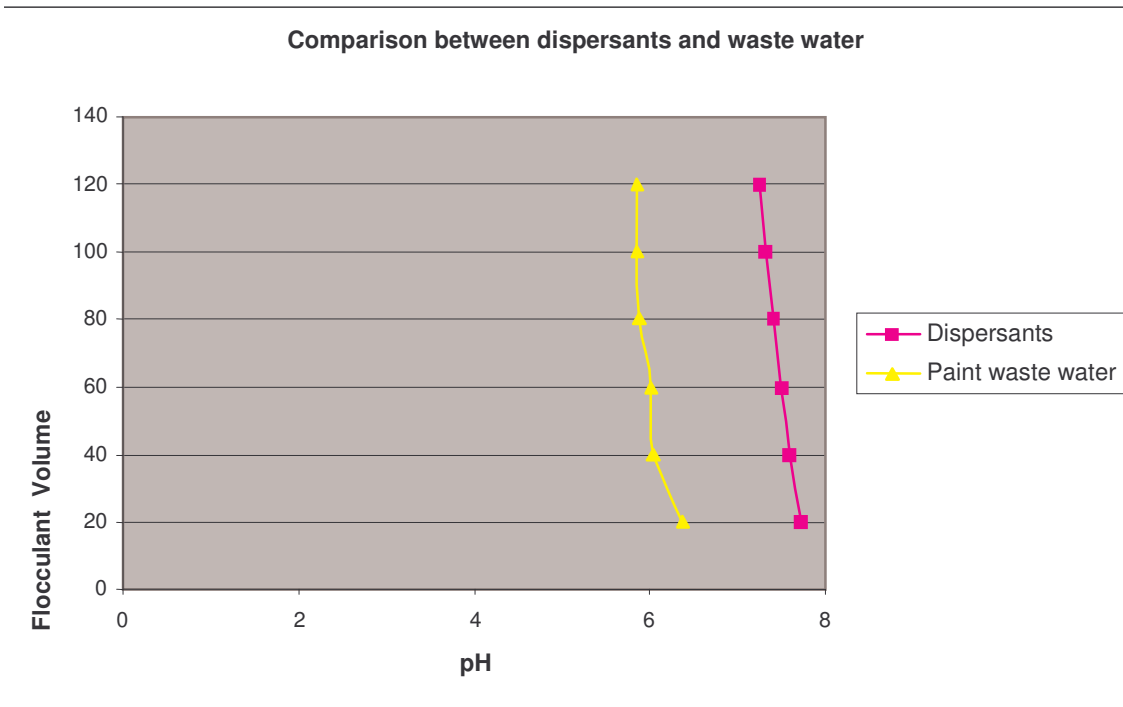


Figure C.1.1.a Results obtained when flocculating dispersants and paint wastewater

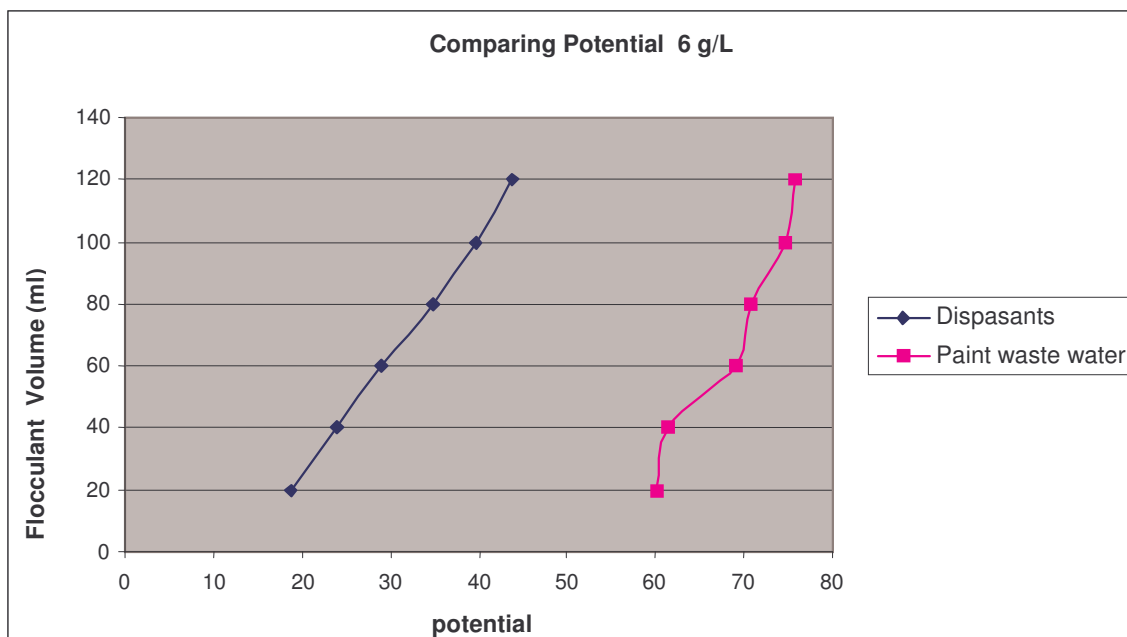


Figure C.1.1.b Results obtained when flocculating dispersants and paint wastewater

C.1.2 Flocculent Concentration 7g/l

Table C.1.2 Results obtained when flocculating dispersants and paint wastewater

Dispersants					
	Sample	Dispersants Vol	Flocc Vol	pH	Potential
	1	400	20	7.68	32.2
	2	400	40	7.42	38.8
	3	400	60	7.28	43.1
	4	400	80	7.1	53.9
	5	400	100	7.01	58.7
	6	400	120	6.93	63.7
Paint					
	Sample	Vol w w	Vol flocc	pH	redox potential
	1	400	20	6.6	35.9
	2	400	40	6.44	40.3
	3	400	60	6.6	45.3
	4	400	80	6.58	39.7

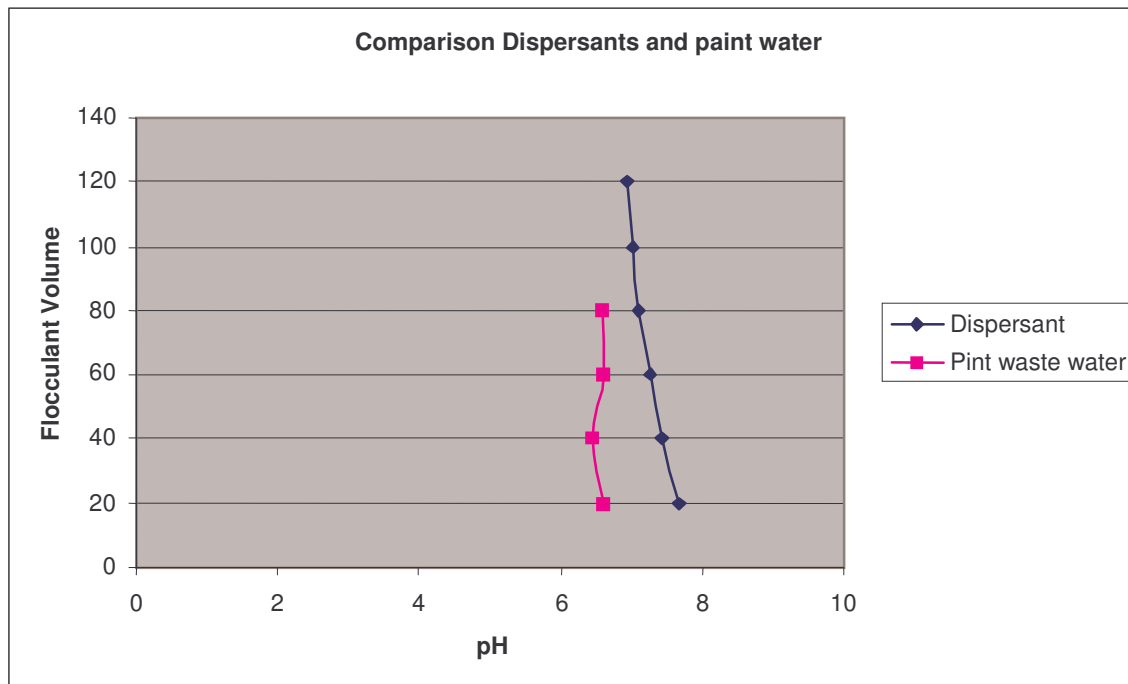


Figure C.1.2.a Results obtained when flocculating dispersants and paint wastewater

