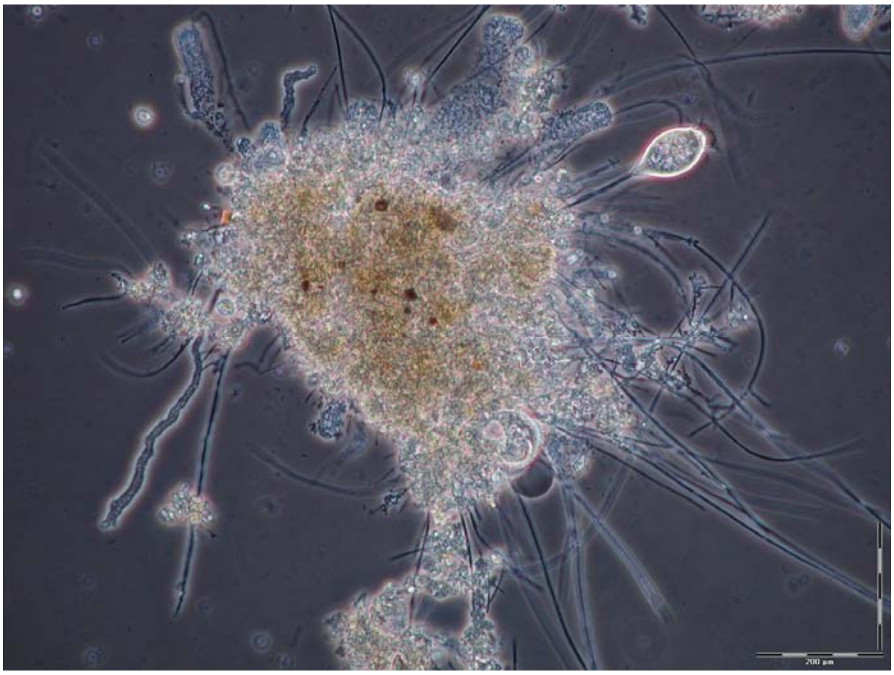

# Effects of cation addition on the flocculation behaviour of activated sludge at applied constant shear force

*Master's Thesis in the International Master's Programme "Environmentally Sustainable Process Technology"*

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Göteborg, Sweden, 2007
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Cover page: Micrograph of activated sludge floc
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# Abstract

Cations are believed to influence the bioflocculation in the activated sludge process, which in turn, affects the settling and dewatering characteristics of the activated sludge. In our study cations were added externally to activated sludge and their effects on bioflocculation were observed in terms of flocs disintegration when exposed to shear forces, settling characteristics (SISV and SSVI) and dewaterability (CST). Both mono- and di-valent cations were studied which included $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Cu^{2+}$ and $Zn^{2+}$. It was also a part of the study to investigate the bioflocculation of activated sludge diluted with rain water which was significantly deficient in cations. In deflocculation tests, sludge was exposed to high shear force which disintegrated the flocs. When mono-valent cations ($Na^+$ and $K^+$) were added at a concentration from 5 to 20 meq/l, the sludge flocs disintegrated less compared to the control with no cation addition. Lower concentrations specially 5 and 10 meq/l showed better floc stabilizing effects than higher concentration levels. In case of di-valent cation additions, $Ca^{2+}$ and $Mg^{2+}$ caused less floc disintegration while $Cu^{2+}$seemed to have the opposite effect. When $Zn^{2+}$ was added to samples the same level of floc disintegration as that of the control was observed. $Ca^{2+}$and $Mg^{2+}$ kept the deflocculation levels lowest at 5 and 10 meq/l, respectively. $Cu^{2+}$ addition gave increased deflocculation with increased concentration levels. Upon additions of rain water, increased deflocculation was observed. Both mono-valents ($Na^+$ and $K^+$) caused deteriorated settling characteristics by increasing the SSVI and lowering the SISV compared to the controls. While $Na^+$ addition showed positive effects on sludge dewaterability, $K^+$ addition resulted into the opposite effect. $Ca^{2+}$improved the settling characteristics of the activated sludge at all concentration levels. $Mg^{2+}$ showed inconsistent improvement in settling with increased concentrations. Addition of $Ca^{2+}$ raised the CST values whereas the addition of $Mg^{2+}$ lowered the CST values, which are suggestive of deteriorated and improved dewaterability, respectively. Surprisingly, better settling properties were observed for $Cu^{2+}$and $Zn^{2+}$, in spite of the significant deflocculation these ions caused. $Cu^{2+}$ addition improved the dewaterability whereas $Zn^{2+}$ addition did the opposite. Addition of rain water raised the SSVI and SISV values, indicating deteriorated settling properties of the sludge.

# Abbreviations

| | |
|---|---|
| ASP | Activated Sludge Process |
| BOD | Biological Oxygen Demand |
| BW | Bound Water |
| CST | Capillary Suction Time |
| DLVO | Deryagin, Landau, Verwey and Overbeek |
| DNA | Deoxyribonucleic Acid |
| DO | Dissolved Oxygen |
| EPS | Extracellular Polymeric Substances |
| HRT | Hydraulic Retention Time |
| MLSS | Mixed Liquid Suspended Solids concentration |
| SISV | Sludge Initial Settling Velocity |
| RAS | Returned Activated Sludge |
| SRT | Solid Retention Time |
| SS | Suspended Solids |
| SSVI | Stirred Specific Volume Index |
| SV | Sludge Volume |
| WWTP | Wastewater Treatment Plant. |

# 1. Introduction

## 1.1. Background

Reducing the volume of organic matters and nutrient elements like phosphorus and nitrogen, to a certain permitted level, is the main concern for the municipal waste water treatment plants. Effluents with excess amount of organic or nutrients may pose threat to the delicate balance of the ecosystem in the receiving waters. Usually municipal waste water is treated in the activated sludge process due to its simpler and robust operations. In this process, microorganisms, mainly bacteria, metabolize organic and inorganic substances into environmentally acceptable forms. This causes growth of microbial cells which spontaneously aggregate in flocs. This mechanism is known as bio-flocculation which is a critical factor for the satisfactory operation of a treatment plant. Most wastewater treatment plants incorporate the use of chemicals at some points in the system. Although there are multiple uses for chemicals in wastewater treatment systems, there are two major reasons for chemical dosing to aerobic biological systems treating municipal wastewater: phosphorus removal and prevention of sludge bulking/foaming.

Although biological treatment has proved to be highly efficient, it can also be inconsistent in its effectiveness, usually due to environmental conditions or poor operation and maintenance. Sludge settling and dewatering are two important factors for the efficient operation of an activated sludge process. In case of poor sludge settling, much organic matters escape with the effluent from the secondary treatment unit while poor dewaterabiltiy makes the sludge handling difficult and expensive.

Since floc size and density are critical factors for settling and dewatering of activated sludge suspensions, the process and extent of bio-flocculation will ultimately determine the settling and dewatering properties (Sobeck and Higgins, 2002). Since the invention of the activated sludge process in 1914 (Ardern and Lockett, 1914), researchers have sought to better understand the process of bio-flocculation. From all the research works, it can be hypothesized that the extent of bio-flocculation depends on both operating conditions in the plant as well the sources of the waste water coming into the plant. Important factors include temperature, dissolved oxygen concentration, presence of cations, turbulence, substrate loading etc.

The effects of cations on the flocculation of activated sludge have been investigated in many studies. Municipal sewage has varying cation concentrations, depending on hydraulic loading, hardness of drinking water as well as on discharge into the sewer system. The dilution with storm water makes the waste water deficient in cations while high industrial discharge can give excessive concentrations of cations. Steiner and co-workers (1976) found that polyvalent cations were important for the floc structure because they form bonds between the exopolymers in the sludge matrix, probably by binding to carboxyl and hydroxyl groups. Though there are many types of cations present in the waste water $Ca^{2+}$ and $Mg^{2+}$ are the most investigated and have been reported to have good effects on flocculation of activated sludge. There are discrepancies between findings from different studies, which make it necessary to perform more detailed investigations on the effects of cations on flocculation of activated sludge.

# 2. Literature review

## 2.1 General Waste Water Treatment Processes (WWTP)

In a typical WWTP, waster water is received from various sources like domestic sewage, industrial effluent and stormwater. The composition of the incoming waste water varies also a lot depending on the sources. While waste water received from domestic sources can be loaded with high organic content, that from industrial effluents may also have high presence of metals and inorganic particles. Untreated wastewater may have an adverse effect on the flora and fauna present in the receiving water bodies and land, so, before discharged, the effluent from a WWTP must satisfy certain criteria set by the local/regional authorities.

In a continuous WWTP, the principal treatment steps are:

*1. Primary treatment:* This is a screening process which removes the entering gross solid materials in the process. The entering waste water is passed through a bar screen to remove larger solids and kept in primary settler for settling of remaining large solids.

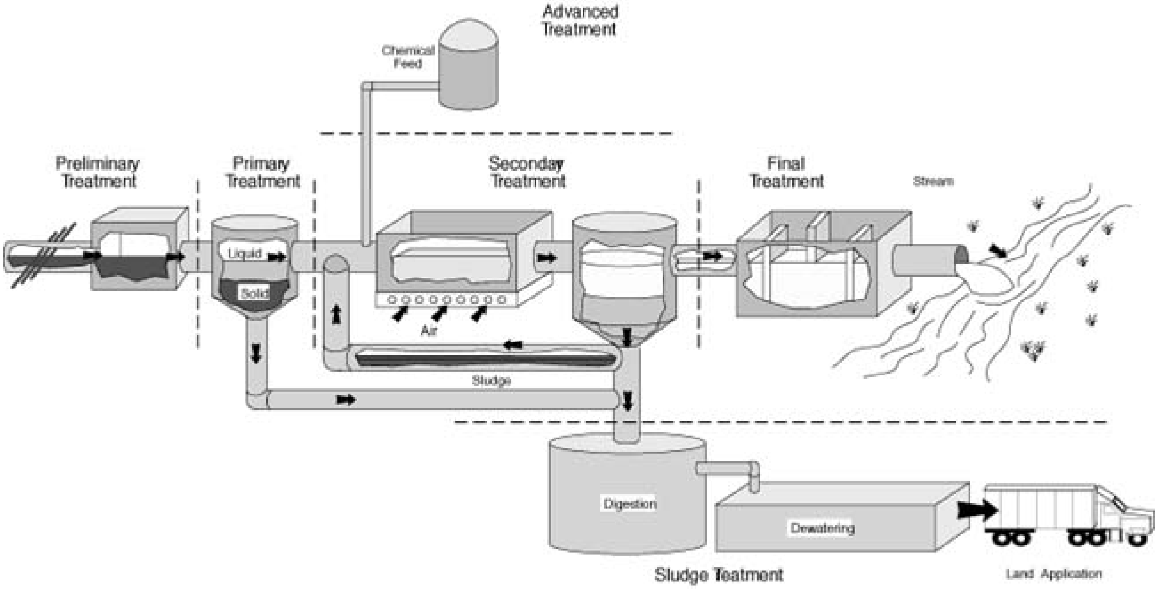

**Figure 2.1.** Continuous Waste Water Treatment Process (WWTP).

*2. Secondary Treatment:* It is designed to substantially reduce the organic content of the incoming waste water. This step includes biological or chemical precipitation processes for removal of nitrogen and phosphorus. The biological secondary treatment can be done either by suspended process or in fixed film process or by combination of both. Activated sludge process is the most widely used biological process. Among others are, fludized bed reactors, filter beds, biological aerated filters and membrane biological reactors .The final step of this process is the secondary settling where the bio flocs and precipitate materials are settled out .

*3. Tertiary Treatment:* This step provides a final stage to raise the effluent quality before it is discharged to the receiving water bodies. More than one tertiary treatment process may be used at any treatment plant. This is always the last step if disinfection of pathogens is expected. Filtration, lagoon and constructed wetland are common type of tertiary treatment.

*4. Sludge Treatment:* The produced and accumulated sludge from different treatment steps must be effectively treated and disposed off. The main purposes of the sludge treatment are to reduce the sludge volume and moisture content. The practiced methods of doing this are: aerobic digestion, anaerobic digestion and composting. The choice of sludge handling method depends on the amount and composition of sludge as well as dumping site specific requirements.

## 2.2 The Activated Sludge Process (ASP)

It is the most practiced process due to its simplicity and robustness. A conventional ASP mainly consists of mixing and settling step. The mixing step is done in the aeration tank by supplying compressed air, pure oxygen or mechanical aeration to the incoming waste water. The aeration keeps the mixture in suspension form and supplies vital oxygen to living microorganisms. After a certain contact period, microbial aggregates are formed, known as flocs. The mixed liquid is transferred to a settler where large flocs are expected to settle in the bottom of the settler and there by producing a clear effluent known as supernatant. The supernatant is withdrawn from the system and a part of the settled material is returned to the aeration tank to re-seed the new waste water entering the tank. This fraction of the sludge is called return activated sludge (RAS). The rest of the sludge in the bottom of settler is withdrawn for sludge treatment.

Various configurations of the activated sludge process are possible, such as: different shapes of aeration tank (plug flow or completely mixed stirred tanks), combination of several tanks, different feed patten of waste water, dissimilar aeration systems etc (Henze et al., 2005). For biological removal of phosphorus and nitrogen, conventional ASP can be modified with anoxic and anaerobic tanks.

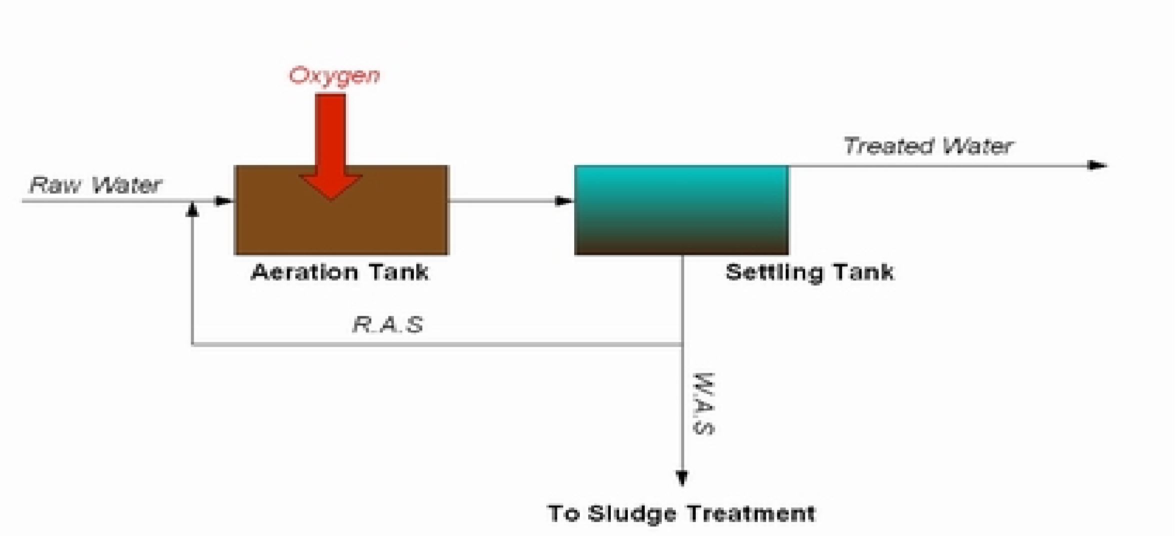

**Figure 2.2.**The activated sludge process.

*Nitrogen removal:* Biological nitrogen removal is accomplished in two steps: nitrification followed by de-nitrification. Nitrogen is present in the ammonium form in the waste water, which is converted to nitrate under aerobic condition. In the later step, nitrate is converted to nitrogen gas under anoxic condition (Henze et al., 2005).

*Phosphorus removal:* It can be done by a process called enhanced biological phosphorus removal. In this process some specific bacterial species, called polyphosphate accumulating organisms are selected and introduced in the treatment process. These bacteria can accumulate a considerable amount of phosphorus in their cells. This process requires both aerobic and anaerobic conditions (Henze et al., 2005). Chemical precipitation can also be applied for phosphorus removal by applying iron salts like ferric chloride or aluminum salts like alum. The difficulties with chemical precipitaion include difficult sludge handling and expansive chemicals. However, the chemical method is more efficient that biological removal method.

### 2.2.1 Composition of waste water

Depending on the sources and seasonal variations, the composition of influent wastewater may vary considerably. It mainly consists of water with varying extent of organic and inorganic matters and microorganisms. Some of the organic matters are readily degradable during the treatment while some other may find their way to the effluent from the treatment plant. Considerable dilution is expected in the events of heavy rainfall or snow melting.

### 2.2.2 Microbial species:

The types and concentrations of various organisms in the activated sludge depend on the sources of waste water and the conditions prevailing in treatment plant. A very diversified group of organisms are involved in the biological processes in the treatment plant. Bacteria constitute the majority of microorganisms present in activated sludge. Bacteria that require organic compounds for their supply of carbon and energy (heterotrophic bacteria) predominate, whereas bacteria that use inorganic compounds for cell growth (autotrophic bacteria) occur in proportion to concentrations of carbon and nitrogen. Both aerobic and anaerobic bacteria may exist in the activated sludge, but the preponderance of species are facultative, able to live either in the presence or lack of dissolved oxygen.

Fungi, rotifers, and protozoa are also residents of activated sludge. The later microorganisms are represented largely by ciliated species, but flagellated protozoa and amoebae may also be present. Protozoa serve as indicators of the activated sludge condition, and ciliated species are instrumental in removing free swimming bacteria from the water. Additionally, viruses of human origin may be found in raw sewage influent, but a large percentage appears to be removed by the activated-sludge process.

### 2.2.3. Exopolymers

Extracellular polymeric Substances (EPS) are produced by the sludge bacteria and forms the network where bacteria are embedded. The exopolymers are the third major component of activated sludge along with water and micro-organisms (Li and Ganczarczyk, 1990) and influence on the sludge structure (Perker et al.,1972; Pavoni et al., 1972). The EPS consist mainly of neutral sugar and gluconic acid (Steiner et al., 1976) and also protein and humic-type substances (Eriksson and Alm, 1991). Characterization of extracted EPS has shown that a portion of the polysaccharides and proteins are made up of uronic acid (Brown and Lester,1980; Frolund et al.,1996) and amino acid, respectively and both have carboxyl groups in the structure which contributes to the negative charge of the bio-flocs (Forster,1971; Horan and Eccles, 1986). Exopolymers have carboxyl and hydroxyl groups in their structure and polyvalent ions are found to make bonds with these functional groups which form the sludge matrix (Steiner et al., 1976). EPS are thought to have high water binding capacity (Dugan and Parson, 1987; Parson and Dugan, 1971) and is bound to the EPS matrix (Schmitt and Flemming, 1999). Ultra structural studies of microbial flocs by correlative microscopy reveal a complex polymeric matrix that may promote resistance within the floc, thus affecting the flux of water in and out of the floc (Liss et al., 1996). Since bio-flocs are primarily made up of EPS, it can be interfered that interaction between the EPS will be important for bio-flocculation along with the characteristics of the EPS (Sobeck and Higgins, 2002).