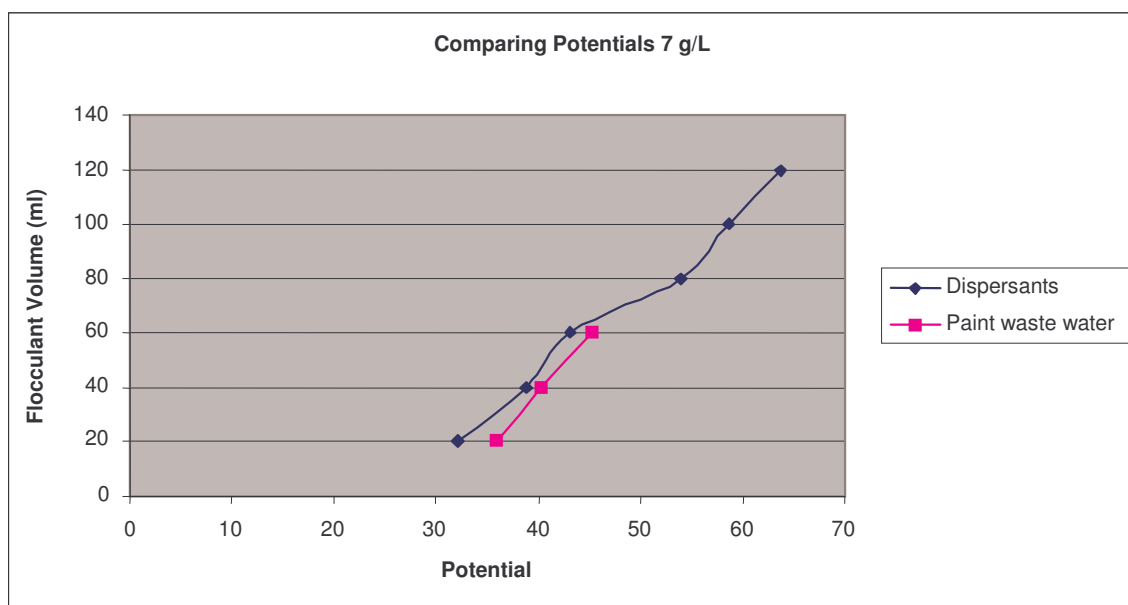


Figure C.1.2.b Results obtained when flocculating dispersants and paint wastewater

C.1.3 Flocculent Concentration 8g/l

Table C.1.3 Results obtained when flocculating dispersants and paint wastewater

Dispersants	Sample	Dispersants Vol	Flocc Vol	pH	Potential
	1	400	20	7.78	17
	2	400	40	7.59	26
	3	400	60	7.42	33.5
	4	400	80	7.17	49.5
	4	400	100	7.18	49.2
	5	400	120	6.96	61.3
Paint	Sample	Vol w w	Vol flocc	pH	redox potential
	1	400 ml	20	6.6	37.6

	2	400 ml	40	6.56	39.9
	3	400 ml	60	6.83	20.9
	4	400 ml	80	6.44	45.1
	5	400 ml	100	6.5	40.4
	6	400 ml	120	6.54	40.2

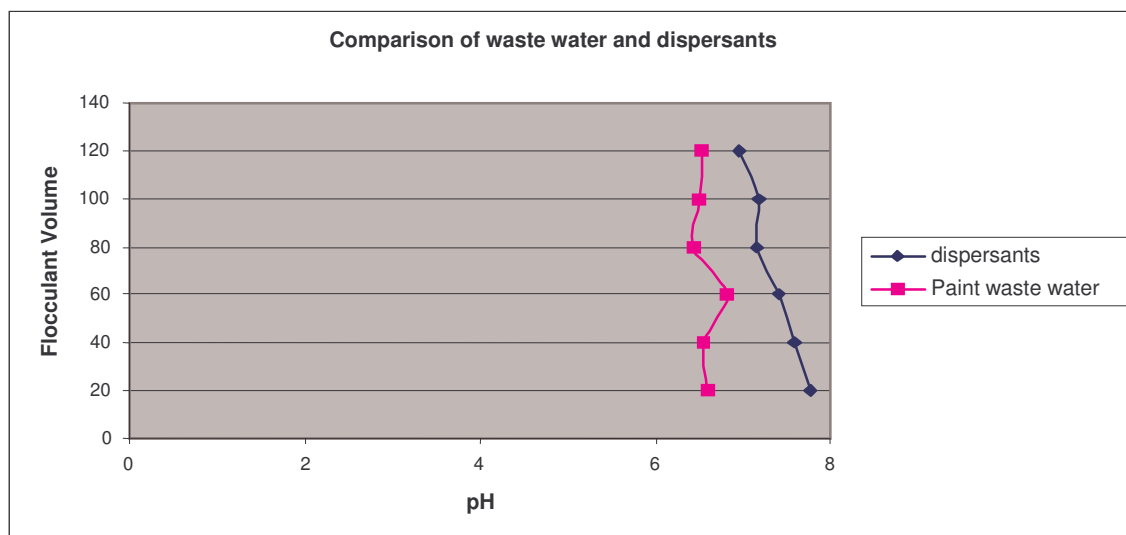


Figure C.1.3.a Results obtained when flocculating dispersants and paint wastewater

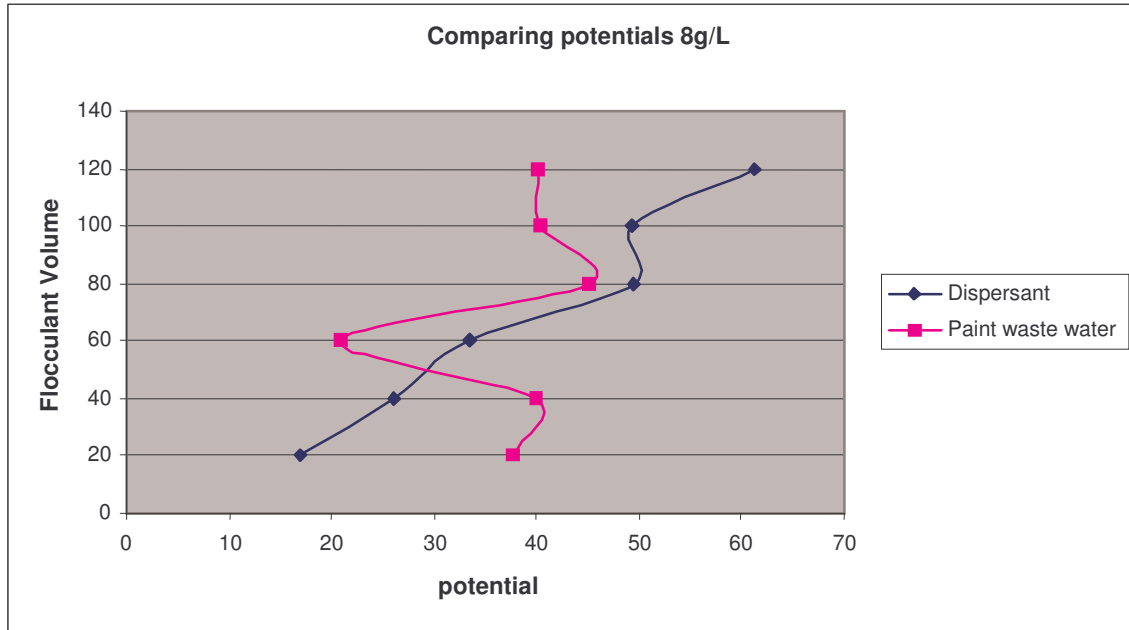


Figure C.1.3.b Results obtained when flocculating dispersants and paint wastewater

C.1.4 Flocculent Concentration 52g/l

Table C.1.4 Results obtained when flocculating wastewater and paint wastewater

Dispersants					
	Sample	dispersant vol	Vol flocc	pH	Potential
	1	400	20	6.78	83.1
	2	400	40	4.68	204.4
	3	400	60	4.43	216.3
	4	400	80	4.33	223
	5	400	100	4.25	226.9
	6	400	120	4.17	229.7
Paint					
	Sample				

	1	400	20	6.82	30.7
	2	400	40	6.49	45.1
	3	400	60	6.3	56.1
	4	400	80	6.15	62.4
	5	400	100	6.02	70.5
	6	400	120	5.38	102.9

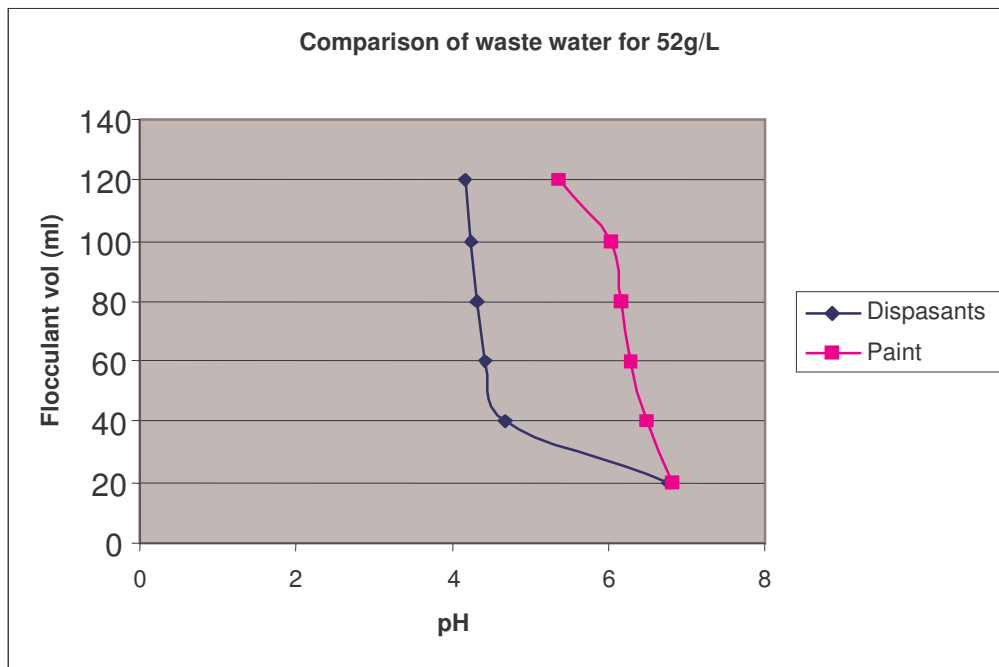


Figure C.1.4.a Results obtained when flocculating dispersants and paint wastewater

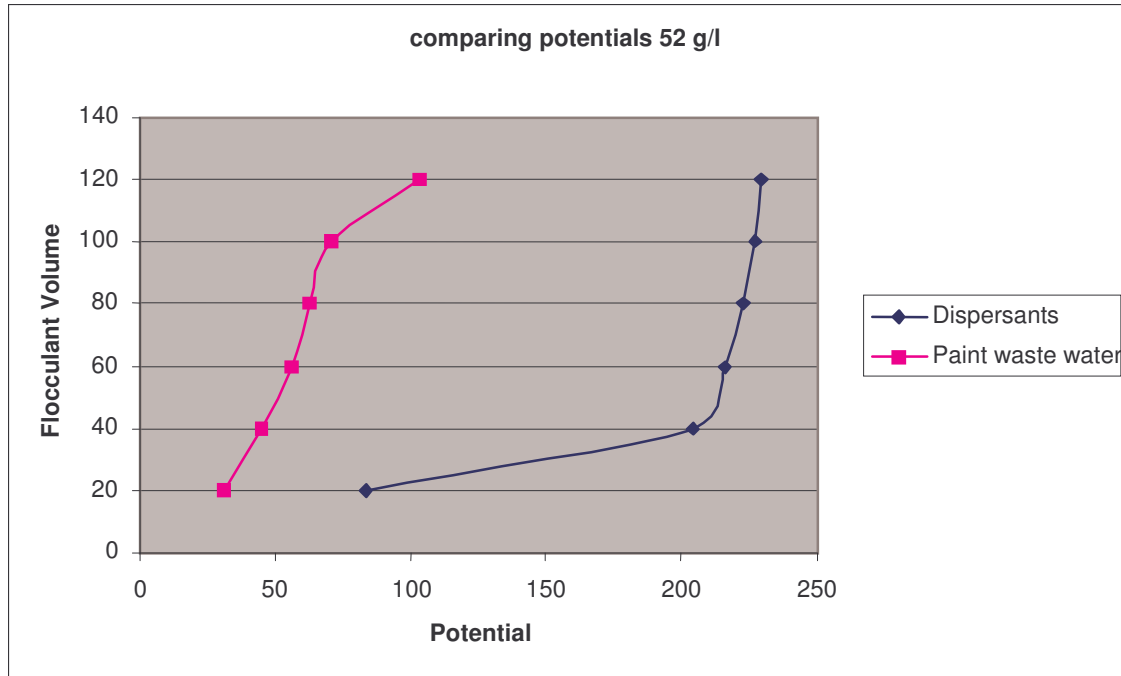


Figure C.1.4.b Results obtained when flocculating dispersants and paint wastewater

C.1.5 Flocculent Concentration 109g/l

Table C.1.5 Shows potential and pH data at Various Volumes of flocculant

Dispersants					
	Sample	dispersant vol	Vol flocc	pH	Potential
	1	400	20	6.43	18.8
	2	400	40	4.43	23.9
	3	400	60	4.27	29.1
	4	400	80	4.2	34.9
	5	400	100	4.15	39.6
	6	400	120	4.09	43.8
Paint					
	Sample	dispersant vol	Vol flocc	pH	Potential
	1	400	20	4.93	128.7

	2	400	40	4.33	158.5
	3	400	60	4.2	166
	4	400	80	4.11	170.8
	5	400	100	4.02	174.6
	6	400	120	4.01	175

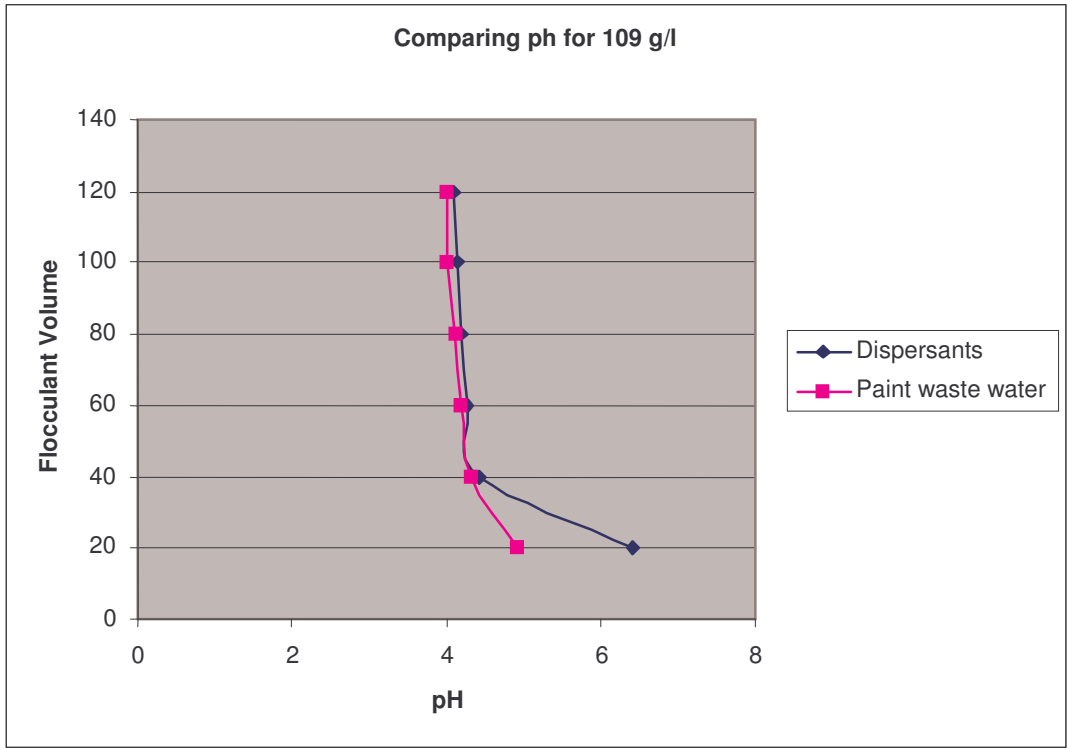


Figure C.1.5.a Results obtained when flocculating dispersants and paint wastewater

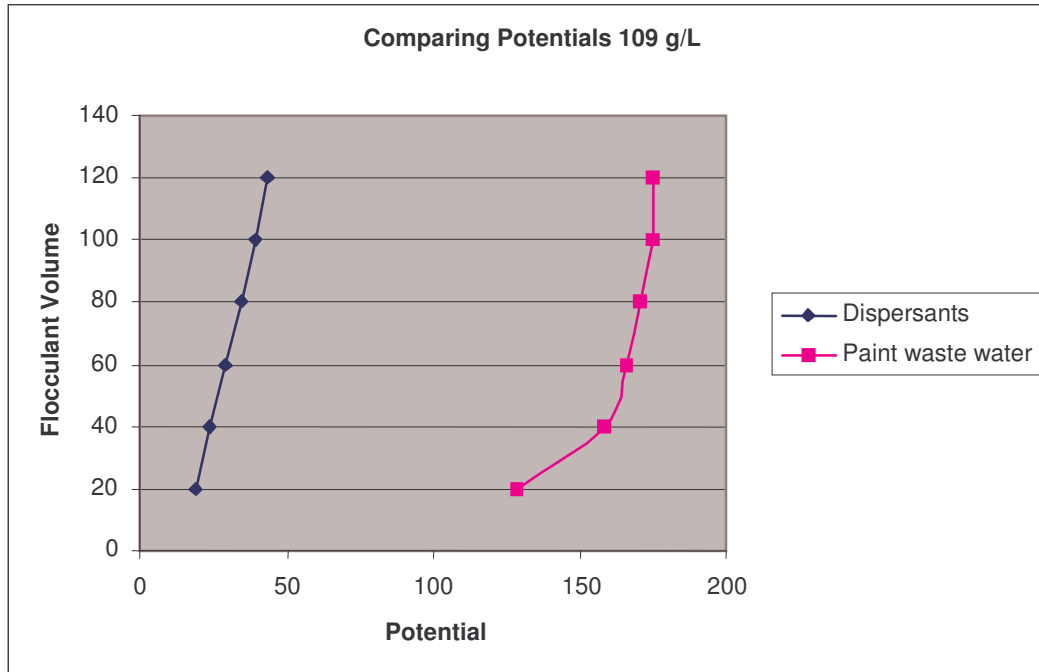


Figure C.1.5.b Results obtained when flocculating dispersants and paint wastewater

C.2 Comparing the turbidity of dispersants at different concentrations

Experimental work was done to compare the turbidity of different initial dispersant concentrations. Results obtained are tabulated below.