### 2.2.4. Bio-flocs

Activated sludge floc is a heterogeneous mixture of particles, micro organisms, colloids, organic polymers and cations whose composition depends on the origins (Forster 1976; Urbain et al., 1993). The efficiency with which flocs are removed by settling out from the aqueous phase, depends on directly on their size and density and hence their structure. The settling capacity of the floc is a matter of interest in waste water treatment because of the greater complexity of the floc constituents and their chaotic structure (Jorand et al.,1995).

In activated sludge, different aggregation mechanisms can be distinguished at different scales: aggregation inside the floc, between micro-colonies and the rest of the floc and aggregation between flocs. The last mechanism can be related to the nature of different sludges at different conditions. It also involves the exopolymers that bridge cells (Jorand et al.,1995). In the suggested structure model, flocs have three structural levels: microflocs , which are primarily particles 2.5 µm in size, secondary particles (13µm) linked together by exo-polymers and forming tertiary structures having a mean diameter of 125µm (Jorand et al.,1995).

In aquatic systems, bacteria often exist in aggregates glued together by a matrix of extracellular polymeric substances (EPS).The importance of EPS for the integrity of such aggregates has been demonstrated in many studies. The quantity and properties of EPS components are therefore expected to affect the strength of microbial aggregates in terms of the forces keeping together. According to general DLVO theory, van der Waal’s forces and electrostatic forces affect inter-particle attraction, as do also non-DLVO forces such as hydrophobic interaction, steric forces and polymer entanglement (Mikkelsen and Nielsen, 2001).

EPS has floc stabilizing effects and it gives an indication that polymer entanglement is an important factor in floc stability. Such entanglements may be purely physical or could be due to the gel-networks formed by the bridging of polymer components by some di-valent cations. The polymer entanglement can also explain the incomplete re-flocculation after deflocculation of flocs (Mikkelsen and Nielsen, 2001). It is possible that cohesion forces in bacterial colonies are greater than the forces involved in the more stochastic adhesion occurring in subsequent reflocculation. This could be due to stronger interaction between similar cells or it could be related to entanglement forces, which once broken, can't form instantly. During high shear rate, changes occur in the cell surfaces. Such changes could be related to changed EPS attachment pattern or to variations in EPS production related to cell activity ( Mikkelsen and Nielsen, 2001).

## 2.3 Useful performance parameters

In the routine operation of an activated sludge process, there are some measurable parameters which can give a clear indication about the performance of the process such as**:**

### 2.3.1 Effluent turbidity

Even after good flocculation, there are some solid particles that find their way in the supernatant. They are mostly small fragmented flocs and free bacterial cells. Instead of measuring these suspended solid directly, turbidity is measured due to its simplicity and sensitivity. Reasonably good correlation between turbidity and suspended solids have been found (Wahlberg, 1992; Wilén, 1997).The turbidity has been found to correlate well with the number of free cells in the supernatant and with the sludge filterability (Rasmussen et al., 1994).

### 2.3.2 Sludge Volume Index (SVI)

It is the most practiced way of determining settling and compaction of activated sludge. SVI is the volume occupied by 1 gm of sludge after 30 minutes of settling in a graduated cylinder. SVI of 100ml/g or less is considered satisfactory while SVI of more than 150ml/g is an indication of bulking sludge. There are several modified methods to measure SVI like Diluted Sludge Volume Index (DSVI) and Stirred Specific Volume Index (SSVI). The DSVI is done by diluting the sludge with process effluent until the settled volume is 250 ml/l or less after 30 minutes. SSVI is measured at MLSS concentration of 3.5 gm/l and slow stirring is done to minimize the wall effects. Both of these methods were developed to eliminate the recognized effects of MLSS, which is the case for SVI (Dick and Vesilind,1969).

### 2.3.3 Initial Settling Velocity (ISV)

This is the settling rate of the interface of bulk sludge through a graduated cylinder. ISV depends on the diameter of the cylinder, the concentration of MLSS, the sludge volume, the temperature of the water as well as on the floc structure and size (Daigger and Roper, 1985; Göhle and Björlebnius, 1996). Usually ISV is measured at every treatment plant to get an indication of how much the secondary settler can be loaded. It is also possible to mathematically model the performance of a settler by measuring ISV at different MLSS concentrations, the solids-flux theory.

### 2.3.4 Dewaterability

Biological sludge is a highly hydrated structure. It has been shown that moisture content can represent 95-98% of the sludge matrix (Smollen, 1988 and 1990). The moisture content is distributed into Free Water and Bound Water (BW). Some studies have shown that BW consists of three components based on different binding forces involved: interstitial water (water entrapped in the matrix), vicinal water (water held by surface forces) and water of hydration (water held by chemical bonds) (Robinson and Knocke, 1992; Vesilind, 1994). Poorer settling and dewatering properties have been related to BW content (Smollen, 1999; Barber and Veenstra, 1986). In bench scale studies for glucose based synthetic waste water, greater amount of EPS was correlated to observed excess amount of bound water content.(Liao et al.,2000).

Dewatering is one of the most expensive and least understood processes in the activated sludge process. The dewatering is seldom technically and economically optimal. The absence of understanding of the dewatering process is due to the complexity and dynamics of sludge matrix. Some important characteristics for sludge dewatering are: particle size distribution, floc structure and composition, bound water content, added chemicals, viscosity etc. ( Bruus et al.,1992 ). Floc size and particle size distributions (PSD) are considered two of the most important factors in dewatering of sludge (Karr and Keinath, 1978; Lawler, 1986; Novak et al, 1988). The optimal dose of flocculant before dewatering also depends on PSD (Roberts and Olsson, 1975). Karr and Keinath (1978) also showed that supra-colloidal fraction of particles (in the size range of 1-100 μm with a density less than or equal to that of water) and anaerobic digested sludge strongly affect the dewaterability. There seems to be a general agreement that the appearance of smaller flocs decrease the dewaterability. Lawler (1986) showed that the dewaterabilty decreases with decreasing particle size, measured at specific surface area. Novak et al. (1988) showed that smaller particles in a broad particle size distribution tend to blind the sludge during filtering.

## 2.4. Important factors affecting activated sludge flocs

Activated sludge is a complex ecosystem which can be affected by a single factor or interplay of various factors. Some of the factors are**:**

### 2.4.1 Sources of waste water

An activated sludge process receives waste water from various sources and the composition varies. The composition of the waste water depends not only on the sources but also on the transformation taking place in the sewer system (Nielsen et al.,1992). Waste water received from domestic sources are mostly of organic origin, thereby contributing to the activated sludge process. In a typical treatment plant, waste water is received from various types of industries and their composition also varies a lot. It can be loaded with high inorganic particle and ionic content which can adversely affect the microbial community in the activated sludge process. During storm water events, large quantity of water enters the system and the waste water becomes very diluted, furthermore, the temperature of the waste water may decrease considerably (Mattson, 1997).

### 2.4.2 Temperature

Both the temperature of incoming waste water and ambient conditions can affect the activated sludge process. It can be assumed that seasonal variation is the most influential factor for temperature fluctuation in the treatment plant. It has been found that sludge deflocculation increases and the flocculation physicochemical properties deteriorate under temperature shift from 30 to 45$^{o}$ C (Morgan et al., 2005). They found that, up shifts of temperature from 35 C to 45 $^{o}$ C had three major effects: an increase in effluent soluble oxygen chemical demand (SCOD) and effluent suspended solid concentration and deterioration in sludge settling characteristics. It has also been found that decreased microbial activity caused by a temperature reduction leads to increased deflocculation of activated sludge (Wilén et al., 2000). Temperature shifts can alter the physical properties like viscosity and floc structure as well as biological activities of the species present in the activated sludge.

### 2.4.3 Ions

Influent wastewater to an activated sludge process contains both mono- and poly-valent ions at varying concentrations. High industrial discharge into the sewer system can contribute to the higher concentration of ions while dilution with rain water can reduce that by manifolds. In many studies the effects of ions on floc properties have been investigated. Higgins and Novak, (1997) reported that addition of cations to the feed of two full scale activated sludge systems improved the settling dramatically and in one system, the thickened solid content was doubled. These results indicate that cation imbalance is a common cause of sludge settling and dewatering problems in industrial activated sludge plant. Theses imbalances can be corrected by addition of the cation deemed to be deficient by analysis of the mono-valent to divalent ratio or the calcium to magnesium ratio. Higgins and Novak (1997) also suggested that a cation balance exists for a given system that optimizes settling and dewatering characteristics. They also found that batch addition of cations did not affect the settling and dewatering of the activated sludge while feed addition did improve these characteristics. This suggests other mechanism besides physiochemical interactions can be important in improving settling and dewatering due to cation addition. They reported that the bound biopolymer content increased in laboratory activated sludge reactors as the di-valent cation concentration in the feed increased. The divalent cation addition could increase biopolymer productions or improve binding of biopolymer to the floc as the biopolymer is produced by the microorganisms.

### 2.4.4 Shear Forces

In treatment plants, activated sludge contains both large flocs and smaller sized single dispersed cells which come into the effects of turbulence at different levels due to the aeration, mechanical mixing or pumping. The dispersed cell population of a given sludge depends on the turbulence in the system, as the cells may adhere to flocs during quiescent conditions while cells are eroded from floc surfaces at high shear rates (Wahlberg, 1992). As the cell sizes are in the micron range, their motion is more affected by shear forces than by Brownian motion (Gregory, 1989). Therefore the kinetic energy affecting the flocs stability in a turbulent system is assumed to originate from turbulent shear while the effect of temperature is assumed negligible.

Mikkelsen and Nilsen (2001) proposed the Adhesion-Erosion model which is suitable for the modeling of deflocculation of activated sludge in a turbulent shear field. The adhesison–erosion balance of the cells is assumed to be governed by an average or equivalent Gibb’s energy of adhesion ($\Delta G_{ad}$) and an upper limit to the adhesion. This upper limit is related to the crowding of flocs at high concentration and there by related to sludge rheology (Mikelsen, 1999).

For a given turbulent shear rate, the dispersed mass fraction for different total solids content of activated sludge can be modelled as (Mikkelsen and Keiding, 1999):

$$M_t = m_{d\infty} + (m_{d,max} . K . m_{d\infty})/(1+K_m . m_{d\infty})$$

Where $M_t$ is the total solid concentration, $m_{d\infty}$ is the equilibrium dispersed mass concentration, $m_{d,max}$ is the upper solid limit and $K_m$ is the equilibrium constant. From the above equation, it can be said that dispersion will increase with the solid content of sludge and the dispersion will increase rapidly, as the total solids concentration approaches $m_{d,max}$. The equilibrium constant, $K_m$, on the other hand, determines the magnitude of dispersion, as a large $K_m$ corresponds to large adhesion affinity due to strong inter-cell bonds.

### 2.4.5 Dissolved Oxygen (DO)

Dissolved oxygen is an important element for sustaining the biological activities of microbes present in the activated sludge. In the activated sludge process, the sludge is sometimes exposed to limited oxygen concentrations especially during high organic loading in secondary settler or during biological nitrogen removal processes. It is known that oxygen limitation can cause deflocculation of the activated sludge flocs and gives a turbid effluent (Eikelboom and Van Buijsen.1981). Wilén and Balmér (1998) reported that the adsorption capacity of colloidal material onto the activated sludge flocs expressed as a decrease in turbidity, was greater in aerobic than in anaerobic conditions. They also reported that short periods with low DO concentration in the aeration tank at a full scale plant led to increased turbidities. Li and Ganczarczyk (1993) studied the influence of different process parameters on the size distribution and dispersion of activated sludge flocs. They concluded that organic loading and the availability of DO were the two most significant factors influencing the size distribution of activated sludge flocs.

## 2.5 Theories relating bio-flocculation and cations

To explain the interaction between the cations and activated sludge and their effects on floc formation and other parameters, several theories have been proposed with varying extent of success and limitations. These are:

### 2.5.1 The DLVO theory

This is a classical colloidal theory describing charged particles surrounded by counter ions in two layers. The first layer is a tightly packed layer of counter ions called Stern Layer. The second layer, called diffuse layer consists of less tightly packed counter ions (Adamson, 1990). The concentration of counter ions in the bulk solution is less than the diffuse layer which creates an electrical potential surrounding the charged particle. This double layer of ions surrounding the particle creates repulsion with the adjacent particles and hinders aggregation. With increased ionic concentration, the repulsive force gets decreased due to the compression of double layer. This helps short range attraction forces to promote aggregation (Sobeck and Higgins, 2002). Several researchers have performed experiments that support the DLVO theory for the role of cations on bioflocculation.

The DLVO theory has its limitations as well, theoretically, the DLVO theory is only applicable for describing the behavior of colloidal particles (less than a few μm). Sludge flocs, however includes a broad range of floc sizes from 1 to 1000 μm and most flocs have sizes larger than 10 μm. (Barbusinski and Koscielniak, 1995; Li and Ganczarczyk 1990). It also fails to explain the increased deterioration of floc properties at higher cationic concentrations in several studies.

### 2.5.2 The alginate theory

Bruus et al. (1992) first proposed this theory to describe the role of cations on bio flocculation. Alginate is a polysaccharide produced by bacteria and is typically made up of repeating manuronic and guluronic acid. The unique composition of this polysaccharaide results into alginate gels in the presence of calcium ions. Several bacteria present in the activated sludge have been found to produce alginate (Sobeck and Higgins, 2002).

Bruus et al.,(1992) demonstrated that high concentration of sodium added to the activated sludge resulted in floc deterioration due to the displacement of $Ca^{2+}$ by $Na^{+}$. They also reported that addition of $Mg^{2+}$ resulted in the same floc deterioration. As a result they concluded biopolymers have greater affinity for $Ca^{2+}$ than $Mg^{2+}$ which supports the role of alginate in bio-flocculation.

### 2.5.3 The di-valent cation bridging theory (DCB)

The first researcher to propose the DCB included Mckinney (1952) and Tezuka (1969). According to this theory, divalent cations bridge negatively charged functional ions within the EPS and this bridge helps to aggregate and stabilize the matrix of bio-polymer and microbes, thereby promoting bio-flocculation. The DCB theory has been supported by findings from several studies that divalent specially $Ca^{2+}$ and $Mg^{2+}$ helps flocculation. Higgins and Novak (2002) reported that when the sum of mono-valent cation concentration ($Na^{+}$, $NH_4^{+}$and $K^{+}$) divided by the sum of the divalent cations ($Ca^{2+}$ and $Mg^{2+}$) was greater than 2, then this could cause floc property deterioration.

# 3. Experimental Procedures

## 3.1 Activated sludge sample

Samples were taken from the aeration tank of the Rya WWTP, Göteborg, Sweden. The plant receives waste water from approximately 550,000 people and 220,000 equivalents of industry, mainly food processing and pulp & paper. The plant is designed for biological nitrogen removal utilizing pre-denitrification and post nitrification in a trickling filter (Balmér et al., 1998). Phosphorus removal is done by adding ferrous sulphate (FeSO4).The plant is run for a low solid retention time (SRT), 2-4 days. The flow to the plant varies considerably from 175,000 to 1,425,000 m$^3$/d with an average daily flow of about 350,000 m$^3$/d.

All the experiments were performed immediately after sample collection and at the laboratoray facility at the Rya WWTP. Hence the alteration of sludge properties due to transportation and storage can be assumed negligible.

## 3.2. Methods and Materials

### 3.2.1 Selected cations and doses

To observe the effects of cation addition on activated sludge, both mono ( Na+, K+) and di-valents ($Ca^{2+}$, $Mg^{2+}$, $Cu^{2+}$ , $Zn^{2+}$) were chosen. These cations are present in the influent waste water at varying concentration levels and in many studies they have been reported to affect the activated sludge process. To observe the presence of cations in the activated sludge sample, we measured cation concentration in the filtered sludge on different testing days (deflocculation tests) which are summarized in the following table:

| Test Date | Concentration (meq/g MLSS) | | | | | |
|---|---|---|---|---|---|---|
| | Na+ | K+ | $Ca^{2+}$ | $Mg^{2+}$ | $Cu^{2+}$ | $Zn^{2+}$ |
| 2007-04-14- (Na+ test) | **0.31525** | **0.168639** | **0.544265** | **0.23272** | **0.009094** | **0.010767** |
| 2007-05-15- ( $Mg^{2+}$ test) | **0.423997** | **0.243122** | **0.606297** | **0.297521** | **0.010644** | **0.012984** |
| 2007-04-27- ( $Ca^{2+}$ test) | **0.286824** | **0.141363** | **0.568241** | **0.20635** | **0.008024** | **0.010137** |
| 2007-04-18- ( K+ test) | **0.315582** | **0.151481** | **0.568106** | **0.229526** | **0.008848** | **0.010944** |
| 2007-06-08- ( $Cu^{2+}$ test) | **0.430024** | **0.139705** | **0.506571** | **0.208118** | **0.009893** | **0.009721** |
| 2007-05-16- ( $Zn^{2+}$ test) | **0.436332** | **0.16616** | **0.557797** | **0.292528** | **0.009604** | **0.027328** |
| Average concentration. | **0,367826** | **0.3368** | **0.558** | **0.2444** | **0.009278** | **0.013564** |

The concentration levels of cations in the supernatant of the activated sludge collected from Rya WWTP, were measured in some previous studies. In total 62 samples were analyzed and the average cation concentrations were as follows:

| Concentration (meq/l) | | | | | |
|---|---|---|---|---|---|
| Na+ | K+ | $Ca^{2+}$ | $Mg^{2+}$ | $Cu^{2+}$ | $Zn^{2+}$ |
| 4.265163 | 0.371678 | 1.063061 | 0.529818 | 0.014193 | 0.002794 |

We added cations in the concentration levels of 5, 10, 15, 20 and 25 meq/l with activated sludge samples. So from the summarized results in the above tables, it can be said that these added concentration levels are considerably higher than the background concentrations of the corresponding cations .This helps to differentiate the effects of added cations from the background levels. At each cationic experiment, one reference reactor was run without any cation addition which is called control.

For the rain water addition tests, no cations were added and the cationic composition of rain water was as follows:

| Concentration (meq/l) | | | | | |
|---|---|---|---|---|---|
| Na+ | K+ | $Ca^{2+}$ | $Mg^{2+}$ | $Cu^{2+}$ | $Zn^{2+}$ |
| 0.07105 | 0.06571 | 0.413 | 0.07253 | 0 | 0.00148 |
| Total concentration | | | | | 0.62377 |

### 3.2.2 Deflocculation test

The objective of the deflocculation tests was to study the stability of the flocs in the activated sludge. Two reactors were run in parallel during the experiments. Reactors were of 3 litre volume with 4 baffles to induce vigorous turbulence at high shear rate. Shear was provided by 4-bladed stirrers controlled by electrical mixers. Two litre of the sample was added to each reactor. The sludge sample was mixed carefully to maintain homogeneous composition of sludge before pouring it in the reactor. In the first phase, the sludge sample was stirred at 100 rpm for 30 min to homogenize it. At the beginning of second phase, 50 ml of sample was withdrawn with a syringe to measure the turbidity of the supernatant after centrifugation at 2100 rpm for 2 min (800×*g*). This was recorded as turbidity at time zero. Then cation was added at different concentrations from a stock solution of the specific cation and was stirred for 60 min at 700 rpm to create a G value of 1700 s-1. Samples were taken out at every 10 min interval and were immediately centrifuged at 2100 rpm for 2 min. The supernatant turbidity was measured at λ = 650 nm with a spectrophotometer (HACH).During each test, 30 ml of sample were taken out for MLSS measurement. Besides, pH and conductivity (µs/cm) were measured at the start and end of each test.