Table C.2 The turbidity of different dispersant feed concentrations

Dispersant Vol	Flocc Vol	6 g/l	7 g/l	8 g/l	52 g/l	109 g/l
400	20	1000	733	913	329	1000
400	40	888	768	755	6.84	1000
400	60	672	625	571	6.66	453
400	80	517	561	479	2.03	346
400	100	452	449	391	16.55	341
400	120	446	433	301	15.81	892

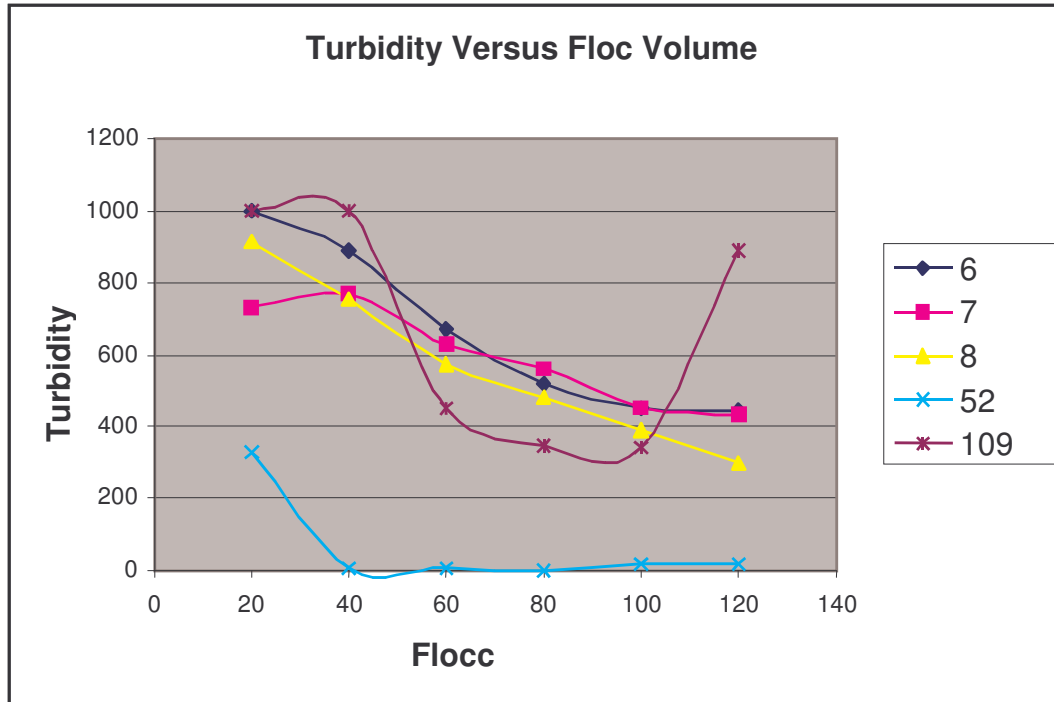


Figure C.2 The turbidity of different dispersant feed concentration as volume is increased

C.3 Investigating particle nucleation versus growth in dispersants

The amount of flocculent used in flocculation plays a major role in the size of floccs, as well as the extent of flocculation. Experimental work was done to investigate the volume that produces the good floccs which produce a thin cake and comparatively clear resultant water. This was done for both dispersants.

C.3.1 Dispersants A - EFKA-5071

Table C.3.1 shows how turbidity changes with flocculent volume.

Disp Vol	Flocc Vol	Turbidity(FTU)EFKA-5071
400	10	733
400	20	329
400	30	279
400	40	6.84

400	50	17.26
400	60	6.66
400	70	6.06
400	80	2.03
400	90	5.35
400	100	16.55
400	110	2.71
400	120	15.81
400	130	28.71
400	140	4.45
400	150	28.71
400	160	14.74
400	170	42.74
400	180	53

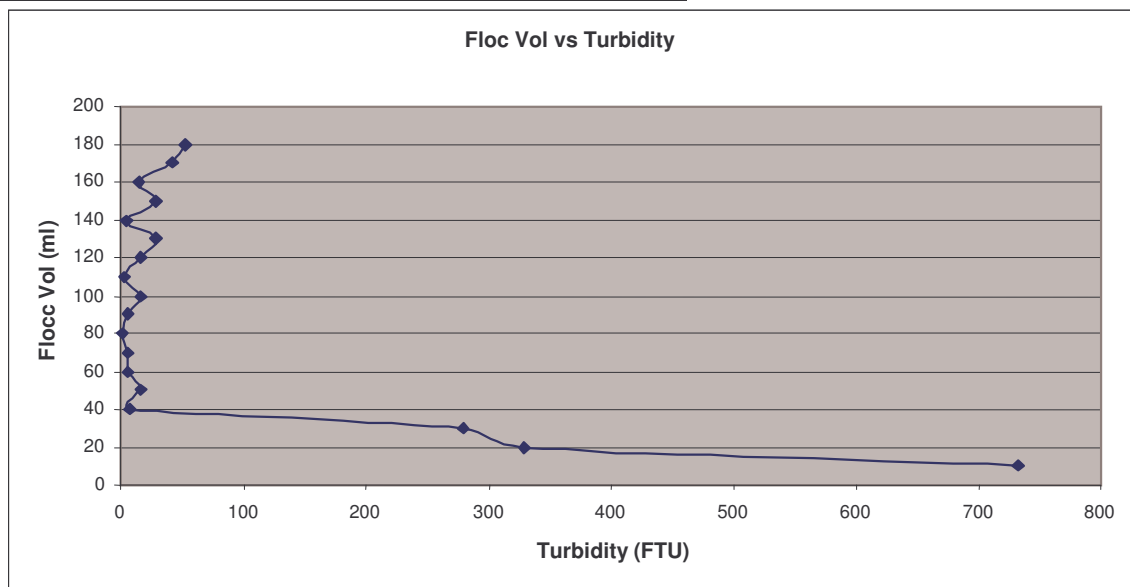


Figure C.3.1 How turbidity changes with flocculent volume

C.3.2 Dispersants B - EFKA-6230

Table C.3.2 How turbidity changes with flocculent volume

Disp Vol	Flocc Vol	Turbidity(FTU) EFKA-6230
400	10	17.11
400	20	3.81
400	30	6.83
400	40	3.77

400	50	2.36
400	60	3.96
400	70	1.11
400	80	4.83
400	90	2.01
400	100	1.58
400	110	1.2
400	120	2.33
400	130	2.36
400	140	2.99
400	150	0.91
400	160	4.57
400	170	3.07
400	180	4.86

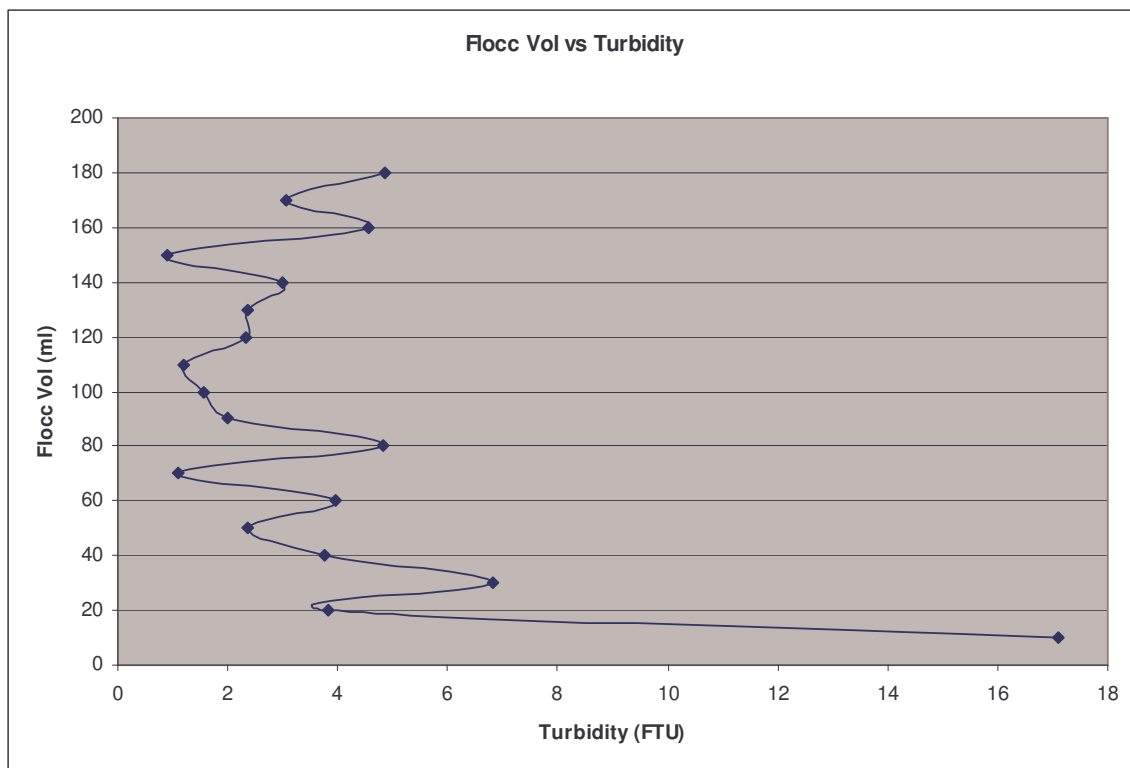


Figure C.3.2 How turbidity changes with flocculent volume

C.3.3 Dispersants A and Dispersants B - EFKA-5170

Table C.3.3 How turbidity changes with flocculent volume

Flocc Vol	Turbidity(FTU)EFKA-5071	Turbidity(FTU) EFKA-6230
10	733	17.11
20	329	3.81
30	279	6.83
40	6.84	3.77
50	17.26	2.36
60	6.66	3.96
70	6.06	1.11
80	2.03	4.83
90	5.35	2.01
100	16.55	1.58
110	2.71	1.2
120	15.81	2.33
130	28.71	2.36
140	4.45	2.99
150	28.71	0.91
160	14.74	4.57
170	42.74	3.07

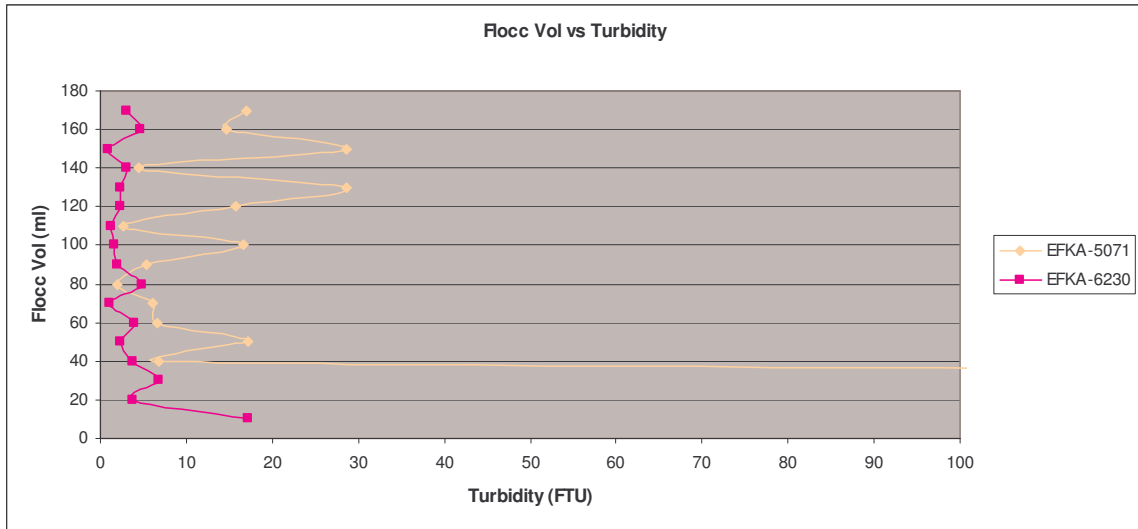


Figure C.3.3 How turbidity changes with flocculent volume for both dispersants

C.4 The effect relationship between dispersant feed concentration and pH, Potential and Turbidity

Table.C.4.1 Jar tests conducted on the effect of dispersant feed concentration

initial Concentration	Volume dispersants	Volume Flocculent	pH	Potential	Turbidity
1%	400 ml	20	4.14	181.0	2.01
		40	3.77	196.1	1.10
		60	3.64	202.3	0.68
		80	3.54	207..	0
		100	3.46	209.1	0
		120	3.38	213.5	5.89
1.5%	400 ml	20	4.31	131.6	145
		40	3.86	193.6	2.58
		60	3.66	200.9	2.19
		80	3.59	204.2	0.98
		100	3.52	207.9	1.56
		120	3.47	209.4	1.42
2%	400 ml	20	6.78	83.1	329
		40	4.68	204.4	6.84
		60	4.43	216.3	6.66
		80	4.33	223.0	2.03
		100	4.25	226.9	16.55
		120	4.17	229.7	15.81
2.5%	400 ml	20	4.09	161.0	548
		40	5.67	150.9	5.64
		60	3.75	199.8	2.25
		80	3.56	206.7	3.51
		100	3.47	210.1	1.34
		120	3.38	213.9	1.48
3%	400 ml	20	6.14	57.0	557

		40	6.50	75.2	80.8
		60	3.94	193.5	3.58
		80	3.72	201.5	2.53
		100	3.55	208.2	2.47
		120	3.46	211.5	2.82
3.5%	400 ml	20	5.82	83.4	622
		40	6.68	70.1	176

		60	4.15	182.8	11.75
		80	3.64	201.9	5.57
		100	3.52	208.2	6.86
		120	3.41	212.1	10.27
4%	400 ml	20	7.05	50.0	881
		40	6.80	64.6	780
		60	4.01	190.3	13.86
		80	3.77	196.5	2.16
		100	3.68	192.5	1.43
		120	3.71	198.4	104

C.5 Experimental results on particle size distribution for Dispersant A, for flocculent concentrations 7 g/l and 52 g/l

The contents of this section show results obtained from experiments done on measuring the particle size distribution of flocculated Dispersant A samples, using the Malvern Mastersizer. Each sample was measured three times and the average value for each size is presented below.

C.5.1. Dispersant A (7g/l)

C.5.1.1 Dispersant A (7g/l) 20ml

Presented below are the results obtained from experiments done on 20 ml of Dispersant A (7g/l).

$$d(0.1) = 5.808 \mu\text{m}$$

$$d(0.5) = 31.262 \mu\text{m}$$

$$d(0.9) = 546.668 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00

6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.01
26	0.317	0.06
27	0.356	0.15
29	0.399	0.24
30	0.448	0.30
31	0.502	0.35
32	0.564	0.38
33	0.632	0.39
34	0.710	0.38
35	0.796	0.36
36	0.893	0.32
37	1.002	0.29
38	1.125	0.25
39	1.262	0.23
40	1.416	0.22
41	1.589	0.23
42	1.783	0.27

43	2.000	0.32
44	2.244	0.40
45	2.519	0.49
46	2.825	0.59
47	3.170	0.71
48	3.557	0.84
49	3.991	0.98
50	4.477	1.12
51	5.024	1.27
52	5.637	1.43
53	6.325	1.59
54	7.096	1.76
55	7.962	1.94
56	8.934	2.13
57	10.024	2.32
58	11.247	2.53
59	12.619	2.73
60	14.159	2.93
61	15.887	3.11
62	17.825	3.26
62	20.000	3.37
63	22.440	3.42
64	25.179	3.40
65	26.251	3.30
66	31.698	3.13
67	35.566	2.90
68	39.905	2.62
69	44.774	2.33
70	50.233	2.05
71	56.366	1.80
72	63.246	1.58
73	70.963	1.41
74	79.621	1.24
75	89.337	1.07
76	100.237	0.83
77	112.468	0.49

78	141.589	0.00
79	158.865	0.00
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.08
86	355.656	2.54
87	399.052	4.43
88	399.052	4.43
89	447.744	5.80
90	502.377	6.15
91	563.677	5.89
92	632.456	2.47
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.1.2 Dispersant A (7g/l) 40ml

Presented below are the results obtained from experiments done on 40 ml of Dispersant A (7g/l).

$$d(0.1) = 18.159 \mu\text{m}$$

$$d(0.5) = 42.068 \mu\text{m}$$

$$d(0.9) = 87.569 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	

2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.01
26	0.317	0.06
27	0.356	0.15
29	0.399	0.24
30	0.448	0.30
31	0.502	0.35
32	0.564	0.38
33	0.632	0.39
34	0.710	0.38
35	0.796	0.36
36	0.893	0.32
37	1.002	0.29
38	1.125	0.25

39	1.262	0.23
40	1.416	0.22
41	1.589	0.23
42	1.783	0.27
43	2.000	0.32
44	2.244	0.40
45	2.518	0.05
46	2.825	0.08
47	3.170	0.11
48	3.557	0.13
49	3.991	0.16
50	4.477	0.18
51	5.024	0.21
52	5.637	0.23
53	6.325	0.26
54	7.096	0.30
55	7.962	0.38
56	8.934	0.49
57	10.024	0.67
58	11.247	0.93
59	12.619	1.28
60	14.159	1.76
61	15.887	2.34
62	17.825	3.03
62	20.000	3.79
63	22.440	4.62
64	25.179	5.42
65	28.251	6.17
66	31.698	6.79
67	35.566	7.22
68	39.905	7.44
69	44.774	7.42
70	50.233	7.14
71	56.366	5.67
72	63.246	5.17
73	70.963	4.28

74	79.621	3.39
75	89.337	2.53
76	100.237	1.74
77	112.468	1.12
78	141.589	0.42
79	158.865	0.12
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.1.3 Dispersant A (7g/l) 60ml

Presented below are the results obtained from experiments done on 60 ml of Dispersant A (7g/l).

$$d(0.1) = 16.604 \mu\text{m}$$

$$d(0.5) = 36.345 \mu\text{m}$$

$$d(0.9) = 70.868 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00

35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.10
47	3.170	0.13
48	3.557	0.16
49	3.991	0.18
50	4.477	0.20
51	5.024	0.21
52	5.637	0.23
53	6.325	0.26
54	7.096	0.32
55	7.962	0.41
56	8.934	0.56
57	10.024	0.83
58	11.247	1.20
59	12.619	1.70
60	14.159	2.34
61	15.887	3.10
62	17.825	3.97
62	20.000	4.88
63	22.440	5.81
64	25.179	6.65
65	28.251	7.35
66	31.698	7.83
67	35.566	8.04
68	39.905	7.95
69	44.774	7.57

70	50.233	6.91
71	56.366	6.05
72	63.246	5.05
73	70.963	4.00
74	79.621	2.95
75	89.337	2.04
76	100.237	0.95
77	112.468	0.01
78	141.589	0.00
79	158.865	0.00
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.1.4 Dispersant A (7g/l) 80ml

Presented below are the results obtained from experiments done on 80 ml of Dispersant A (7g/l).

$$d(0.1) = 15.610 \mu\text{m}$$

$$d(0.5) = 36.444 \mu\text{m}$$

$$d(0.9) = 75.945 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00

15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.05
45	2.518	0.08
46	2.825	0.10
47	3.170	0.13
48	3.557	0.16
49	3.991	0.18
50	4.477	0.21
51	5.024	0.24