A test was run to find the effects of stirring on floc stability without cation addition and it was observed that at 100 rpm flocs remain almost stable while at 700 rpm significant destabilization of flocs were observed. That’s why for sludge homogenization and deflocculation purpose, 100 and 700 rpm were selected, respectively.

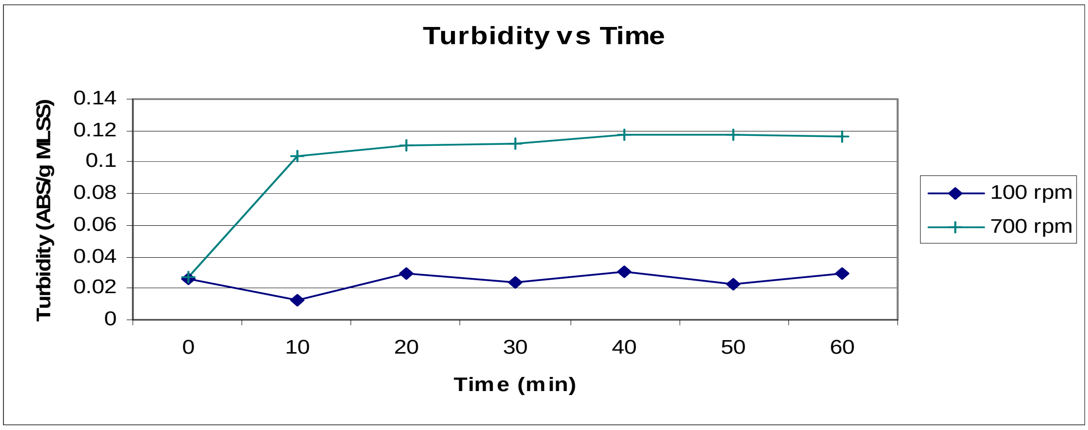

**Figure 3.2.2** Effects of shear force on floc stability

### 3.2.3 Reflocculation & settling test

The objectives of the reflocculation tests were to observe the settling properties of the activated sludge after cation addition. A well-mixed sludge sample of 4 liters was placed in a 5 litre beaker. Appropriate volumes of cationic stock solutions were added to obtain the desired cation concentration, and were stirred for 30 min at 100 rpm. Sample of 30 ml was withdrawn from the reactor to measure MLSS concentration. After stirring for 30 min, 3 litres of the sample was carefully transferred into a graduated cylinder to avoid the breakage of flocs. The cylinder was equipped with a stirrer rotating at 1 rpm to minimize wall effects during settling. The sludge was settled for 30 min and the height of falling interface of sludge was recorded at each minute. The sludge interface heights during settling and after 30 min were used to calculate the SISV and SSVI, respectively. Supernatant samples at 50, 40, 30, 20, 15 cm depth of the cylinder height were withdrawn with a pipette to measure the turbidity. Also pH and conductivity were measured before and after of cationic stock solution addition.

### 3.2.4 Capillary suction time (CST) test

The dewatering properties of the activated sludge was studied in the capillary suction time tests. The same procedure as for the reflocculation test was followed and after 30 minute of settling, the supernatant was removed carefully, leaving only the settled sludge in the bottom. Samples were taken from this sludge for MLSS measurement. Chromatographic filter paper was used for CST measurement and two circles of 1 and 2.5 cm radius were drawn on it. A metallic ring of 1 cm radius was placed on the circumference of the inner circle and was filled with 5 ml of sludge. Time was recorded from the release of sludge in the ring to saturation of the outer circle circumference by water released from sludge. The recorded time is CST. This procedure was repeated four times to take standard deviation into consideration.

### 3.2.5 Sample preparation for background ion measurement by ICP-MS

The sludge samples were homogenized. Concentrated $HNO_3$ (0.8 ml) and miliQ water (7.2 ml) were added to 2 ml homogenized sludge in a glass test tube. The sludge was then digested at 120 °C for 2 hours by HACH method. The samples were filtered through 0.45 µm filters. The samples were then diluted 25-250 times and 100 µL of 0.1 mg/l internal standard (Rh) and 100 µL of concentrated Nitric acid (69%) were added. Then the present ions were measured by using ICP-MS.

# 4. Results and Discussions

## 4.1 Deflocculation test

In these tests, and the effect of cation addition on floc stability was studied. A shear force of 700 rpm was applied to erode the sludge flocs. The deflocculation was measured as a gradual increase in supernatant turbidity. The test results and brief explanations are given below.

### 4.1.1 Addition of $Na^+$

High rates of deflocculation were observed for both the control and $Na^+$ added activated sludge sample (Figure 4.1.1). This was due to the intense turbulence in the reactor created by 700 rpm of shearing and baffles. The resulting kinetic force, might break the larger flocs into smaller fragments and erosion of small partices and single cells from the floc structure. Addition of $Na^+$, seemed to suppress the effects of higher shear at varying extent at various concentration level. It may be due to the fact that, added sodium ions suppress the negative surface charge on the flocs. At 5meq/l concentration level, sodium seemed to have the best flocculation effect. However, the initial turbidity was lower for the 5 meq/l sample which could have effected the later development in turbidity. At all other concentration levels, deflocculations were almost the same but lower than the control. In this short term test, equilibrium conditions were not reached except for 5 meq/l. theoretically, equilibrium turbidity should be reached after infinite time (Mikkelsen and Keiding, 1999).

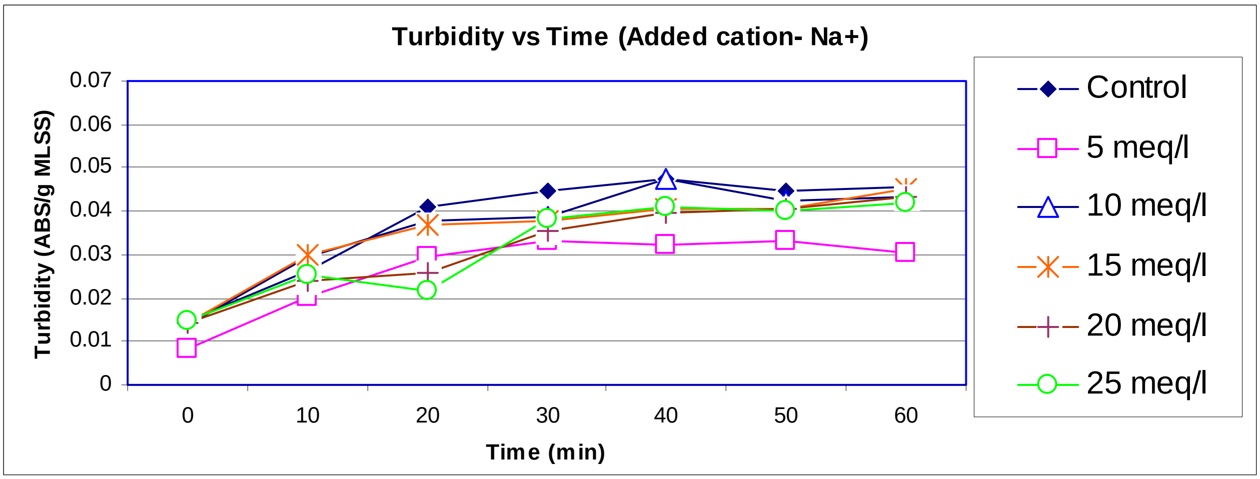

**Figure 4.1.1.** Deflocculation test with $Na^+$.

Neither DLVO nor DCB theory, can clearly explain the results obtained with $Na^+$ addition. According to the DLVO theory, flocculation should increase with increased $Na^+$ concentration, but it was not observed in our experiment. On the other hand, according to the DCB, mono- valent like $Na^+$ replaces the $Ca^{2+}$ from the floc structure and should increases deflocculation due to decreased floc stability. We also observed increased deflocculation with increased $Na^+$ concentration but they were lower than the control. If DCB applies here, deflocculation must be higher for $Na^+$ added samples than for the control, due to the combined effects of high shearing and $Ca^{2+}$ displacement from flocs. So, here it might be assumed that the surface interactions as explained by the DLVO-theory dominates. However, there was no clear difference in impact when dosing different concentrations of ions to the sludge. The lowest dose, 5 meq/l gave the lowest deflocculation which might indicate that higher concentrations influence the polymer bridging properties of di-valent ions.

### 4.1.2 Addition of $K^+$

In the test with $K^+$ addition, the deflocculation patterns observed were almost similar to those from $Na^+$ addition test (Figure 4.1.2). Here, 10 meq/l, was the optimal dose to suppress the deflocculation at the lowest value but no trend to reach equilibrium with increased time was observed. At 5 meq/l concentration, initially the deflocculation was the lowest, but followed that of control with increasing exposure time to shear. For the control and the 15 and 20 meq/l of $K^+$ concentration, the degrees of deflocculation were almost the same. At 25 meq/l, significantly higher deflocculation was observed especially with increased exposure time.

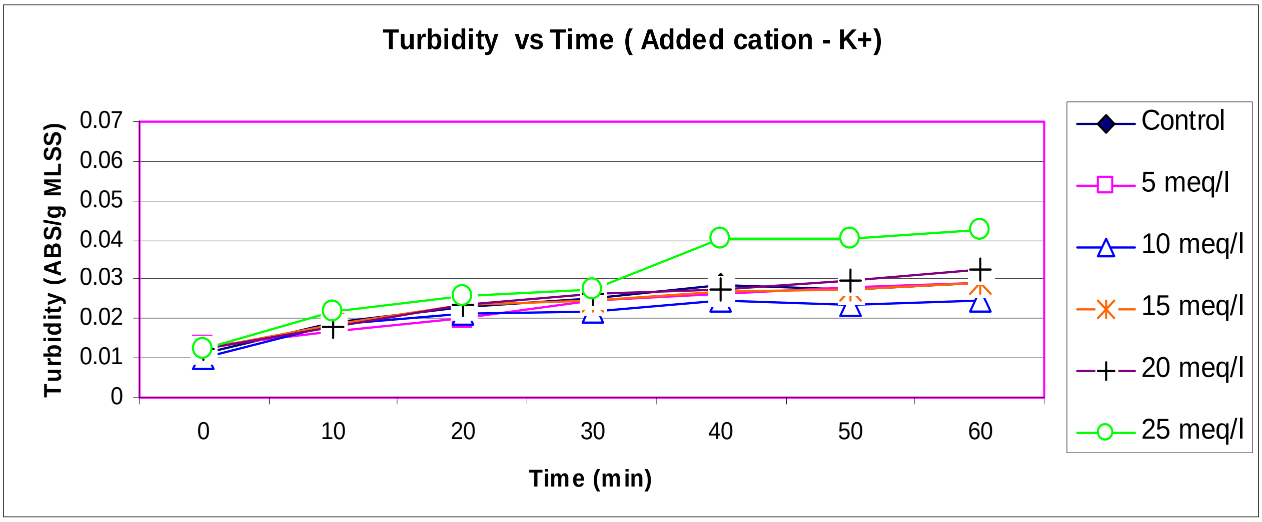

**Figure 4.1.2.** Deflocculation test with $K^+$.

The responses of $K^+$ added to activated sludge can be explained as those for $Na^+$ added tests except for 25 meq/l concentration of $K^+$. At this concentration it seemed like both the surface interactions according to the DLVO-theory occurred at low to moderate concentrations while at the higher concentrations replacement of divalent cations from the floc structure by $K^+$ occurred.

### 4.1.3 Addition of $Ca^{2+}$

For the $Ca^{2+}$ addition test, pronounced reductions in deflocculation were observed for the lower concentration levels of 5 and 10 meq/l. From Figure 4.1.3, it can be seen that the highest floc stability occurred at 5 meq/l. Noticeable increase in floc stability were also observed at both 10 and 20 meq/l concentrations. It was somewhat surprising that, at 15 meq/l the deflocculation was higher than at 20 meq/l. Here it can be assumed that a complex ecosystem like activated sludge may not always respond in the same predictable manner. At 25 meq/l, the deflocculation was almost same as that for control, though bit higher at the end.

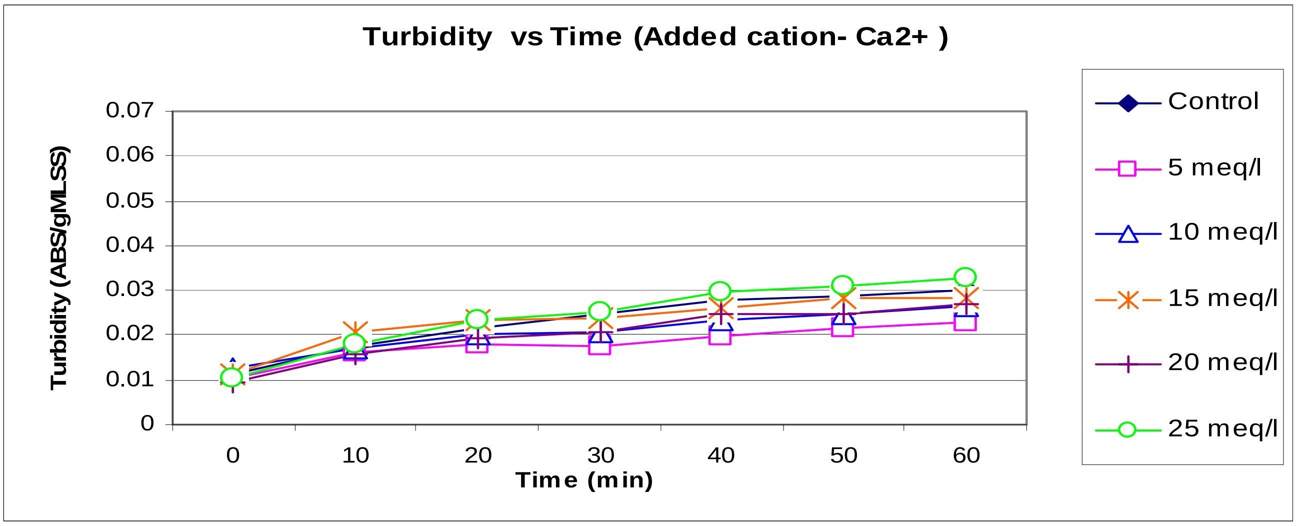

**Figure 4.1.3.** Deflocculation test with $Ca^{2+}$.

The responses of $Ca^{2+}$ added to activated sludge can be explained by both the alginate theory and DCB theory. It might be possible that some alginate gel producing bacteria were present in the activates sludge sample, and the 5 meq/l $Ca^{2+}$ concentrations were optimal for gel production which caused better floc stability. The same reasoning can be hold good for the DCB theory where $Ca^{2+}$ ions bridge the EPS produced by bacteria cells, thereby promoting increased floc stability.

### 4.1.4 Addition of $Mg^{2+}$

From Figure 4.1.4, it can be observed that $Mg^{2+}$ reduced the deflocculation at all concentration levels tested, but the effects were not as significant as those of $Ca^{2+}$, although their chemical properties are very similar. Addition of $Mg^{2+}$ at 10 and 25 meq/l caused increased floc stability. At a dosage of 15 meq/l, improved floc stability was observed. At both 20 and 5 meq/l, the degree of deflocculation was almost the same as that of the control which seemed erratic.

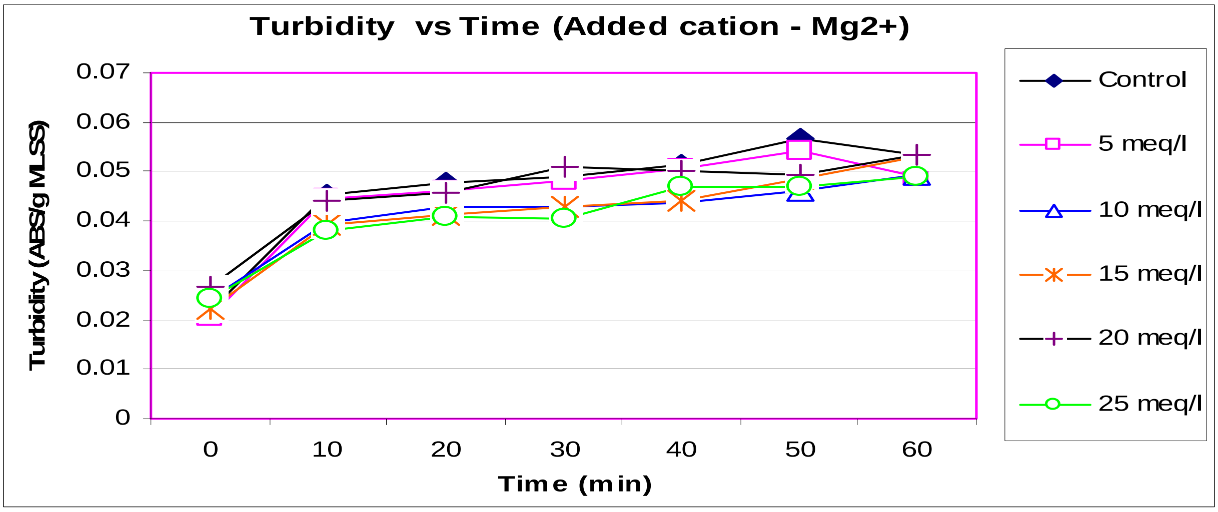

**Figure 4.1.4.** Deflocculation test with $Mg^{2+}$.

As the decrease in deflocculation was not related to increased $Mg^{2+}$ concentrations, firm conclusions regarding the effect of the added ion cannot be made. Therefore, the DLVO theory cannot explain the difference in floc stability. As well, the alginate theory can not be applied as $Mg^{2+}$ doesn't help in alginate gel production. As $Mg^{2+}$ has the ability to create EPS bridging like $Ca^{2+}$, the DCB theory can be applied to explain the lower deflocculation at 10, 15 and 25 meq/l. But the same level of deflocculation at both low (10 meq/l) and high (25 meq/l) concentration of $Mg^{2+}$seemed confusing.

### 4.1.5 Addition of $Cu^{2+}$

From Figure 4.1.5 the significantly detrimental effect on activated sludge flocs of added $Cu^{2+}$ can be observed. The floc disintegrated with increased $Cu^{2+}$ concentrations. It can be assumed that at all concentration levels, $Cu^{2+}$ had considerable toxic effects on the present microorganism in activated sludge. The reduced floc stability could be caused by decreased EPS production or some other biological effects.

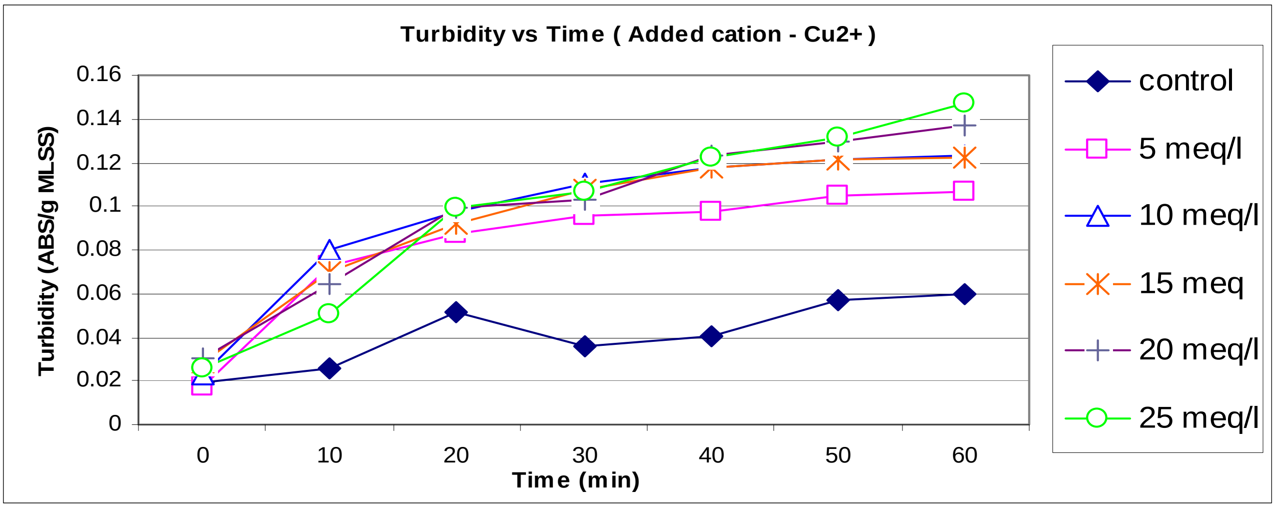

**Figure 4.1.5.** Deflocculation test with $Cu^{2+}$.

### 4.1.6 Addition of $Zn^{2+}$

In the $Zn^{2+}$ addition test, no effects on floc stability were observed except at 20 meq/l concentration. It might be possible that $Zn^{2+}$ had some flocculating effects on activated sludge, but deflocculation induced by high shear, made it negligible.

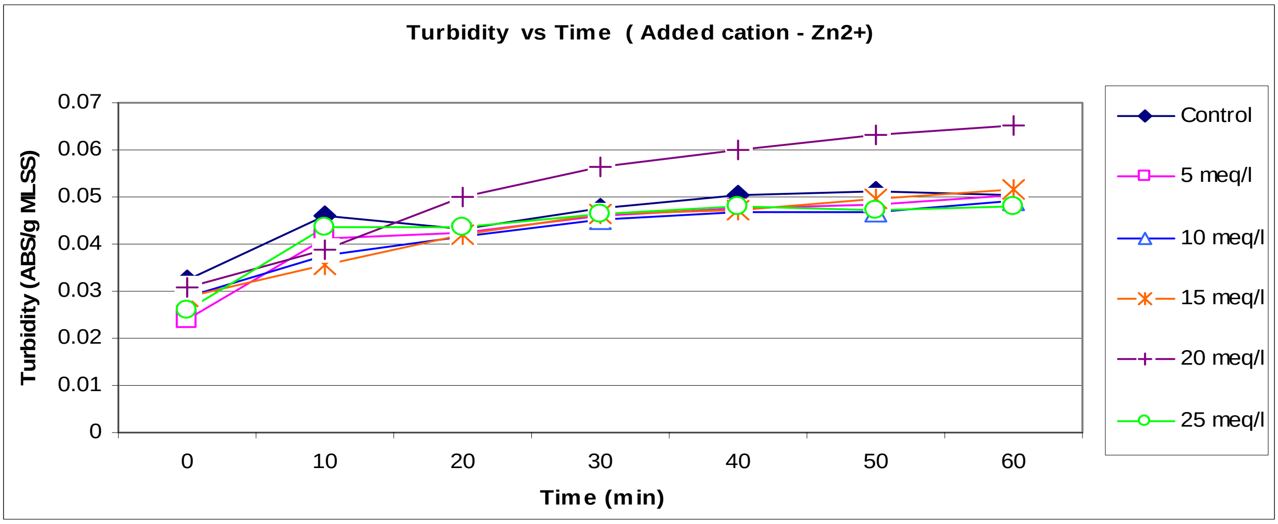

**Figure 4.1.6.** Deflocculation test with $Zn^{2+}$.

### 4.1.7 Control test ($Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$)

The purpose of the control tests were to observe the effects of added cations on activated sludge sample collected on the same day. The before mentioned tests were done at different days, so it is erroneous to compare the effects of different cations as sludge compositions might not be the same at different days. The ions $Na^+$ , $K^+$ and $Ca^{2+}$ showed slightly lower deflocculation than the control whereas $Mg^{2+}$added to the sludge sample showed significantly lower deflocculation (Figure 4.1.7). So it can be deduced that $Mg^{2+}$can cause the highest floc stability in sludge in a highly turbulent condition.

It was evident from the previous tests that $Cu^{2+}$ and $Zn^{2+}$ do not have floc stabilizing effects on the activated sludge, so they were not included in these control tests.

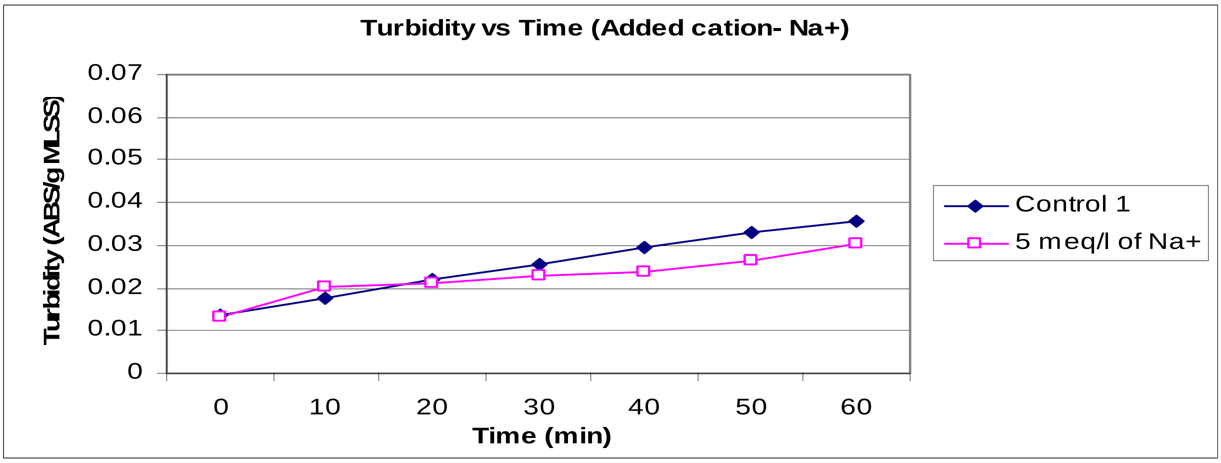

**Figure 4.1.7(a).** Control - deflocculation test with $Na^+$.

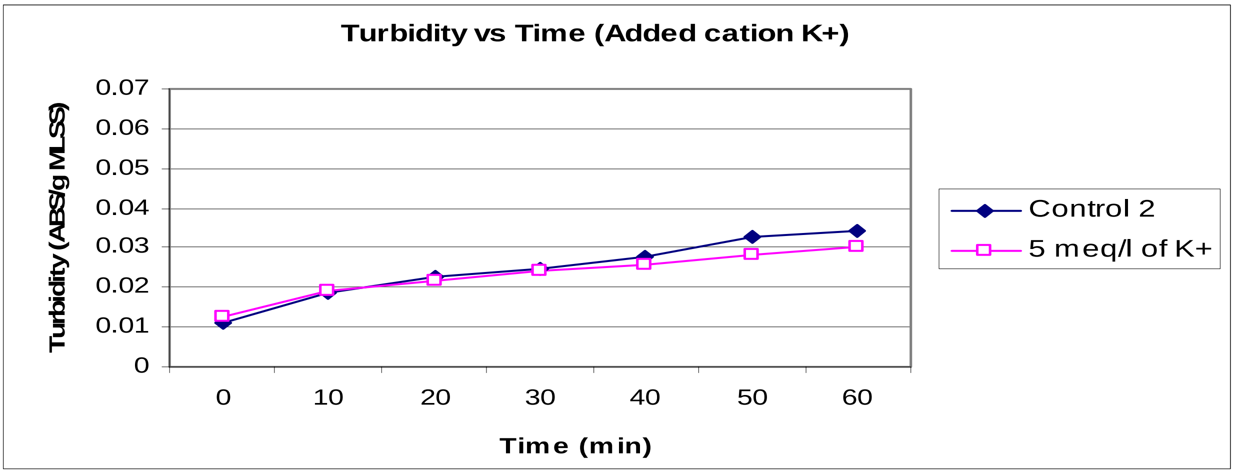

**Figure 4.1.7(b).** Control- deflocculation test with $K^+$.

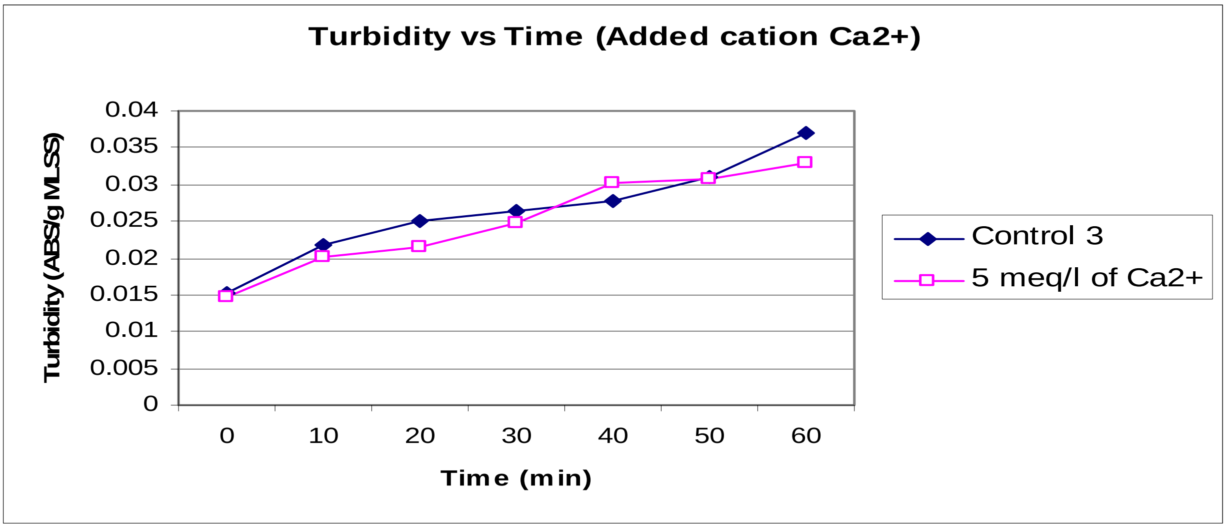

**Figure 4.1.7(c).** Control - deflocculation test with $Ca^{2+}$.

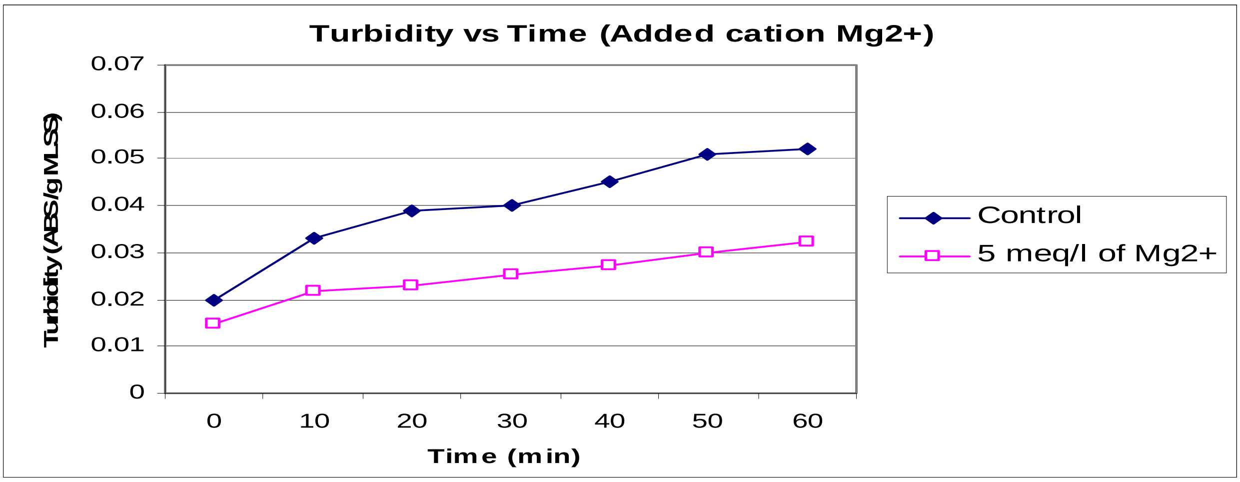

**Figure 4.1.7(d).** Control- deflocculation test with $Mg^{2+}$.

### 4.1.8. Addition of coupled cations

In this test, the combined effects of both mono and di-valents were studied. At high applied shear rate, mono and di-valents were added either at 1:1 or 1:2 ratio. It can be observed from the Figure 4.1.8 that reduction of deflocculation was quite minimal when coupled cations were added. From the previous tests, considerably lower flocculations were observed, when single cations were added in various concentration levels including 5 and 10 meq/l.

Higgins and Novak reported that when mono- and di-valent ratio is 1:1 or 1:2, good flocculation were observed. It might be possible that some flocculation did happen in our tests, but due to the intense shear, the floc disrupted relatively more due to this effect compared to the effect of added cations. It is possibility that the added cations affected the flocculation capacity and were not as strong as when they were added as individual ions.

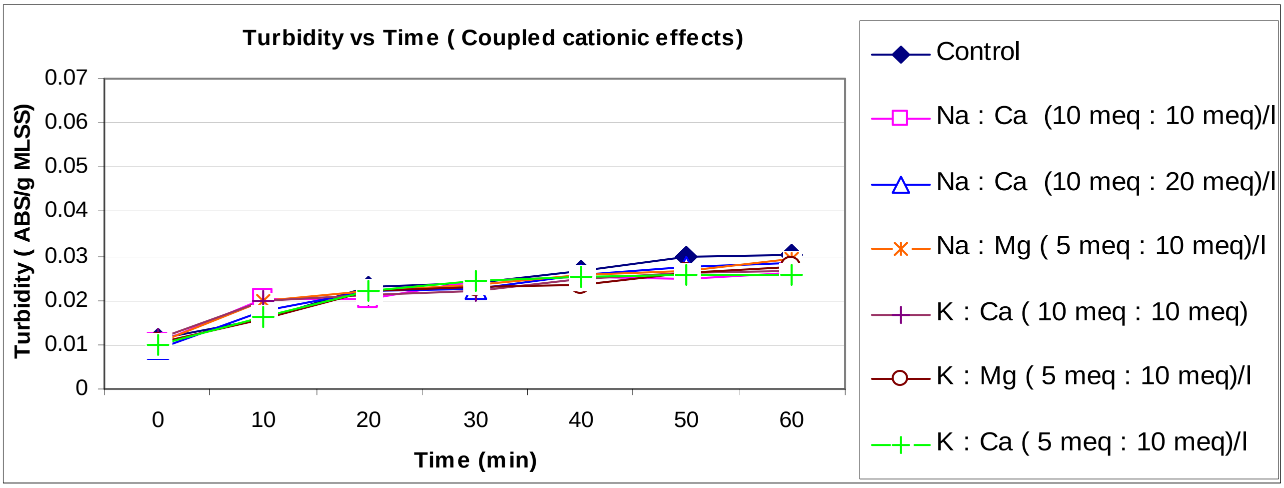

**Figure 4.1.8**. Deflocculation test with coupled cations.

### 4.1.9 Addition of rain water:

From the test of dilution of activated sludge with rain water, some significant deflocculations were observed (Figure 4.1.9). From the ionic composition measurement of rain water, the total concentration of all the six cations tested in this study was 0.62377 meq/l which can be regarded as considerably low. At 50 and 75 % dilution of activated sludge with rain water, the sludge flocs seemed to disrupt more readily at applied shear. Higgins and Novak (1997) reported that when present in the feed to an activated sludge process, the cations are able to become enmeshed in the biopolymer network as the biopolymer is produced, creating a stronger denser floc. So it can be assumed that the flocs diluted in rain water were much more fragile as they were deficient in cations. So at high shear force, the fragile structure was eroded into smaller particles and single cells resulting in increased turbidity of the supernatant. The decreased ionic strength of the water would also according to the DLVO-theory, cause increased repulsion between particles and hence a higher degree of deflocculation (Zita and Hermansson, 1994).

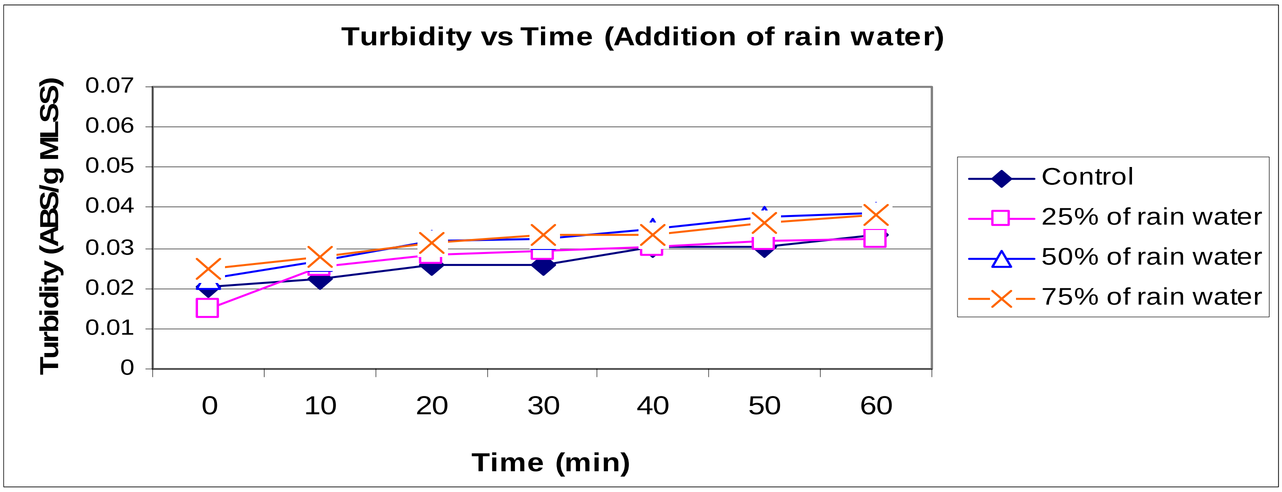

**Figure 4.1.9**.Deflocculation test with rain water.

## 4.2 Reflocculation and settling tests

In the reflocculation test, slow stirring was applied to reflocculate the sludge. The different ions were added and the decrease in turbidity was monitored after 30 minutes of settling at different depths of the settling cylinder. Simultaneously the SSVI and SISV were measured to see whether a short term effect of cation addition exists.