52	5.637	0.28
53	6.325	0.33
54	7.096	0.42
55	7.962	0.56
56	8.934	0.76
57	10.024	1.04
58	11.247	1.43
59	12.619	1.93
60	14.159	2.53
61	15.887	3.23
62	17.825	4.00
62	20.000	4.80
63	22.440	5.59
64	25.179	6.29
65	28.251	6.86
66	31.698	7.25
67	35.566	7.42
68	39.905	7.34
69	44.774	7.03
70	50.233	6.05
71	56.366	5.80
72	63.246	4.97
73	70.963	4.08
74	79.621	3.20
75	89.337	2.34
76	100.237	1.61
77	112.468	1.04
78	126.191	0.22
79	141.589	0.02
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00

87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.1.5 Dispersant A (7g/l) 100ml

Presented below are the results obtained from experiments done on 100 ml of Dispersant A (7g/l).

$$d(0.1) = 14.112 \mu\text{m}$$

$$d(0.5) = 31.379 \mu\text{m}$$

$$d(0.9) = 60.835 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00

10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.01
44	2.244	0.07
45	2.518	0.10
46	2.825	0.14

47	3.170	0.18
48	3.557	0.21
49	3.991	0.24
50	4.477	0.27
51	5.024	0.29
52	5.637	0.33
53	6.325	0.40
54	7.096	0.51
55	7.962	0.69
56	8.934	0.96
57	10.024	1.34
58	11.247	1.85
59	12.619	2.50
60	14.159	3.27
61	15.887	4.13
62	17.825	5.06
62	20.000	5.97
63	22.440	6.81
64	25.179	7.47
65	28.251	7.91
66	31.698	8.07
67	35.566	7.92
68	39.905	7.45
69	44.774	6.75
70	50.233	5.81
71	56.366	4.77
72	63.246	3.68
73	70.963	2.64
74	79.621	1.72
75	89.337	0.48
76	100.237	0.00
77	112.468	0.00
78	126.191	0.00
79	141.589	0.00
80	178.250	0.00
81	200.000	0.00

82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.1.6 Dispersant A (7g/l) 120ml

Presented below are the results obtained from experiments done on 120 ml of Dispersant A (7g/l).

$$d(0.1) = 14.387 \mu\text{m}$$

$$d(0.5) = 31.729 \mu\text{m}$$

$$d(0.9) = 61.282 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00

5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00

42	1.783	0.00
43	2.000	0.01
44	2.244	0.07
45	2.518	0.10
46	2.825	0.14
47	3.170	0.17
48	3.557	0.20
49	3.991	0.23
50	4.477	0.25
51	5.024	0.28
52	5.637	0.31
53	6.325	0.37
54	7.096	0.47
55	7.962	0.64
56	8.934	0.90
57	10.024	1.27
58	11.247	1.77
59	12.619	2.41
60	14.159	3.19
61	15.887	4.06
62	17.825	5.00
62	20.000	5.92
63	22.440	6.78
64	25.179	7.47
65	28.251	7.93
66	31.698	8.12
67	35.566	7.99
68	39.905	7.55
69	44.774	6.85
70	50.233	5.92
71	56.366	4.87
72	63.246	3.77
73	70.963	2.72
74	79.621	1.79
75	89.337	0.50
76	100.237	0.00

77	112.468	0.00
78	126.191	0.00
79	141.589	0.00
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.2 Dispersant A (52g/l)

C.5.2.1 Dispersant A (52g/l) 20ml

Presented below are the results obtained from experiments done on 20 ml of Dispersant A (52g/l).

$$d(0.1) = 15.687 \mu\text{m}$$

$$d(0.5) = 42.897 \mu\text{m}$$

$$d(0.9) = 91.924 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00

14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.05
45	2.518	0.07
46	2.825	0.09
47	3.170	0.12
48	3.557	0.16
49	3.991	0.20
50	4.477	0.25

51	5.024	0.31
52	5.637	0.38
53	6.325	0.46
54	7.096	0.57
55	7.962	0.70
56	8.934	1.86
57	10.024	1.07
58	11.247	1.32
59	12.619	1.63
60	14.159	2.01
61	15.887	2.45
62	17.825	2.97
62	20.000	3.53
63	22.440	4.15
64	25.179	4.77
65	28.251	5.38
66	31.698	5.93
67	35.566	6.38
68	39.905	6.70
69	44.774	6.85
70	50.233	6.80
71	56.366	6.55
72	63.246	6.09
73	70.963	5.46
74	79.621	4.70
75	89.337	3.85
76	100.237	2.97
77	112.468	2.10
78	141.589	1.48
79	158.866	0.10
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00

86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.2.2 Dispersant A (52g/l) 40ml

Presented below are the results obtained from experiments done on 40 ml of Dispersant A (52g/l).

$$d(0.1) = 22.241 \mu\text{m}$$

$$d(0.5) = 56.169 \mu\text{m}$$

$$d(0.9) = 112.663 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00

10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00

47	3.170	0.00
48	3.557	0.00
49	3.991	0.06
50	4.477	0.08
51	5.024	0.12
52	5.637	0.16
53	6.325	0.22
54	7.096	0.28
55	7.962	0.36
56	8.934	0.45
57	10.024	0.56
58	11.247	0.70
59	12.619	0.87
60	14.159	1.09
61	15.887	1.37
62	17.825	1.72
62	20.000	2.14
63	22.440	2.66
64	25.179	3.26
65	28.251	3.94
66	31.698	4.67
67	35.566	5.42
68	39.905	6.13
69	44.774	6.74
70	50.233	7.21
71	56.366	7.46
72	63.246	7.47
73	70.963	7.21
74	79.621	6.68
75	89.337	5.91
76	100.237	4.98
77	112.468	3.93
78	141.589	2.89
79	158.866	1.90
80	178.250	1.30
81	200.000	0.01

82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.2.3 Dispersant A (52g/l) 60ml

Presented below are the results obtained from experiments done on 60 ml of Dispersant A (52g/l).

$$d(0.1) = 27.561 \mu\text{m}$$

$$d(0.5) = 68.076 \mu\text{m}$$

$$d(0.9) = 113.669 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00

5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00

42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00
47	3.170	0.00
48	3.557	0.00
49	3.991	0.00
50	4.477	0.00
51	5.024	0.01
52	5.637	0.08
53	6.325	0.11
54	7.096	0.15
55	7.962	0.20
56	8.934	0.26
57	10.024	0.34
58	11.247	0.44
59	12.619	0.56
60	14.159	0.71
61	15.887	0.90
62	17.825	1.15
62	20.000	1.46
63	22.440	1.85
64	25.179	2.32
65	28.251	2.88
66	31.698	3.52
67	35.566	4.22
68	39.905	4.98
69	44.774	5.72
70	50.238	6.42
71	56.368	7.01
72	63.246	7.43
73	70.963	7.62
74	79.621	7.55
75	89.337	7.21
76	100.237	5.77

77	112.468	4.78
78	141.589	3.62
79	158.866	2.53
80	178.250	1.47
81	200.000	0.12
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.2.4 Dispersant A (52g/l) 80ml

Presented below are the results obtained from experiments done on 80 ml of Dispersant A (52g/l).

$$d(0.1) = 30.073 \mu\text{m}$$

$$d(0.5) = 96.513 \mu\text{m}$$

$$d(0.9) = 911.266 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00

36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00
47	3.170	0.00
48	3.557	0.00
49	3.991	0.00
50	4.477	0.02
51	5.024	0.07
52	5.637	0.08
53	6.325	0.11
54	7.096	0.14
55	7.962	0.18
56	8.934	0.23
57	10.024	0.29
58	11.247	0.37
59	12.619	0.47
60	14.159	0.59
61	15.887	0.75
62	17.825	0.95
62	20.000	1.20
63	22.440	1.50
64	25.179	1.85
65	28.251	2.25
66	31.698	2.69
67	35.566	3.14
68	39.905	3.58
69	44.774	3.99
70	50.238	4.33

71	56.368	4.57
72	63.246	4.68
73	70.963	4.65
74	79.621	4.47
75	89.337	4.14
76	100.237	3.68
77	112.468	3.11
78	141.589	2.47
79	158.866	1.78
80	178.250	1.05
81	200.000	0.31
82	224.404	0.02
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.06
88	399.052	1.02
89	447.744	2.51
90	502.377	4.07
91	563.677	5.34
92	632.456	6.13
93	709.627	6.15
94	796.214	5.28
95	893.367	3.87
96	1002.374	1.82
97	1124.683	0.03
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.2.5 Dispersant A (52g/l) 100ml

Presented below are the results obtained from experiments done on 100 ml of Dispersant A (52g/l).

$$d(0.1) = 32.588 \mu\text{m}$$

$$d(0.5) = 78.069 \mu\text{m}$$

$$d(0.9) = 150.739 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00

30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00
47	3.170	0.00
48	3.557	0.00
49	3.991	0.00
50	4.477	0.00
51	5.024	0.00
52	5.637	0.00
53	6.325	0.06
54	7.096	0.09
55	7.962	0.14
56	8.934	0.19
57	10.024	0.25
58	11.247	0.32
59	12.619	0.40
60	14.159	0.51
61	15.887	0.63
62	17.825	0.80
62	20.000	1.01
63	22.440	1.29
64	25.179	1.64

65	28.251	2.09
66	31.698	2.65
67	35.566	3.31
68	39.905	4.06
69	44.774	4.87
70	50.238	5.71
71	56.368	6.49
72	63.246	7.17
73	70.963	7.66
74	79.621	7.89
75	89.337	7.84
76	100.237	7.47
77	112.468	6.80
78	141.589	5.90
79	158.866	4.82
80	178.250	3.66
81	200.000	2.48
82	224.404	1.48
83	251.785	0.31
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00