### 4.2.1 Addition of $Na^+$

From the supernatant turbidity test, significantly improvement in reflocculation were observed at 20 and 25 meq/l concentrations whereas moderate reflocculations were observed at 5, 10 and 15 meq/l concentrations (Figure 4.2.1.(a)). The classical DLVO theory can be applied to explain the good reflocculation at higher concentrations of $Na^+$.

Higher SSVI were observed with increased ion concentration (Figure 4.2.1.(b). Theoretically the SSVI should be lower at a higher degree of flocculations due to the compact accumulation of flocs after settling and also due to compressed diffuse boundary layer. The reason to the increased SSVI in our tests is not known but might be because of the formation of flocs of irregular shape and highly branched structure, which had much void space after settling. As the SSVI increased, the SISV decreased (Figure 4.2.1(b). It could be due to the fact that flocs of extended surface area were formed, which experienced considerable drag force while settling.

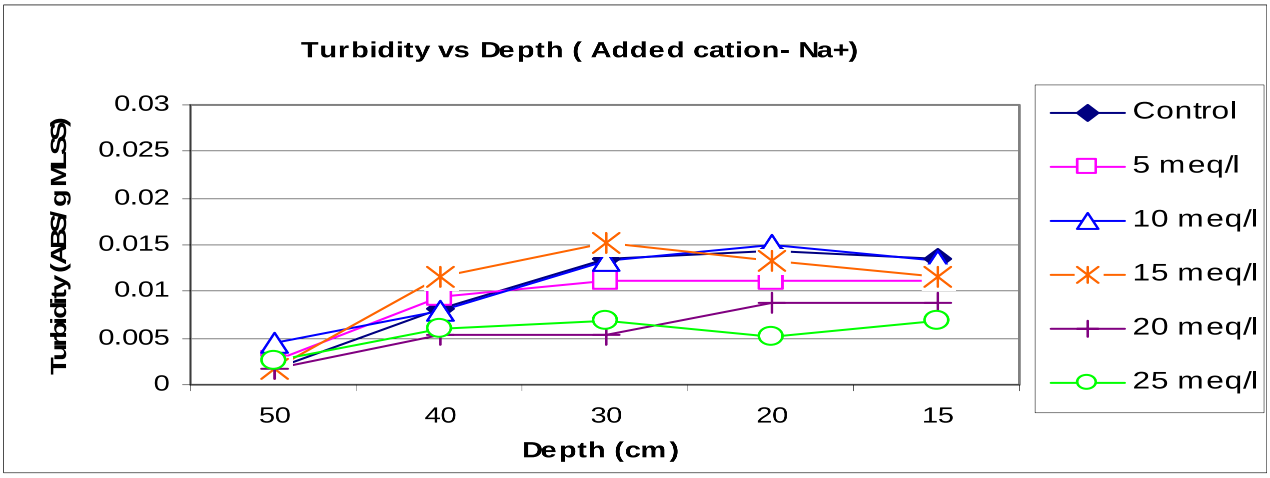

**Figure 4.2.1(a).** Reflocculation test with $Na^+$.

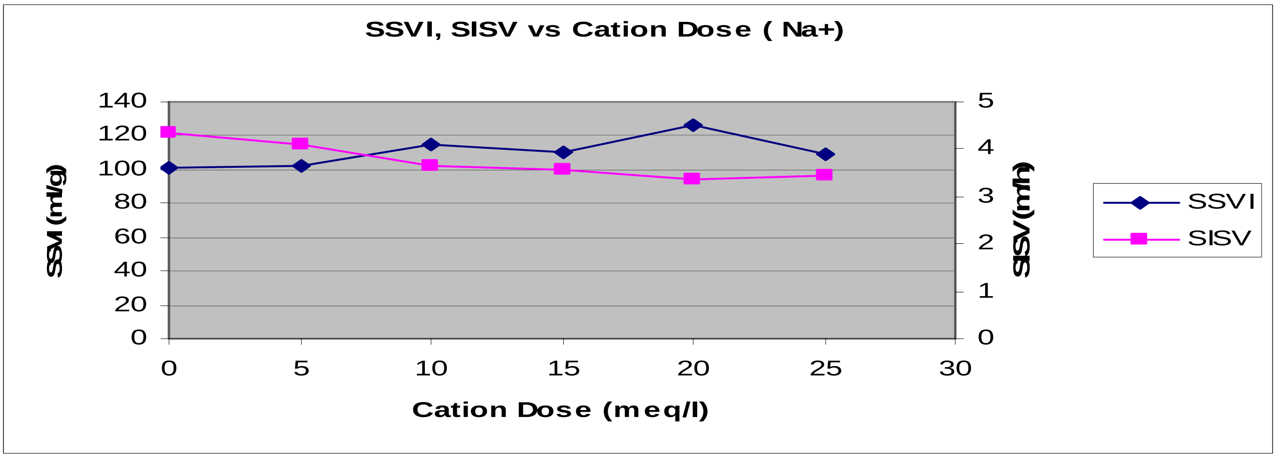

**Figure 4.2.1(b).**Settling test with $Na^+$.

### 4.2.2 Addition of $K^+$

Relatively good reflocculation was observed at all tested concentrations of $K^+$ tested (Figure 4.2.2). At the higher concentrations a tendency towards less reflocculation was observed. SSVI were higher at all concentrations levels tested compared to the control. Thus, $K^+$ behaved in a similar way as $Na^+$. SISV for all concentration levels were lower than the control except at 5 meq/l, which probably had to do with the measurement.

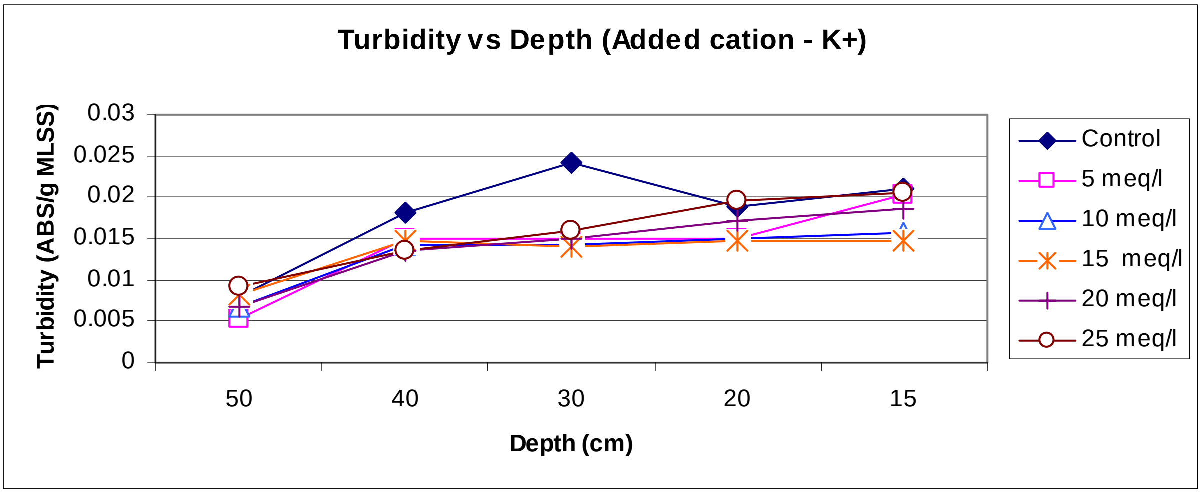

**Figure 4.2.2(a).** Reflocculation test with $K^+$.

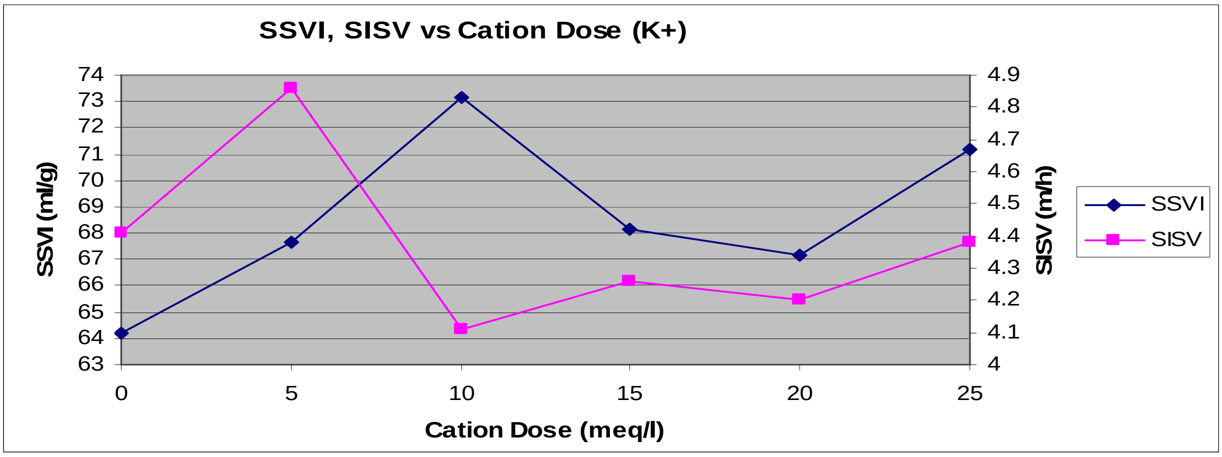

**Figure 4.2.2(b)** Settling test with $K^+$.

### 4.2.3 Addition of $Ca^{2+}$

From Figure 4.2.3(a), good reflocculation can be observed at the lower concentrations of $Ca^{2+}$ specially at 5 meq/l. Higher concentrations (20 and 25 meq/l) $Ca^{2+}$ were observed to have detrimental effects on flocculation. The reflocculation at lower concentrations can be explained in the light of both the alginate and the DCB theory. The 5 meq/l, might be the optimal dose where both alginate gel production and EPS bridging were maximum. As the $Ca^{2+}$ concentration increased, the SSVI became lower. It can be assumed that flocs of regular and compact structure were formed when calcium was added. Also higher SISV values were observed with increased $Ca^{2+}$ concentration.

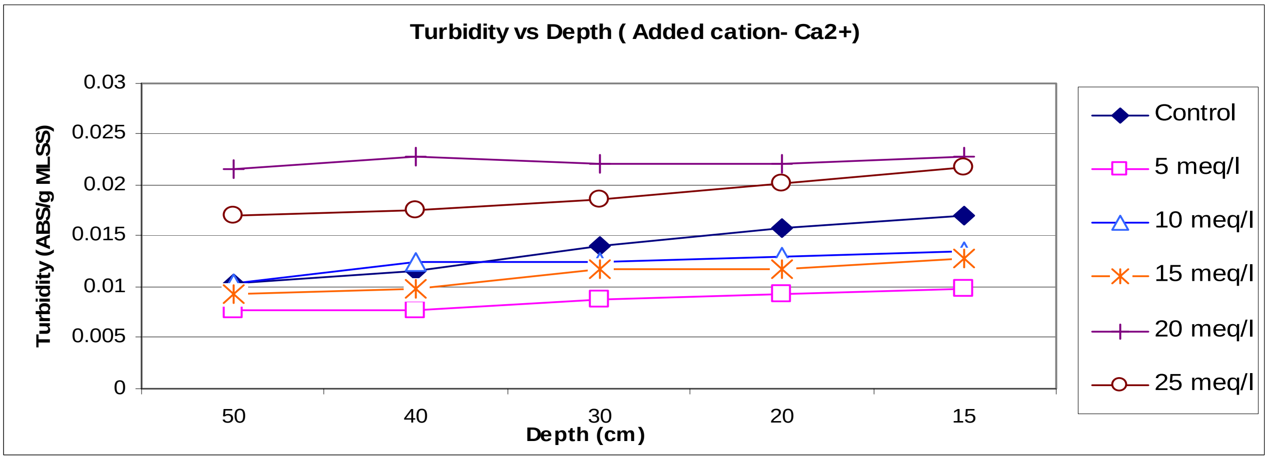

**Figure 4.2.3(a).** Reflocculation test with $Ca^{2+}$.

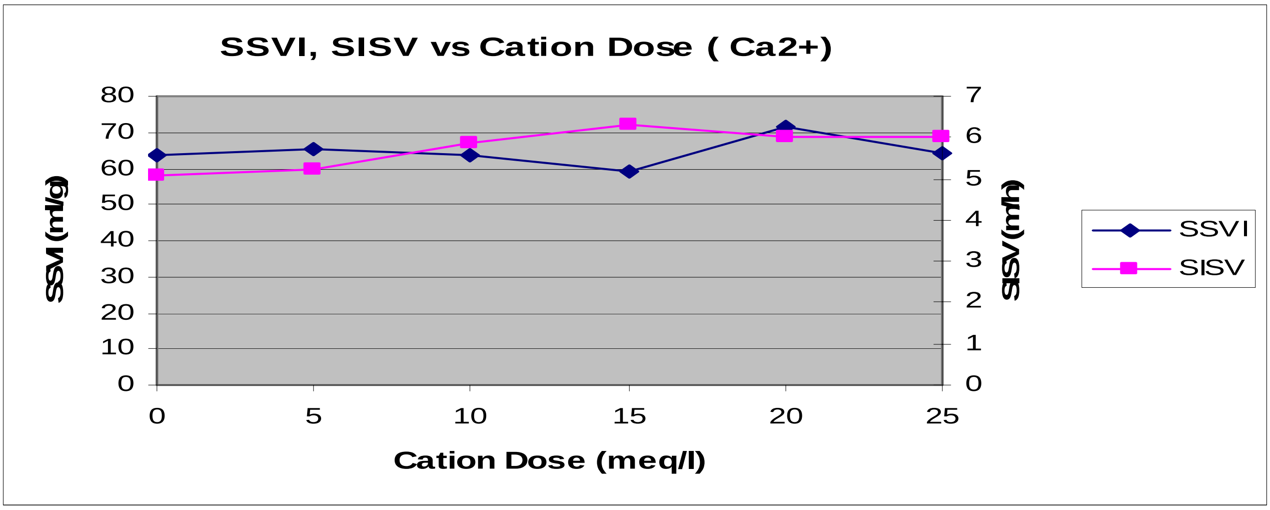

**Figure 4.2.3(b).** Settling test with $Ca^{2+}$.

### 4.2.4 Addition of $Mg^{2+}$

From the test with $Mg^{2+}$, significant reflocculations were observed for 15meq/l and 10 meq/l. moderately good flocculations were observed at 5, 20 and 25 meq/l. It can be said from Figure 4.2.4(a) that 15 meq/l was the optimal dose for flocculation. Probably a $Mg^{2+}$ concentration of 5 meq/l was not sufficient to cause maximum flocculation, and at 20 and 25 meq/l had some physico-chemical effects on micro-organisms. There was no consistent pattern in the change in SSVI with $Mg^{2+}$ dose. At the highest doses of $Mg^{2+}$, the SSVI went down (Figure 4.2.4(b)). The SISV went down as the SSVI went up.

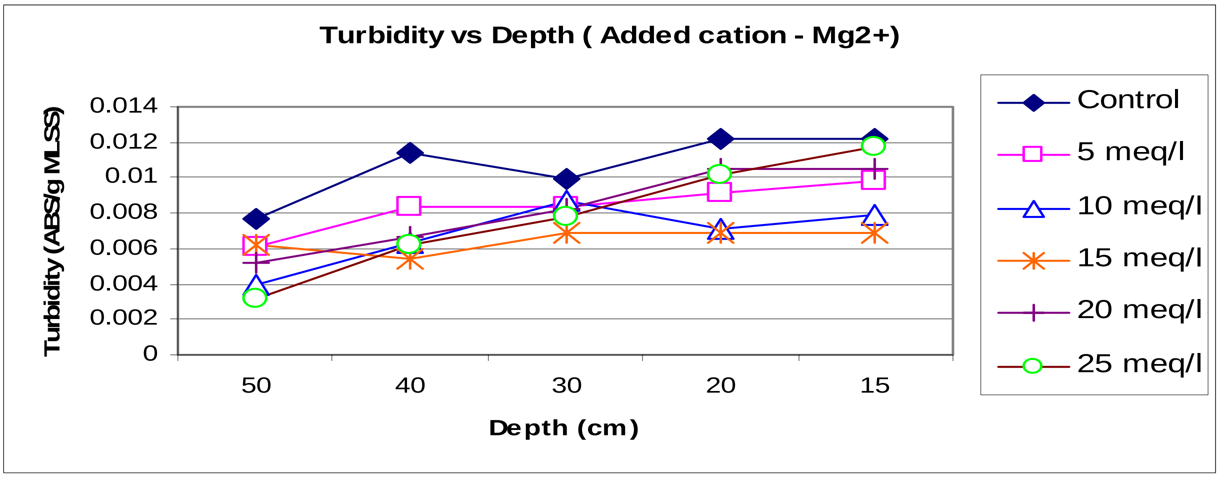

**Figure 4.2.4(a).** Reflocculation test with $Mg^{2+}$

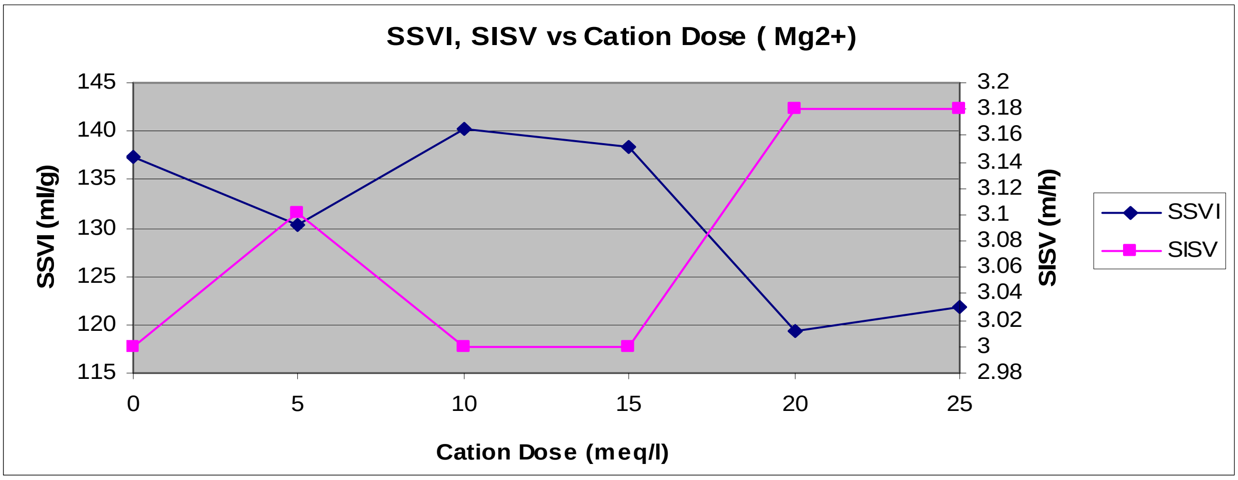

**Figure 4.2.4(b)**.Settling test with $Mg^{2+}$ .

### 4.2.5 Addition of $Cu^{2+}$

Pronounced deflocculation was observed at all concentration levels of $Cu^{2+}$ tested (Figure 4.2.5a). Almost ceased biological activities of the organisms in the $Cu^{2+}$ added activated sludge was observed in the microscopic study. Probably due to this, the sludge flocs fell apart into single cells as there were no formations of binding agents like EPS or alginate gels by the bacterial cells anymore.

As the flocs deflocculated, there was a trend towards decreased SSVI which might be due to the formation of smaller and more regularly shaped flocs. The SISV increased as the SSVI decreased (Figure 4.2.5b).

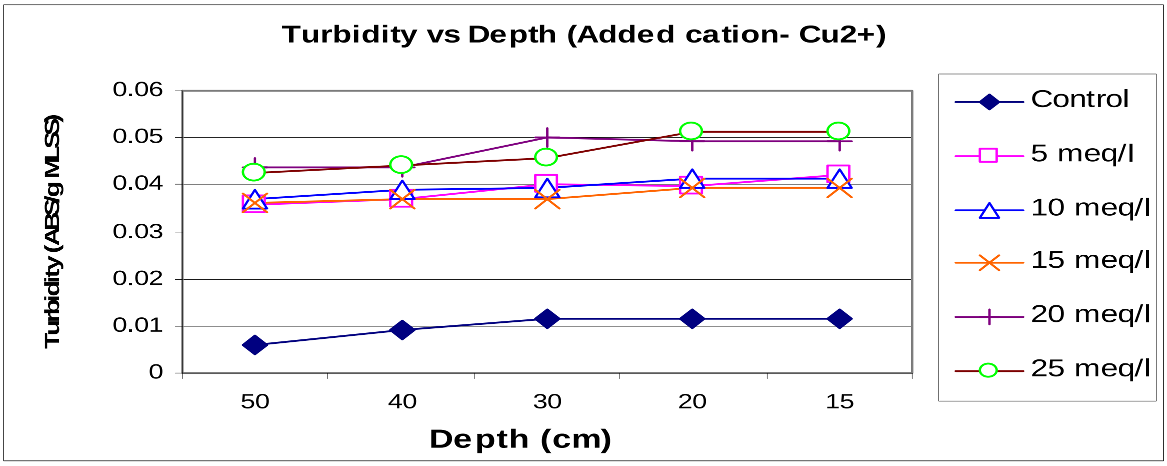

**Figure 4.2.5(a).** Reflocculation test with $Cu^{2+}$.

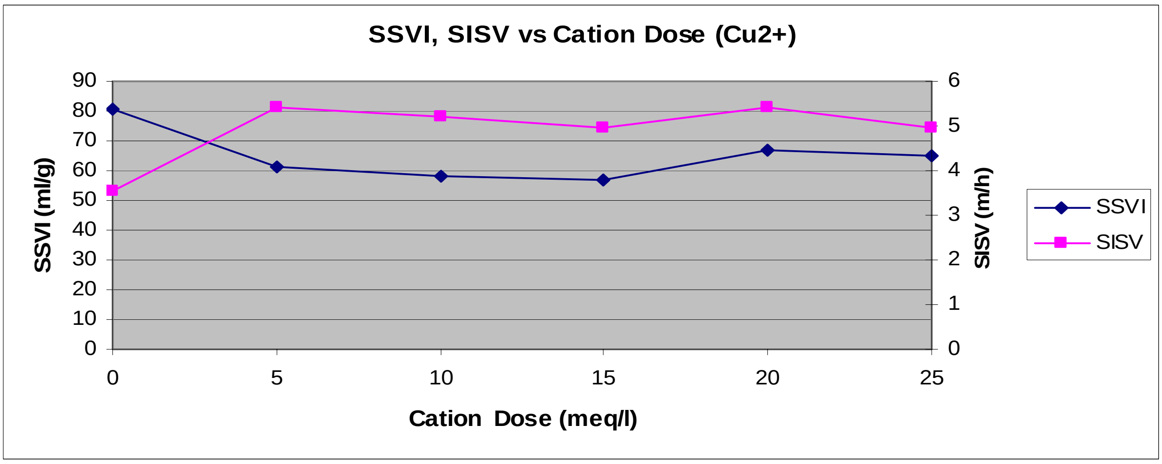

**Figure 4.2.5(b).** Settling test with $Cu^{2+}$.

### 4.2.6 Addition of $Zn^{2+}$

The effects of $Zn^{2+}$ addition on deflocculation, SSVI and SISV were almost the same as those from $Cu^{2+}$ addition test and same reasoning can be applied here as well (Figure 4.2.6).

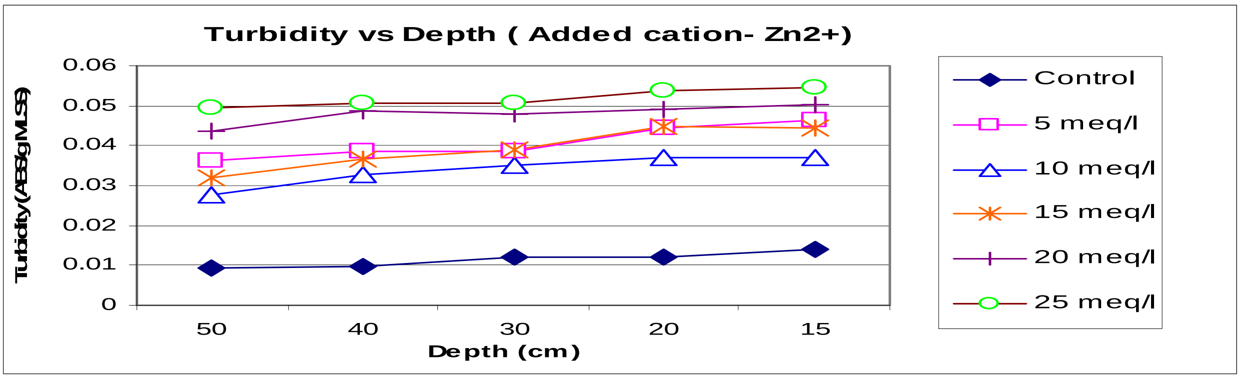

**Figure 4.2.6(a).** Reflocculation test with $Zn^{2+}$.

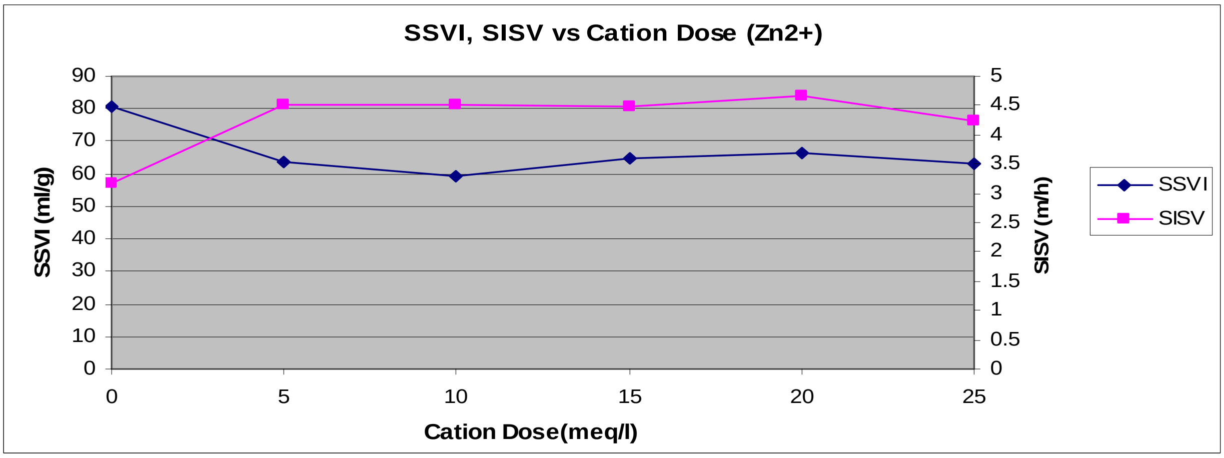

**Figure 4.2.6(b).** Settling test with $Zn^{2+}$ .

### 4.2.7 Addition of rain water

Activated sludge diluted with rain water, showed significant deflocculation, especially at 50 and 75 % of dilution (Figure 4.2.7). At 50 and 75 % dilution of activated sludge with rain water, sludge flocs seemed to deflocculate readily even in the presence of flocculation favouring conditions like slow stirring.

SSVI plot showed an erratic pattern at 25 % of dilution, though at 50 and 75% dilution the SSVI got higher as expected. The higher SSVI were due to the poor settling properties of the deflocculated sludge. The SISV values were getting lower with increased degree of deflocculation.

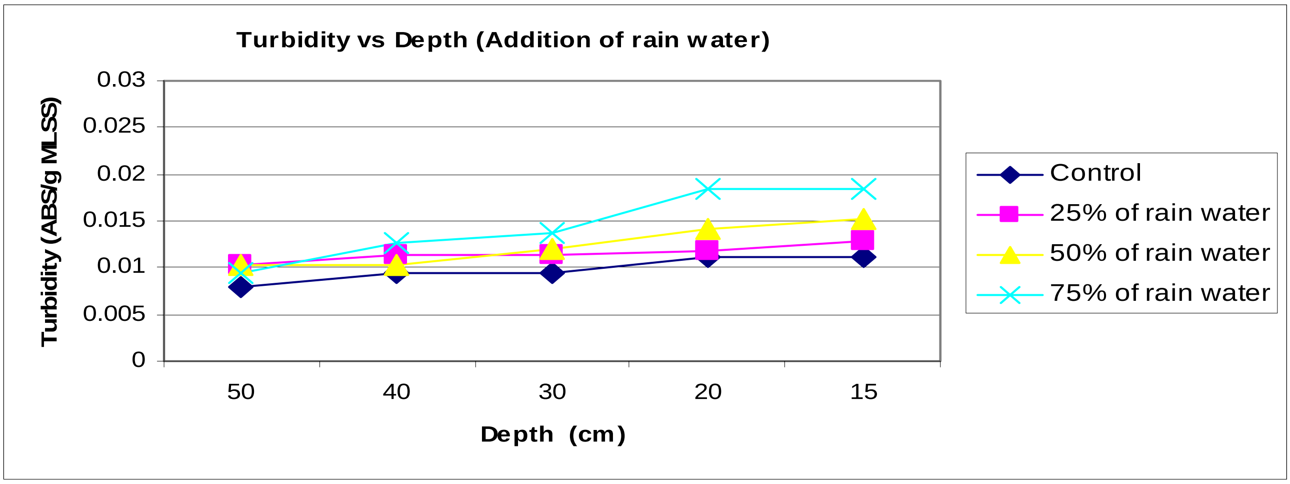

**Figure 4.2.7(a).**Reflocculation test with rain water.

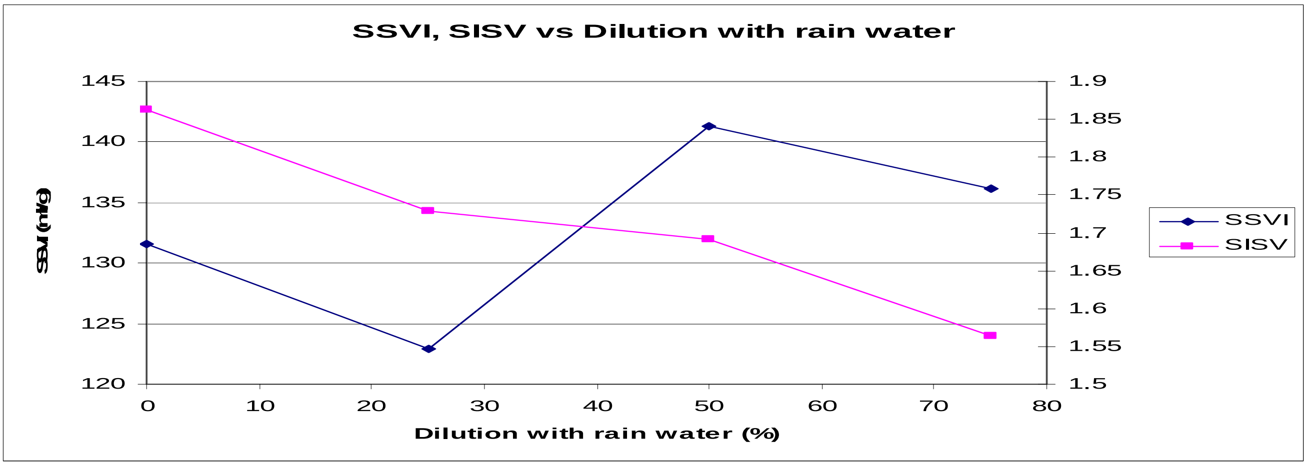

**Figure 4.2.7(b)**.Settling test with rain water.

### 4.3 Dewaterability test (CST):

In this study, the water releasing capacity of sludge flocs, known as dewaterability, was tested. Higher CST refers to poor and lower CST refers to good dewaterabilty respectively.

### 4.3.1 Addition of $Na^+$

From Figure 4.3.1, it is observed that the dewatering properties improved at addition of low to moderate concentrations of sodium which is indicated by lower CST values. From the reflocculation tests result with $Na^+$, we observed increased flocculation with increased concentrations especially for 20 and 25 meq/l. So theoretically a well flocculated sludge should dewater better which was not clearly observed in our test. CST values were slightly higher at 20 and 25 meq/l concentrations. That could be due to the higher levels of hydrophilic bond formation in the floc structure. Because of this more water can be attached as bound water which is hard to release during dewatering.

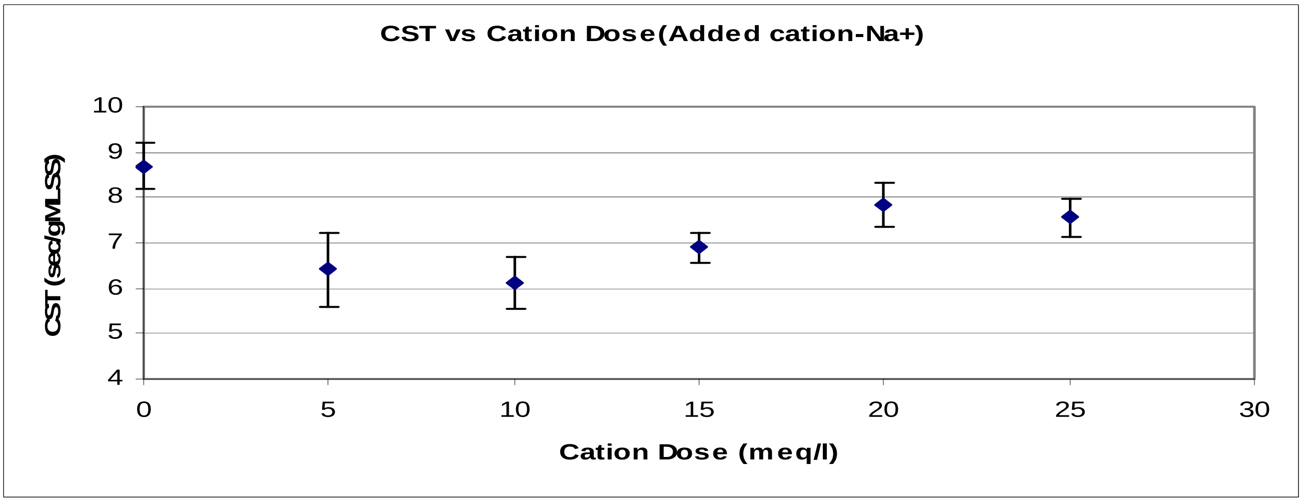

**Figure 4.3.1.** CST test with $Na^+$.

### 4.3.2 Addition of $K^+$

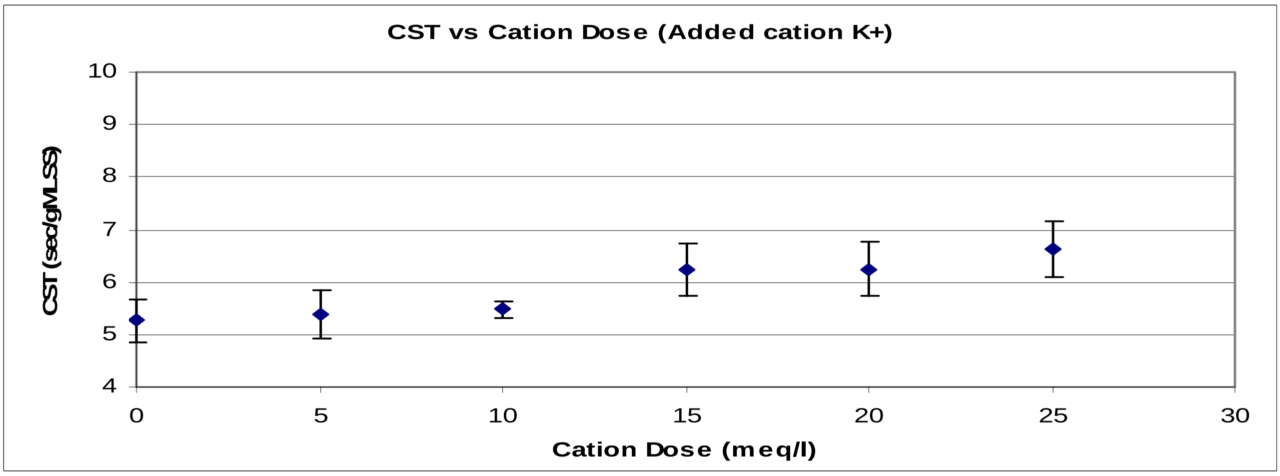

**Figure 4.3.2.** CST test with $K^+$.

For the $K^+$ addition test, the CST values were raising consistently with increased concentration levels and were higher than the control at all tested concentrations. From the reflocculation test with $K^+$, it was observed that better flocculation compared to for the control occurred at all concentration levels tested with especially good properties at 5, 10 and 1 meq/l. This is in contradiction with the theory regarding flocculation and dewatering. One explanation might be that increased $K^+$ concentrations helped to produce more hydrophilic bonds in the floc structure which raised the CST values.

### 4.3.3 Addition of $Ca^{2+}$

When $Ca^{2+}$ was added, the dewaterability deteriorated with increased concentration. From the reflocculation test with $Ca^{2+}$, good flocculation was observed for 10 and 15 meq/l whereas increased deflocculations were observed for 20 and 25 meq/l. However, almost the same high CST values were observed at all these concentrations. So, it can be assumed that in the presence of $Ca^{2+}$, bound water increases in the floc structure irrespective of flocculation and deflocculation properties.