101	1782.502	0.00
101	2000.000	0.00

C.5.2.6 Dispersant A (52g/l) 120ml

Presented below are the results obtained from experiments done on 120 ml of Dispersant A (52g/l).

$$d(0.1) = 26.458 \mu\text{m}$$

$$d(0.5) = 65.166 \mu\text{m}$$

$$d(0.9) = 127.528 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00

15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00
47	3.170	0.00
48	3.557	0.00
49	3.991	0.00
50	4.477	0.04
51	5.024	0.10

52	5.637	0.13
53	6.325	0.17
54	7.096	0.22
55	7.962	0.27
56	8.934	0.33
57	10.024	0.41
58	11.247	0.49
59	12.619	0.60
60	14.159	0.74
61	15.887	0.93
62	17.825	1.18
62	20.000	1.49
63	22.440	1.90
64	25.179	2.41
65	28.251	3.02
66	31.698	3.71
67	35.566	4.48
68	39.905	5.38
69	44.774	6.05
70	50.238	6.76
71	56.368	7.30
72	63.246	7.65
73	70.963	7.73
74	79.621	7.53
75	89.337	7.03
76	100.237	6.28
77	112.468	5.31
78	141.589	4.23
79	158.866	3.07
80	178.250	2.01
81	200.000	1.04
82	224.404	0.08
83	251.785	0.31
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00

87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.3 Dispersant A (109g/l)

C.5.3.1 Dispersant A(109g/l) 20ml

Presented below are the results obtained from experiments done on 20 ml of Dispersant A (109g/l).

$d(0.1) = 21.424 \mu\text{m}$

$d(0.5) = 49.949 \mu\text{m}$

$d(0.9) = 94.834 \mu\text{m}$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00

9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.04

46	2.825	0.07
47	3.170	0.09
48	3.557	0.12
49	3.991	0.15
50	4.477	0.19
51	5.024	0.22
52	5.637	0.26
53	6.325	0.30
54	7.096	0.34
55	7.962	0.39
56	8.934	0.44
57	10.024	0.51
58	11.247	0.61
59	12.619	0.77
60	14.159	1.01
61	15.887	1.34
62	17.825	1.80
62	20.000	2.38
63	22.440	3.10
64	25.179	3.92
65	28.251	4.82
66	31.698	5.73
67	35.566	6.60
68	39.905	7.34
69	44.774	7.86
70	50.233	8.13
71	56.366	8.07
72	63.246	7.68
73	70.963	6.99
74	79.621	6.03
75	89.337	4.90
76	100.237	3.71
77	112.468	2.52
78	141.589	1.32
79	158.866	0.25
80	178.250	0.00

81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.3.2 Dispersant A(109g/l) 40ml

Presented below are the results obtained from experiments done on 40 ml of Dispersant A (109g/l).

$$d(0.1) = 20.013 \mu\text{m}$$

$$d(0.5) = 49.890 \mu\text{m}$$

$$d(0.9) = 97.102 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00

5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.03
38	1.125	0.05
39	1.262	0.05
40	1.416	0.06
41	1.589	0.06

42	1.783	0.07
43	2.000	0.08
44	2.244	0.09
45	2.518	0.10
46	2.825	0.12
47	3.170	0.14
48	3.557	0.17
49	3.991	0.20
50	4.477	0.23
51	5.024	0.27
52	5.637	0.30
53	6.325	0.34
54	7.096	0.38
55	7.962	0.42
56	8.934	0.47
57	10.024	0.55
58	11.247	0.66
59	12.619	0.83
60	14.159	1.07
61	15.887	1.40
62	17.825	1.85
62	20.000	2.40
63	22.440	3.08
64	25.179	3.85
65	28.251	4.85
66	31.698	4.69
67	35.566	5.54
68	39.905	6.34
69	44.774	7.07
70	50.233	7.54
71	56.366	7.80
72	63.246	7.78
73	70.963	7.45
74	79.621	6.84
75	89.337	5.98
76	100.237	4.95

77	112.468	3.84
78	141.589	2.73
79	158.866	1.75
80	178.250	0.42
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.3.3 Dispersant A (109g/l) 60ml

Presented below are the results obtained from experiments done on 60 ml of Dispersant A (109g/l).

$$d(0.1) = 21.9947 \mu\text{m}$$

$$d(0.5) = 51.002 \mu\text{m}$$

$$d(0.9) = 100.798 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00

37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.06
46	2.825	0.08
47	3.170	0.10
48	3.557	0.12
49	3.991	0.17
50	4.477	0.20
51	5.024	0.23
52	5.637	0.25
53	6.325	0.28
54	7.096	0.31
55	7.962	0.35
56	8.934	0.42
57	10.024	0.54
58	11.247	0.71
59	12.619	0.97
60	14.159	1.32
61	15.887	1.80
62	17.825	2.39
62	20.000	3.11
63	22.440	3.91
64	25.179	4.77
65	28.251	5.63
66	31.698	6.43
67	35.566	7.10
68	39.905	7.57
69	44.774	7.80
70	50.238	7.75
71	56.368	7.42

72	63.246	6.82
73	70.963	6.00
74	79.621	5.02
75	89.337	3.97
76	100.237	2.91
77	112.468	1.93
78	141.589	1.07
79	158.866	0.34
80	178.250	0.00
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.3.4 Dispersant A (109g/l) 80ml

Presented below are the results obtained from experiments done on 80 ml of Dispersant A (109g/l).

$$d(0.1) = 24.686 \mu\text{m}$$

$$d(0.5) = 54.801 \mu\text{m}$$

$$d(0.9) = 103.197 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00

30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00
47	3.170	0.00
48	3.557	0.00
49	3.991	0.05
50	4.477	0.08
51	5.024	0.12
52	5.637	0.16
53	6.325	0.20
54	7.096	0.24
55	7.962	0.29
56	8.934	0.33
57	10.024	0.39
58	11.247	0.47
59	12.619	0.59
60	14.159	0.76
61	15.887	1.02
62	17.825	1.39
62	20.000	1.88
63	22.440	2.52
64	25.179	3.28

65	28.251	4.17
66	31.698	5.13
67	35.566	6.09
68	39.905	6.98
69	44.774	7.71
70	50.238	8.19
71	56.368	8.36
72	63.246	8.18
73	70.963	7.65
74	79.621	6.80
75	89.337	5.72
76	100.237	4.50
77	112.468	3.25
78	141.589	2.10
79	158.866	1.09
80	178.250	0.32
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00

101	1782.502	0.00
101	2000.000	0.00

C.5.3.5 Dispersant A (109g/l) 100ml

Presented below are the results obtained from experiments done on 100 ml of Dispersant A (109g/l).

$$d(0.1) = 25.072 \mu\text{m}$$

$$d(0.5) = 56.749 \mu\text{m}$$

$$d(0.9) = 107.217 \mu\text{m}$$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00
14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00

24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.04
46	2.825	0.06
47	3.170	0.06
48	3.557	0.08
49	3.991	0.10
50	4.477	0.12
51	5.024	0.14
52	5.637	0.17
53	6.325	0.20
54	7.096	0.23
55	7.962	0.26
56	8.934	0.30
57	10.024	0.35
58	11.247	0.42
59	12.619	0.53
60	14.159	0.70

61	15.887	0.94
62	17.825	1.29
62	20.000	1.75
63	22.440	2.35
64	25.179	3.07
65	28.251	3.90
66	31.698	4.81
67	35.566	5.73
68	39.905	6.62
69	44.774	7.37
70	50.238	7.93
71	56.368	8.20
72	63.246	8.16
73	70.963	7.79
74	79.621	7.10
75	89.337	6.14
76	100.237	5.01
77	112.468	3.80
78	141.589	2.64
79	158.866	1.35
80	178.250	0.28
81	200.000	0.00
82	224.404	0.00
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00
86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00

96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.5.3.6 Dispersant A (109g/l) 120ml

Presented below are the results obtained from experiments done on 120 ml of Dispersant A (109g/l).

$d(0.1) = 26.864 \mu\text{m}$

$d(0.5) = 59.678 \mu\text{m}$

$d(0.9) = 114.589 \mu\text{m}$

No 1	Size (μm)	Volume (in %)
1	0.020	
2	0.022	0.00
3	0.025	0.00
4	0.028	0.00
5	0.032	0.00
6	0.036	0.00
7	0.040	0.00
8	0.045	0.00
9	0.050	0.00
10	0.056	0.00
11	0.063	0.00
12	0.071	0.00
13	0.080	0.00

14	0.089	0.00
15	0.100	0.00
16	0.112	0.00
17	0.126	0.00
18	0.142	0.00
19	0.142	0.00
20	0.159	0.00
21	0.178	0.00
22	0.200	0.00
23	0.224	0.00
24	0.252	0.00
25	0.283	0.00
26	0.317	0.00
27	0.356	0.00
29	0.399	0.00
30	0.448	0.00
31	0.502	0.00
32	0.564	0.00
33	0.632	0.00
34	0.710	0.00
35	0.796	0.00
36	0.893	0.00
37	1.002	0.00
38	1.125	0.00
39	1.262	0.00
40	1.416	0.00
41	1.589	0.00
42	1.783	0.00
43	2.000	0.00
44	2.244	0.00
45	2.518	0.00
46	2.825	0.00
47	3.170	0.00
48	3.557	0.00
49	3.991	0.00
50	4.477	0.04