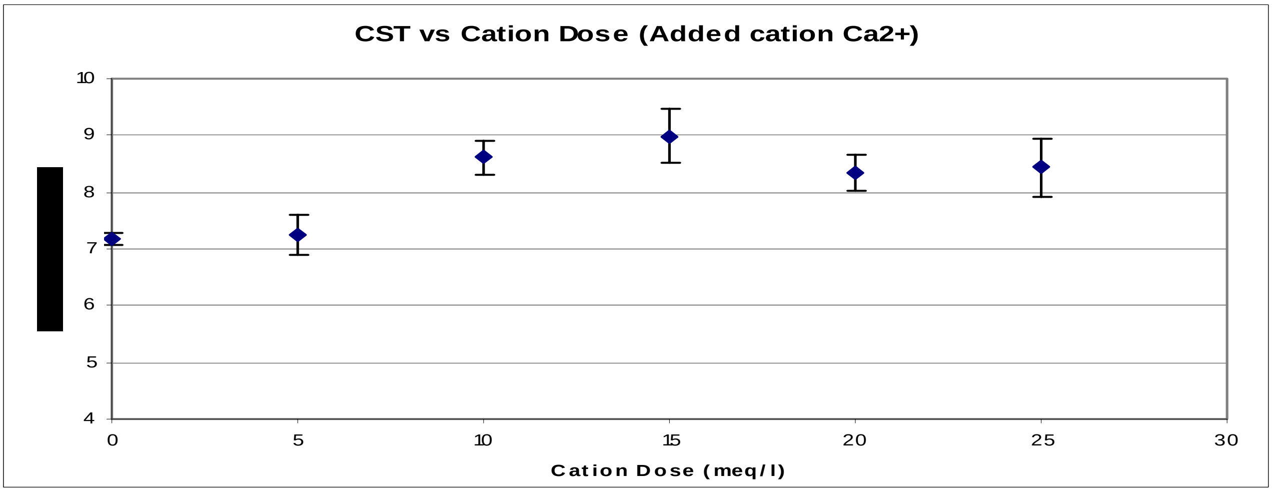

**Figure 4.3.3**. CST test with $Ca^{2+}$.

### 4.3.4 Addition of $Mg^{2+}$

From the previous test with $Mg^{2+}$, good reflocculation was observed for concentration from 5 to 25 meq/l (Figure 4.3.4). However in the CST test, the improvement in dewatering upon $Mg^{2+}$ addition seemed marginal.

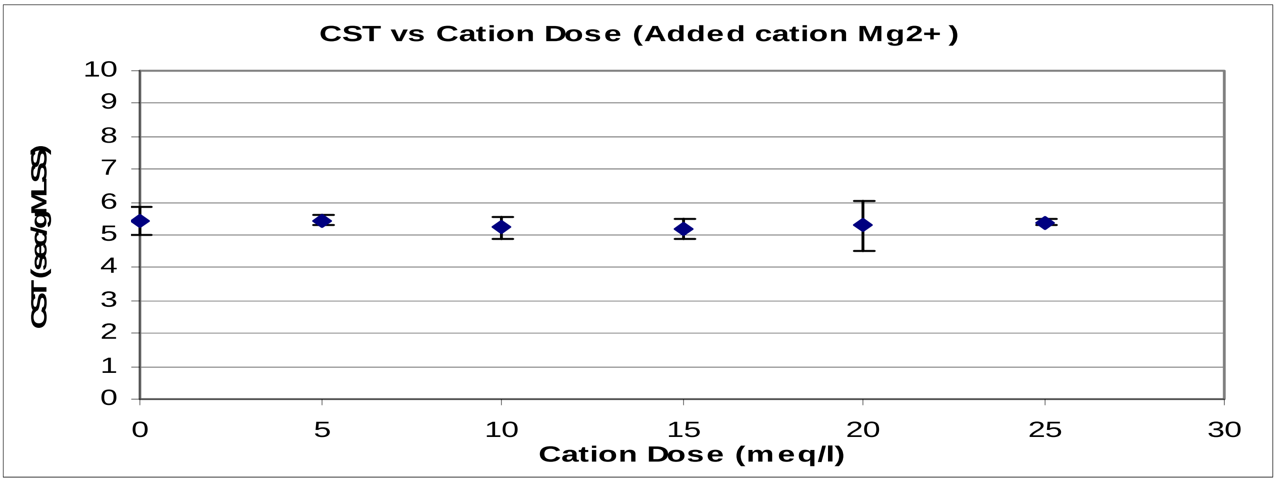

**Figure 4.3.4.** CST test with $Mg^{2+}$.

### 4.3.5Addition of $Cu^{2+}$

Addition of $Cu^{2+}$ improved the dewatering of the sludge (Figure 4.3.5). From the previous reflocculation test, $Cu^{2+}$ seemed to have some toxic effects on sludge flocs. Due to the lack of biological activities, dead cells might lose the capacity to attach water with its structure which improved the dewaterability.

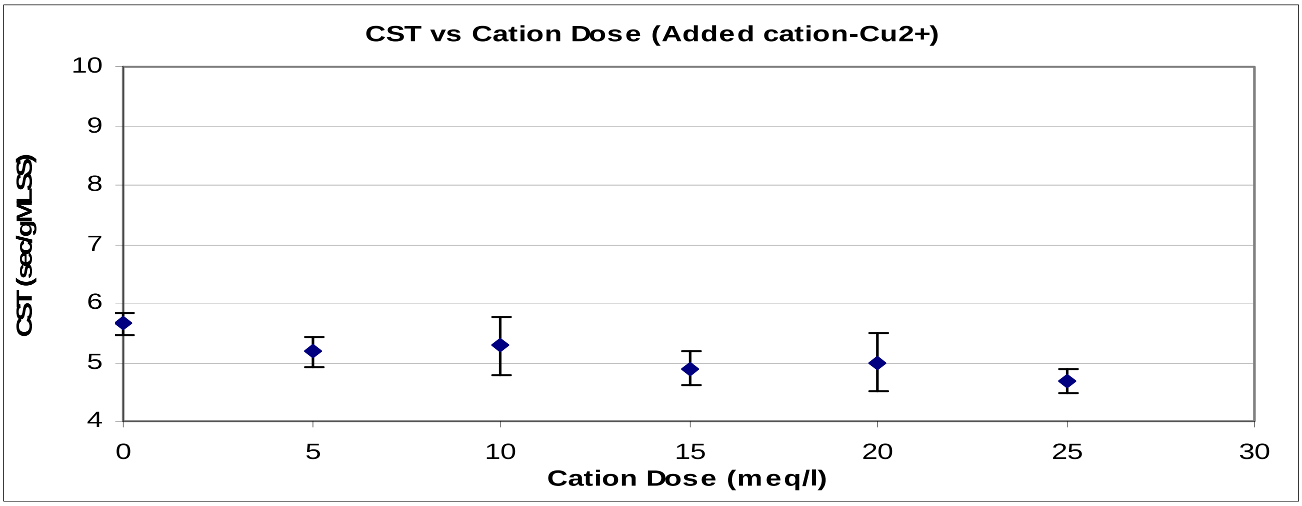

**Figure 4.3.5**. CST test with $Cu^{2+}$.

### 4.3.6. Addition of $Zn^{2+}$

Even though in reflocculation test, $Zn^{2+}$ showed almost the same level of toxic effects as $Cu^{2+}$ on the sludge flocs, the CST test revealed opposite dewatering properties. As the concentration of $Zn^{2+}$ increased, the CST increased (Figure 4.3.6.) It can be a matter of further study to find the reasons of why $Cu^{2+}$ added flocs retain considerable water, in spite of reduced biological activity.

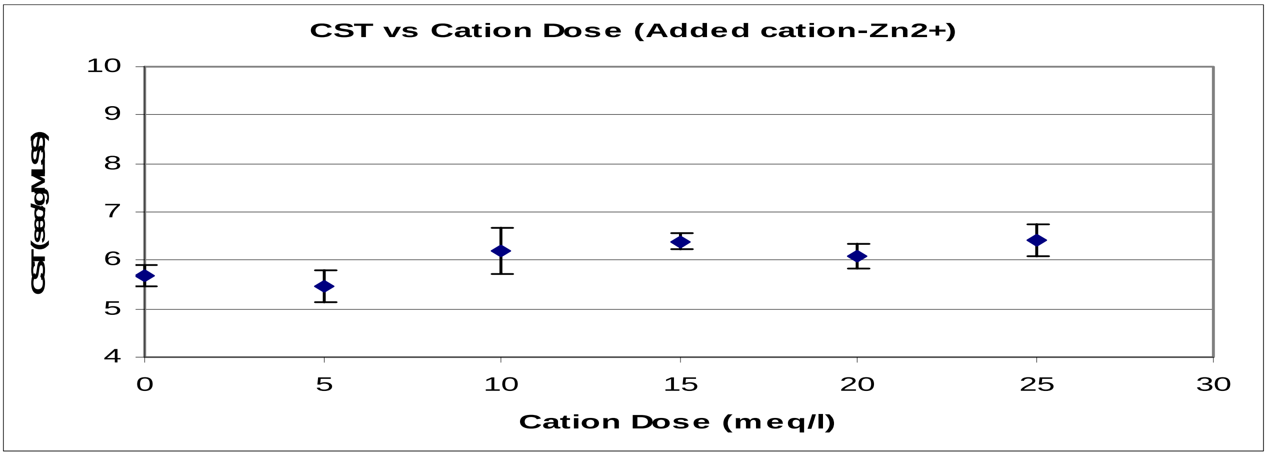

**Figure 4.3.6**. CST test with $Zn^{2+}$.

# 5. Summary of test results

* $Na^+$ added activated sludge maintained higher floc stability than the control at all concentration levels. The highest floc stability was observed at 5 meq/l. Deteriorated settling properties of the flocs were observed with increased $Na^+$ addition. Addition of $Na^+$ at all concentration levels resulted in better dewatering properties. Lowest CST values was observed at 5 and 10 meq/l.

* At 10 meq/l of $K^+$ addition flocs had the highest stability while at 25 meq/l, the floc stability was lower than the control. At all other concentrations, floc stabilities were almost same as that of control. Higher SSVI and lower SISV values were observed upon $K^+$ additions which are indicative of poor settling properties. At 10 meq/l, highest SSVI and lowest SISV values were observed. Deteriorated dewatering properties were observed with increased $K^+$ addition.

* Addition of $Ca^{2+}$ had positive effects on floc stability of activated sludge. Highest level of floc stability was observed at 5 and 10 meq/l. At all other concentrations, floc stability was either higher or equal to that of control. $Ca^{2+}$ addition resulted into improved settling properties of activated sludge at all concentrations. Lowest SSVI and highest SISV were observed at 25 meq/l. Slightly deteriorated dewatering properties of the activated sludge were observed with $Ca^{2+}$ addition. Highest CST value was observed at 15 meq/l.

* Improved floc stabilities were observed at all concentrations of added $Mg^{2+}$. Lowest deflocculation of the sludge flocs was observed at 5 meq/l. Inconsistent improvement in settling properties of activated sludge were observed with increased $Mg^{2+}$ addition. Lowest SSVI and highest SISV were observed at both 20 and 25 meq/l. Slightly improved dewatering properties were observed at 10 and 15 meq/l.

* Significantly lower floc stability of activated sludge was observed at all concentration levels of $Cu^{2+}$. Surprisingly improved settling and dewatering properties were observed with $Cu^{2+}$ addition.

* Addition of $Zn^{2+}$ was observed to have little effects on floc stability. At 20 meq/l, floc stability was least while at other concentrations it was the same as that of control. Improved settling properties were observed at all concentrations. SSVI and SISV values remained almost the same at all concentrations. Deteriorated dewatering was observed at higher concentrations.

* Upon additions of rain water with activated sludge, increased defloccations were observed with increased percentage of added rain water. Inconsistent higher SSVI values and lower SISV values were observed with increased rain water addition which is suggestive of deteriorated settling properties.

* Coupled addition of mono and di-valents at different ratios were observed to have little effects on floc stability. Floc stability was slightly better than control after addition of mono and di-valents either at 1:1 or 1:2.

# 6. Comparative discussions on floc stability, settling and dewatering

It was observed from the floc stability test that high shear force of 700 rpm had considerable effects on the stability of the floc structure. For both the control and cation added samples, supernatant turbidity kept on increasing with time. In some cases cation added activated sludge showed less disintegration than control which could be due to the floc binding capacity of the added cations which made the flocs less susceptible to the high shear force.

From the reflocculation and settling tests, it was observed that both mono- and di-valents had some good settling properties. In some cases, it was found that the cation concentrations were more important than types i.e. mono- or di-valents. Zita and Harmansson,(1994) studied the effects of $K^+$ and $Ca^{2+}$ addition at concentrations ranging from 0.0005 to 0.5 mM on reflocculation of activated sludge sample collected from Rya, WWTP, Göteborg, Sweden. Good reflocculations were observed at all concentrations while best occurred between 0.0005 to 0.05 mM. Both mono- ($K^+$) and di-valent ($Ca^{2+}$) seemed to improve the reflocculation and settling properties. In our study it was found that $K^+$ helped reflocculation at all concentrations while $Ca^{2+}$ helped reflocculations at 5, 10 and 15 meq/l. It was also found that $K^+$ deteriorated the setting properties while $Ca^{2+}$ improved the settling properties of the activated sludge. As none of the traditional theory i.e DLVO, alginate gel or DCB cannot completely explain the flocculation and settling behaviour of activated sludge at different cationic concentration, there might be some other mechanism which can supplement these theories. For example, Urbain et al.,(1993) reported in a highly hydrated system as biological sludge, internal hydrophobic bonding are involved in flocculation mechanisms and their balance with hydrophilic bonding determine the sludge settling properties. Foster (1985b) hypothesized that the size of cations may influence their binding ability to charged (carboxyl) and uncharged groups (hydroxyl) in the ECP. Pavoni et al., (1972) showed that the surface charge reduction is not the prime mechanism in bioflocculation because polymers are able to bridge the cells either electrostatically or physically. It is common to find discrepancies among findings from different studies and the most probable cause may be the testing period i.e, short or long term effect. Cousin et al., (1999) studied short term effects of adding $Ca^{2+}$ at 0, 2, 4, 6, 8, 10 meq/l in the presence of 4 meq/l of $Na^+$. Increased floc sizes were observed until $Ca^{2+}$: $Na^+$ reached 2.5, after this floc sizes were decreased and deteriorated flocculations were observed when $Na^+$ concentrations were higher. This was explained as either increased deflocculation or decreased bacterial attachment affinity. While in another study, Cousin and Ganczarczyk (1998) reported that the addition of sodium to a biological suspension increased floc size and improved floc porosity. In our short time study, addition of $Na^+$ to activated showed good floc stability and addition of Ca:Na in 1:1 or 2:1 resulted into slightly better floc stability than control. Sobeck and Higgins (2002) suggested that addition of cations in batch mode can have a significantly different effect than if similar cation concentrations are added to the feed of the same system and the system is allowed sufficient time to reach steady state.

From the CST tests, $Na^+$ and $Mg^{2+}$ added sludge showed moderate and $Cu^{2+}$ added sludge showed good dewaterability. While K+, $Cu^{2+}$ and $Zn^{2+}$ added sludge showed deteriorated dewaterability of activated sludge. Theoretically good flocculation should be resulted into good dewaterability of activated sludge, however it was not always the case in our study. It has been reported in many studies that factors other than flocculation can affect dewaterability like bound water content, formation of hydrophilic/hydrophobic bonds and presence of ammonia from nitrification process in WWTP. Sobeck and Higgins (2002) reported improved Sludge Volume Index (SVI) and CST, from 5 to15 meq/l for both $Ca^{2+}$ and $Mg^{2+}$. In the same study deteriorated SVI values were observed for $Na^{+}$ addition at 5, 10 and 15 meq/l. Unaltered CST value was observed at 5 meq/l while increased significantly at both 10 and 15 meq/l. Forster et al. (1972) reported that addition of $Ca^{2+}$ reduced the bound water content while addition of $Mg^{2+}$ did not change the bound water content. Ammonium ion present in the mixed liquor appeared to interact with the activated sludge flocs to influence their dewatering properties. An increased presence of ammonium ion in the soluble fraction of sludge resulted into deteriorated dewaterability (Murthy et al.,1998).

# 7. Conclusions

* Presence of shear force showed definite impacts on the flocculating effects of added cations on activated sludge. Significantly, higher supernatant turbidity was observed for floc stability test (700 rpm) than settling tests (100 rpm)

* Mono-valent cations ($Na^+$ and $K^+$) were observed to have positive effects on floc stability.

* Among the di-valents, $Ca^{2+}$ and $Mg^{2+}$ caused positive effects on floc stability while $Cu^{2+}$ caused adverse effects on floc stability, and $Zn^{2+}$ showed almost neutral effects on floc stability.

* Coupled addition of mono- and di-valents either in 1:1 or 1:2 ratio had little positive effects on floc stability.

* Mono-valent cations ($Na^+$ and $K^+$) showed deteriorated settling properties of activated sludge, especially at higher concentrations. While $Na^+$ addition had positive effects on dewatering of activated sludge, $K^+$ had opposite effects.

* All di-valent cations ($Ca^{2+}$, $Mg^{2+}$, $Cu^{2+}$ and $Zn^{2+}$) showed improved settling properties of activated sludge at varying extents. On dewaterability of activated sludge, $Cu^{2+}$had considerably good effects, $Zn^{2+}$ had negative effects and $Ca^{2+}$ and $Mg^{2+}$ had slightly improving and deteriorating effects respectively.

* Addition of rain water resulted into poor floc stability and dewatering of activated sludge. This can be attributed to the deficiency of floc binding cations in rain water.

* In general, better floc stabilization, settling and dewatering effects of added cations on activated sludge were observed at lower concentrations like 5 and 10 meq/l. So it can be said that cation concentration levels as well as cation type is an important factor for the studied properties of activated sludge.

* It is observed from all the test results that good flocculation can not always be positively correlated with good settling and dewaterability characteristics of activated sludge.

# 8. Recommendations

For better understanding of the mechanisms involved in bioflocculations and related properties like settling and dewaterability, the followings can be studied as the continuation of this thesis work:

* To study the cations for their long term effects on flocculation of activated sludge.

* To study the distributions of cations in between floc matrix and supernatant.

* To study the microbial response to cation additions in terms of ECP, protein, carbohydrate and humic substance productions.

* To explore other cations which may have beneficial effects on flocculation of activated sludge.