51	5.024	0.07
52	5.637	0.08
53	6.325	0.10
54	7.096	0.12
55	7.962	0.15
56	8.934	0.18
57	10.024	0.21
58	11.247	0.26
59	12.619	0.34
60	14.159	0.45
61	15.887	0.61
62	17.825	0.85
62	20.000	1.19
63	22.440	1.62
64	25.179	2.19
65	28.251	2.87
66	31.698	3.66
67	35.566	4.53
68	39.905	5.43
69	44.774	6.31
70	50.238	7.08
71	56.368	7.69
72	63.246	8.05
73	70.963	8.12
74	79.621	7.87
75	89.337	7.30
76	100.237	5.41
77	112.468	4.25
78	141.589	3.07
79	158.866	2.14
80	178.250	1.12
81	200.000	1.16
82	224.404	0.02
83	251.785	0.00
84	282.508	0.00
85	316.979	0.00

86	355.656	0.00
87	399.052	0.00
88	399.052	0.00
89	447.744	0.00
90	502.377	0.00
91	563.677	0.00
92	632.456	0.00
93	709.627	0.00
94	796.214	0.00
95	893.367	0.00
96	1002.374	0.00
97	1124.683	0.00
98	1261.915	0.00
99	1415.892	0.00
100	1588.656	0.00
101	1782.502	0.00
101	2000.000	0.00

C.6.1. Dispersant A Settling Velocity Calculations

Water properties								
density	1000							
viscosity	0							
gravity	10							
7 g/l								
Volume of Solution	Volume of water (violdage 0.4)	Mass of water	Mass of Solution	Mass of Particles	Volume on particles	density of particles	Particles radius	Settling Velocity
0.0004	0	0.168	0.42	0.25	3E-04	985.9	2.73E-04	8.5568
0.0004	0	0.176	0.44	0.26	3E-04	989.6	4.38E-05	1.0135
0.0005	0	0.184	0.46	0.27	3E-04	987.2	3.54E-05	1.01
0.0005	0	0.192	0.48	0.28	3E-04	984.8	3.80E-05	1.2833
0.0005	0	0.2	0.49	0.29	3E-04	979.4	3.04E-05	1.3902
0.0005	0	0.208	0.51	0.31	3E-04	978.3	3.06E-05	1.4753

52g/l								
Volume of Solution	Volume of water (viodage 0.4)	Mass of water	Mass of Solution	Mass of Particles	Volume on particles	density of particles	Particle radius	Settling Velocity
0.0004	0	0.168	0.42	0.25	3E-04	985.9	4.60E-05	1.4388
0.0004	0	0.176	0.44	0.26	3E-04	989.6	5.63E-05	1.304
0.0005	0	0.184	0.46	0.27	3E-04	987.2	5.68E-05	1.6199
0.0005	0	0.192	0.48	0.28	3E-04	984.8	4.56E-04	15.399
0.0005	0	0.2	0.49	0.29	3E-04	979.4	7.54E-05	3.4438
0.0005	0	0.208	0.51	0.31	3E-04	978.3	6.38E-05	3.0694
109g/l								
Volume of Solution	Volume of water (viodage 0.4)	Mass of water	Mass of Solution	Mass of Particles	Volume on particles	density of particles	Particle radius	Settling Velocity
0.0004	0	0.168	0.42	0.25	3E-04	985.9	4.74E-05	1.4844
0.0004	0	0.176	0.44	0.26	3E-04	989.6	4.86E-05	1.1239
0.0005	0	0.184	0.46	0.27	3E-04	987.2	5.04E-05	1.4365
0.0005	0	0.192	0.48	0.28	3E-04	984.8	1.03E-04	3.4877
0.0005	0	0.2	0.49	0.29	3E-04	979.4	5.36E-05	2.4501
0.0005	0	0.208	0.51	0.31	3E-04	978.3	5.73E-05	2.7586

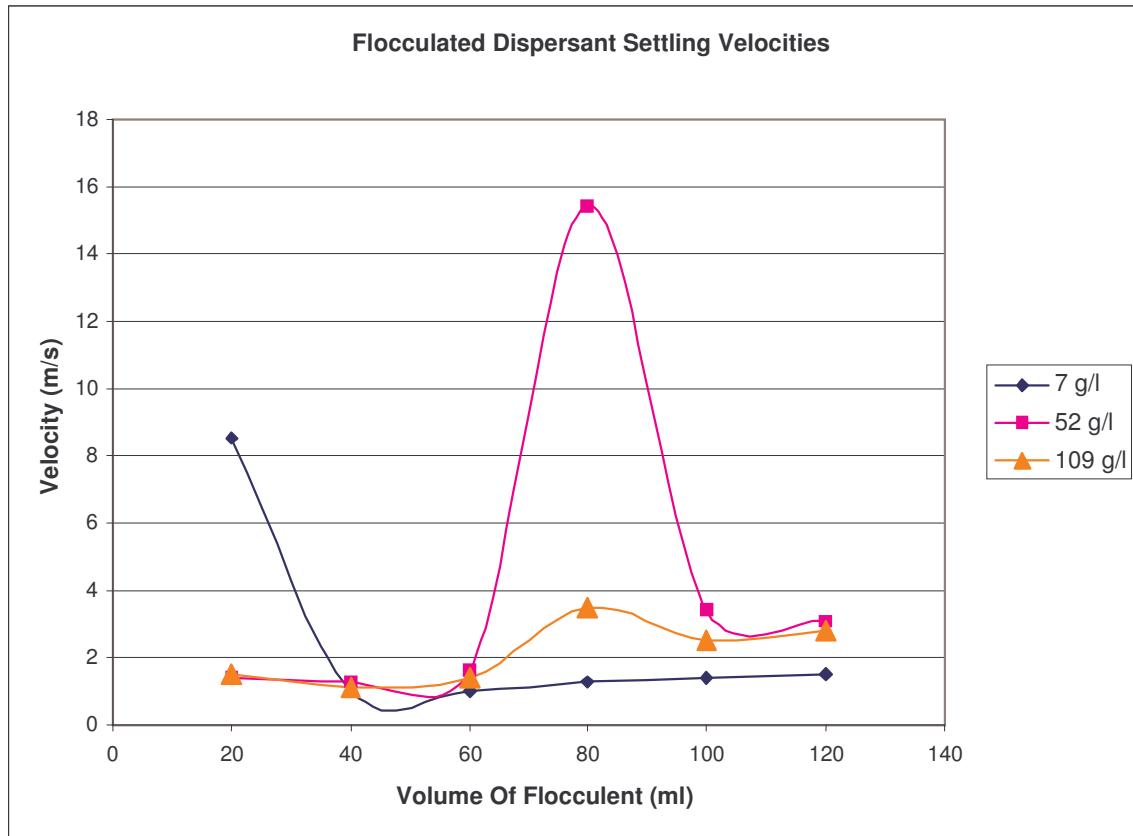


Figure C.6.1 Shows the settling velocities for the three concentrations

Appendix D (Material Safety and Data Sheet)

This section of the Appendix contains information about the material safety and data sheet for the chemicals that were used in the experiments.

D.1. Dispersants:

The dispersants used in this research work were supplied by Ciba chemicals, a company based in the Netherlands. The material safety and data sheet for the two dispersants used in these experiments can be obtained from the Ciba website, using following internet address (www.efka.com).

D.2 Aluminium Sulphate

The material safety and data sheet was adapted from the chemical safety database of Hands-on Science (H-Sci). Comenius–European Cooperation. Tabulated below are the properties for aluminum sulphate.

Common Synonyms	Aluminium sulphate, aluminium hydrate, cake alum
Formula	$Al_2(SO_4)_3 \cdot xH_2O$
Physical properties	Form: off-white powder Stability: stable, but sensitive to moisture Melting point 77°C Specific gravity:2.7
Principal hazards	***Aluminium sulphate is very damaging if it gets into eyes. It may be harmful if swallowed or inhaled.
Safe handling	Wear safety glasses. Work in an adequately ventilated area.
Emergency	<u>Eye contact</u> : Immediately flush the eye with water and continue for ten minutes. If irritation persists, call for medical help. <u>Skin Contact</u> : Wash off with soap and water. <u>If swallowed</u> : Call for medical help if the quantity swallowed is large.
Disposal	Store for later disposal as solid waste.
Protective equipment	Safety glasses.
Further information	Aluminium sulphate Chemical in the HSci database More extensive safety data

D.3. Iron chloride:

The material safety and data sheet was adapted from the chemical safety database of Hands-on Science (H-Sci). Comenius –European Cooperation. Tabulated below are the properties for iron chloride.

Common Synonyms	Iron trichloride, ferric chloride
Formula	FeCl ₃
Physical properties	Form: black crystalline powder Stability: stable, but hygroscopic and very sensitive to moisture. Melting point 304 °C Specific gravity: 2.8
Principal hazards	***Iron trichloride is corrosive, so it can cause burns to the mouth and mucous membranes, and is harmful if swallowed or inhaled.
Safe handling	Wear safety glasses. Work in a well ventilated area and keep the solid off the skin. If working with powdered, rather than crystalline material, use a fume cupboard or glove box.
Emergency	<u>Eye contact</u> : Immediately flush the eye with water and continue for five minutes. If irritation persists, call for medical help. <u>Skin Contact</u> : Wash off with soap and water. <u>If swallowed</u> : Wash out the mouth if the patient is conscious. Call for medical help.
Disposal	Store for later disposal as solid waste.
Protective Equipment	Safety glasses. If gloves are required, nitrile or butyl rubber should be suitable.
Further information	Iron(III) chloride Chemical in the HSci database More extensive safety data