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# 10. Appendices

## (I) Deflocculation tests ( MLSS , supernatant turbidity , pH and conductivity)

**Addition of Na$^+$:**

MLSS data:

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1229 | 0.1233 | 0.123 | 0.122 | 0.1244 | 0.1223 |
| Filter pap.+ sludge wt | 0.1332 | 0.1351 | 0.1338 | 0.1331 | 0.1357 | 0.1333 |
| Sludge wt (g) | 1.03 | 1.18 | 1.08 | 1.11 | 1.13 | 1.1 |
| Avg MLSS (g/l) | | | | | | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (min) | | | | | | |
| 0 | 0.015 | 0.01 | 0.015 | 0.016 | 0.016 | 0.016 |
| 10 | 0.027 | 0.024 | 0.032 | 0.033 | 0.027 | 0.028 |
| 20 | 0.042 | 0.035 | 0.041 | 0.041 | 0.029 | 0.024 |
| 30 | 0.046 | 0.039 | 0.042 | 0.042 | 0.04 | 0.042 |
| 40 | 0.049 | 0.038 | 0.051 | 0.045 | 0.045 | 0.045 |
| 50 | 0.046 | 0.039 | 0.046 | 0.045 | 0.046 | 0.044 |
| 60 | 0.047 | 0.036 | 0.047 | 0.05 | 0.049 | 0.046 |

pH

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.5 | 7.55 | 7.07 | 7.1 | 6.9 | 6.85 |
| 60 min | 7.49 | 7.4 | 7.34 | 7.39 | 7.64 | 7.65 |

## Addition of $K^+$

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.125 | 0.123 | 0.1245 | 0.1252 | 0.1241 | 0.1224 |
| Filter pap.+ sludge wt | 0.143 | 0.141 | 0.1423 | 0.1424 | 0.1418 | 0.1405 |
| Sludge wt (g) | 1.83 | 1.8 | 1.78 | 1.72 | 1.77 | 1.81 |
| Avg MLSS (g/l) | 1.815 | | 1.75 | | 1.79 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.123 | 0.124 | 0.1236 | 0.1231 | 0.1239 | 0.1222 |
| Filter pap.+ sludge wt | 0.140 | 0.141 | 0.1407 | 0.139 | 0.1407 | 0.1389 |
| Sludge wt (g) | 1.74 | 1.7 | 1.71 | 1.59 | 1.68 | 1.67 |
| Avg MLSS (g/l) | 1.72 | | 1.65 | | 1.675 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (min) | | | | | | |
| 0 | 0.02 | 0.023 | 0.018 | 0.021 | 0.02 | 0.021 |
| 10 | 0.035 | 0.029 | 0.033 | 0.032 | 0.03 | 0.037 |
| 20 | 0.042 | 0.035 | 0.038 | 0.04 | 0.039 | 0.043 |
| 30 | 0.046 | 0.043 | 0.039 | 0.042 | 0.043 | 0.046 |
| 40 | 0.052 | 0.046 | 0.044 | 0.046 | 0.045 | 0.068 |
| 50 | 0.05 | 0.049 | 0.042 | 0.047 | 0.049 | 0.068 |
| 60 | 0.053 | 0.051 | 0.044 | 0.05 | 0.054 | 0.071 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.04 | 7.07 | 7.04 | 7.06 | 7.04 | 7.03 |
| 60 min | 7.03 | 7.1 | 7.09 | 7.29 | 7.22 | 7.06 |

Conductivity (µs/cm)

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 461 | 465 | 465 | 457 | 453 | 465 |
| 60 min | 459 | 1400 | 1766 | 2400 | 2700 | 3200 |

## **Addition of $Ca^{2+}$**

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.124 | 0.124 | 0.1214 | 0.1234 | 0.1245 | 0.1241 |
| Filter pap.+ sludge w | 0.143 | 0.143 | 0.14 | 0.143 | 0.1421 | 0.1414 |
| Sludge wt (g) | 1.92 | 1.9 | 1.86 | 1.96 | 1.76 | 1.73 |
| Avg MLSS (g/l) | 1.91 | | 1.91 | | 1.745 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.123 | 0.123 | 0.1243 | 0.1249 | 0.1244 | 0.1246 |
| Filter pap.+ sludge w | 0.142 | 0.142 | 0.1439 | 0.1442 | 0.1436 | 0.1437 |
| Sludge wt (g) | 1.93 | 1.9 | 1.96 | 1.9 | 1.92 | 1.91 |
| Avg MLSS (g/l) | 1.915 | | 1.93 | | 1.915 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (min) | | | | | | |
| 0 | 0.021 | 0.02 | 0.022 | 0.02 | 0.018 | 0.02 |
| 10 | 0.033 | 0.031 | 0.03 | 0.037 | 0.03 | 0.034 |
| 20 | 0.041 | 0.034 | 0.035 | 0.042 | 0.037 | 0.045 |
| 30 | 0.047 | 0.033 | 0.036 | 0.043 | 0.04 | 0.048 |
| 40 | 0.053 | 0.038 | 0.041 | 0.047 | 0.048 | 0.057 |
| 50 | 0.055 | 0.041 | 0.043 | 0.051 | 0.048 | 0.059 |
| 60 | 0.057 | 0.044 | 0.046 | 0.051 | 0.052 | 0.063 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.11 | 7.09 | 7.09 | 7.07 | 7.23 | 7.22 |
| 60 min | 7.1 | 7.14 | 7.07 | 7.08 | 7.2 | 7.19 |

Conductivity (µs/cm)

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 501 | 507 | 511 | 510 | 995 | 1020 |
| 60 min | 497 | 1012 | 1518 | 2000 | 2950 | 3740 |

## Addition of $Mg^{2+}$

MLSS data :

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.11 | 0.12 | 0.1226 | 0.1238 | 0.1179 | 0.1185 |
| Filter pap.+ sludge | 0.13 | 0.13 | 0.1361 | 0.1376 | 0.1309 | 0.1311 |
| Sludge wt (g) | 1.37 | 1.28 | 1.35 | 1.38 | 1.3 | 1.26 |
| Avg MLSS (g/l) | 1.325 | | 1.3 | | 1.28 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.12 | 0.12 | 0.1178 | 0.1232 | 0.1224 | 0.1236 |
| Filter pap.+ sludge | 0.13 | 0.13 | 0.1314 | 0.1359 | 0.1358 | 0.1375 |
| Sludge wt (g) | 1.33 | 1.38 | 1.36 | 1.27 | 1.34 | 1.39 |
| Avg MLSS (g/l) | 1.355 | | 1.315 | | 1.365 | |

Shear Test :

| Added dose (meq/l | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (min) | | | | | | |
| 0 | 0.029 | 0.028 | 0.031 | 0.03 | 0.035 | 0.033 |
| 10 | 0.06 | 0.061 | 0.051 | 0.053 | 0.058 | 0.052 |
| 20 | 0.063 | 0.063 | 0.055 | 0.056 | 0.06 | 0.056 |
| 30 | 0.065 | 0.066 | 0.055 | 0.058 | 0.067 | 0.055 |
| 40 | 0.068 | 0.069 | 0.056 | 0.06 | 0.066 | 0.064 |
| 50 | 0.075 | 0.074 | 0.059 | 0.066 | 0.065 | 0.064 |
| 60 | 0.071 | 0.067 | 0.063 | 0.072 | 0.07 | 0.067 |

pH

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.57 | 7.57 | 7.55 | 7.5 | 7.6 | 7.56 |
| 60 min | 7.41 | 7.46 | 7.51 | 7.46 | 7.51 | 7.46 |

Conductivity (µs/cm)

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 980 | 1020 | 990 | 1001 | 984 | 976 |
| 60 min | 971 | 1496 | 1950 | 2501 | 1851 | 3651 |

## **Addition of Cu$^{2+}$**

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.117 | 0.122 | 0.1226 | 0.1238 | 0.1179 | 0.1185 |
| Filter pap.+ sludge wt | 0.131 | 0.135 | 0.1361 | 0.1376 | 0.1309 | 0.1311 |
| Sludge wt (g) | 1.37 | 1.28 | 1.35 | 1.38 | 1.3 | 1.26 |
| Avg MLSS (g/l) | 1.325 | | 1.365 | | 1.28 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.122 | 0.123 | 0.1178 | 0.1232 | 0.1224 | 0.1236 |
| Filter pap.+ sludge wt | 0.135 | 0.137 | 0.1314 | 0.1359 | 0.1358 | 0.1375 |
| Sludge wt (g) | 1.33 | 1.38 | 1.36 | 1.27 | 1.34 | 1.39 |
| Avg MLSS (g/l) | 1.355 | | 1.315 | | 1.365 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (min) | | | | | | |
| 0 | 0.025 | 0.024 | 0.03 | 0.039 | 0.04 | 0.035 |
| 10 | 0.034 | 0.099 | 0.102 | 0.095 | 0.085 | 0.069 |
| 20 | 0.068 | 0.119 | 0.125 | 0.124 | 0.131 | 0.135 |
| 30 | 0.048 | 0.13 | 0.141 | 0.146 | 0.136 | 0.145 |
| 40 | 0.054 | 0.133 | 0.151 | 0.159 | 0.162 | 0.167 |
| 50 | 0.075 | 0.143 | 0.155 | 0.165 | 0.171 | 0.18 |
| 60 | 0.079 | 0.145 | 0.158 | 0.166 | 0.18 | 0.201 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.57 | 7.56 | 7.45 | 7.51 | 7.45 | 7.48 |
| 60 min | 7.55 | 7.45 | 7.02 | 7.13 | 6.99 | 7.01 |

## Addition of $Zn^{2+}$

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.11 | 0.12 | 0.1226 | 0.1238 | 0.1179 | 0.1185 |
| Filter pap.+ sludge w | 0.13 | 0.13 | 0.1361 | 0.1376 | 0.1309 | 0.1311 |
| Sludge wt (g) | 1.37 | 1.28 | 1.35 | 1.38 | 1.3 | 1.26 |
| Avg MLSS (g/l) | 1.325 | | 1.365 | | 1.28 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.12 | 0.12 | 0.1178 | 0.1232 | 0.1224 | 0.1236 |
| Filter pap.+ sludge w | 0.13 | 0.13 | 0.1314 | 0.1359 | 0.1358 | 0.1375 |
| Sludge wt (g) | 1.33 | 1.38 | 1.36 | 1.27 | 1.34 | 1.39 |
| Avg MLSS (g/l) | 1.355 | | 1.315 | | 1.365 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (min) | | | | | | |
| 0 | 0.043 | 0.033 | 0.037 | 0.035 | 0.038 | 0.042 |
| 10 | 0.061 | 0.056 | 0.048 | 0.059 | 0.047 | 0.053 |
| 20 | 0.057 | 0.058 | 0.053 | 0.059 | 0.055 | 0.068 |
| 30 | 0.063 | 0.063 | 0.058 | 0.063 | 0.061 | 0.077 |
| 40 | 0.067 | 0.065 | 0.06 | 0.065 | 0.062 | 0.082 |
| 50 | 0.068 | 0.066 | 0.06 | 0.064 | 0.065 | 0.086 |
| 60 | 0.067 | 0.069 | 0.063 | 0.065 | 0.068 | 0.089 |

pH

| Added dose (meq/l | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.57 | 7.57 | 7.55 | 7.5 | 7.6 | 7.56 |
| 60 min | 7.41 | 7.46 | 7.51 | 7.46 | 7.51 | 7.46 |

## Addition of coupled ions

MLSS data:

| Added d | 0 | Na:Ca(5:5 | Na:Ca(5:10 | Na:Mg(5:1 | K:Ca(5:5) | K:Mg(5:1 | K:Ca(5:1 |
|---|---|---|---|---|---|---|---|
| Added v | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter pa | 0.11 | 0.1198 | 0.1245 | 0.119 | 0.1182 | 0.119 | 0.1198 |
| Filter+ s | 0.13 | 0.1384 | 0.1431 | 0.1381 | 0.137 | 0.1381 | 0.1388 |
| MLSS(g | 1.88 | 1.86 | 1.86 | 1.91 | 1.88 | 1.91 | 1.9 |
|  |  |  |  |  |  |  |  |

Shear Test:

| Added | 0 | Na:Ca(5: | Na:Ca(5:1 | Na:Mg(5:1 | K:Ca(5:5) | K:Mg(5:1 | K:Ca(5:1 |
|---|---|---|---|---|---|---|---|
| Turbidi | AB | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (r |  |  |  |  |  |  |  |
| 0 | 0.02 | 0.019 | 0.017 | 0.02 | 0.021 | 0.02 | 0.019 |
| 10 | 0.03 | 0.038 | 0.033 | 0.038 | 0.037 | 0.03 | 0.031 |
| 20 | 0.04 | 0.038 | 0.041 | 0.042 | 0.04 | 0.042 | 0.042 |
| 30 | 0.04 | 0.045 | 0.042 | 0.045 | 0.042 | 0.044 | 0.046 |
| 40 | 0.05 | 0.047 | 0.048 | 0.049 | 0.047 | 0.045 | 0.048 |
| 50 | 0.05 | 0.046 | 0.051 | 0.051 | 0.049 | 0.05 | 0.049 |
| 60 | 0.05 | 0.049 | 0.053 | 0.056 | 0.05 | 0.053 | 0.049 |

pH

| Added | 0 | Na:Ca(5: | Na:Ca(5:1 | Na:Mg(5:1 | K:Ca(5:5) | K:Mg(5:1 | K:Ca(5:10) |
|---|---|---|---|---|---|---|---|
| 0 min | 7.0 | 7.03 | 7.05 | 7.05 | 7.02 | 7.07 | 7.04 |
| 60 mir | 7.0 | 7.27 | 7.14 | 7.11 | 7.01 | 7.19 | 7.06 |

Conductivity (µs/cm)

| Addeddos (meq/l) | 0 | Na:Ca(5:5 | Na:Ca(5:10 | Na:Mg(5:1 | K:Ca(5:5) | K:Mg(5:1 | K:C (5:1 |
|---|---|---|---|---|---|---|---|
| 0 min | 620 | 622 | 615 | 629 | 613 | 620 | 621 |
| 60 min | 625 | 3200 | 4350 | 1700 | 1900 | 1300 | 280 |

## Addition of rain water

MLSS data:

| Added dose (meq/l) | 0 | | 25% rain water | |
|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | |
| Filter paper wt (g) | 0.1238 | 0.124 | 0.1269 | 0.124 |
| Filter pap.+ sludge wt (g) | 0.1431 | 0.1432 | 0.1452 | 0.146 |
| Sludge wt (g) | 1.93 | 1.92 | 1.83 | 2.2 |
| Avg MLSS (g/l) | 1.925 | | 2.015 | |

| Added dose (meq/l) | 50% rain water | | 75% rain water | |
|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | |
| Filter paper wt (g) | 0.1235 | 0.122 | 0.1262 | 0.1252 |
| Filter pap.+ sludge wt (g) | 0.1417 | 0.1408 | 0.1453 | 0.1448 |
| Sludge wt (g) | 1.82 | 1.88 | 1.91 | 1.96 |
| Avg MLSS (g/l) | 1.85 | | 1.935 | |

Shear Test :

| Added dose (meq/l) | 0 | 25% rain w | 50% rain w | 75% rain wate |
|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS |
| Time (min) | | | | |
| 0 | 0.039 | 0.03 | 0.041 | 0.048 |
| 10 | 0.043 | 0.051 | 0.05 | 0.054 |
| 20 | 0.05 | 0.057 | 0.059 | 0.061 |
| 30 | 0.05 | 0.059 | 0.06 | 0.064 |
| 40 | 0.058 | 0.061 | 0.064 | 0.064 |
| 50 | 0.058 | 0.064 | 0.07 | 0.07 |
| 60 | 0.064 | 0.065 | 0.072 | 0.074 |

pH

| Added dose (meq/l) | 0 | 25% rain w | 50% rain wa | 75% rain wat |
|---|---|---|---|---|
| 0 min | 7.05 | 7.21 | 7.1 | 7.11 |
| 60 min | 7.05 | 7.11 | 7.06 | 7.06 |

## Control test

MLSS data:

| Added dose (meq | 0 | Na+(5) | 0 | K+(5 | 0 | Ca++(5 | 0 | Mg++(5) |
|---|---|---|---|---|---|---|---|---|
| Added vol'm | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g | 0.1237 | 0.1193 | 0.1201 | 0.120 | 0.121 | 0.123 | 0.12 | 0.1228 |
| Filter+ sludge (g | 0.1397 | 0.1345 | 0.1356 | 0.137 | 0.136 | 0.1379 | 0.13 | 0.1389 |
| MLSS(g/l) | 1.6 | 1.52 | 1.55 | 1.62 | 1.51 | 1.49 | 1.5 | 1.61 |
| | | | | | | | | |

## Shear Test :

| Added | 0 | Na+(5) | 0 | K+(5) | 0 | Ca++(5) | 0 | Mg++(5) |
|---|---|---|---|---|---|---|---|---|
| Turbidi | ABS | ABS | ABS | ABS | ABS | ABS | ABS | ABS |
| Time (r | | | | | | | | |
| 0 | 0.022 | 0.02 | 0.017 | 0.02 | 0.023 | 0.022 | 0.02 | 0.024 |
| 10 | 0.028 | 0.031 | 0.029 | 0.031 | 0.033 | 0.03 | 0.033 | 0.035 |
| 20 | 0.035 | 0.032 | 0.035 | 0.035 | 0.038 | 0.032 | 0.039 | 0.037 |
| 30 | 0.041 | 0.035 | 0.038 | 0.039 | 0.04 | 0.037 | 0.04 | 0.041 |
| 40 | 0.047 | 0.036 | 0.043 | 0.042 | 0.042 | 0.045 | 0.045 | 0.044 |
| 50 | 0.053 | 0.04 | 0.051 | 0.046 | 0.047 | 0.046 | 0.051 | 0.048 |
| 60 | 0.057 | 0.046 | 0.053 | 0.049 | 0.056 | 0.049 | 0.052 | 0.052 |

Ph

| Added dos | 0 | Na+(5) | 0 | K+(5) | 0 | Ca++(5) | 0 | Mg++(5) |
|---|---|---|---|---|---|---|---|---|
| 0 min | 6.8 | 6.82 | 6.82 | 6.81 | 6.79 | 6.83 | 6.9 | 6.85 |
| 60 min | 6.8 | 7.27 | 6.85 | 7.25 | 6.8 | 7.2 | 6.88 | 7.19 |

Conductivity (µs/cm)

| Added dos | 0 | Na+(5) | 0 | K+(5) | 0 | Ca++(5) | 0 | Mg++(5) |
|---|---|---|---|---|---|---|---|---|
| 0 min | 778 | 780 | 781 | 780 | 783 | 775 | 785 | 779 |
| 60 min | 775 | 1802 | 790 | 1858 | 780 | 1829 | 780 | 1835 |

## (II) Reflocculation tests :( MLSS, supernatant turbidity, SSVI, SISV, pH and conductivity)

### Addition of $Na^+$

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1261 | 0.1234 | 0.1236 | 0.1236 | 0.1239 | 0.1233 |
| Filter pap.+ sludge wt ( | 0.1372 | 0.135 | 0.1349 | 0.1348 | 0.1352 | 0.1348 |
| Sludge wt (g) | 1.11 | 1.16 | 1.13 | 1.12 | 1.13 | 1.15 |
| Avg MLSS (g/l) | | | | | | |

Sludge settling data:

| Added | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | | | | | | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| 14 | 8.6 | 9 | 10.4 | 10 | 10.4 | 10.2 |
| 17 | 7.4 | 8.1 | 9.1 | 8.9 | 9.4 | 8.6 |
| 20 | 6.9 | 7.1 | 8.5 | 8 | 8.5 | 8.3 |
| 22 | 6.5 | 6.9 | 7.9 | 7.6 | 8 | 7.4 |
| 25 | 6 | 6.5 | 7.3 | 7 | 7.3 | 7 |
| 28 | 5.6 | 5.9 | 6.8 | | 7.3 | 6.4 |
| 30 | 5.6 | 5.9 | 6.5 | 6.2 | 7.1 | 6.3 |
| SSVI | 100.9009 | 101.7241 | 115.0442 | 110.7143 | 125.6637 | 109.5652 |
| SISV | 4.344 | 4.098 | 3.6394285 | 3.576 | 3.372 | 3.426 |

**Supernatant turbidity data:**

| Added dose | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Depth | | | | | | |
| 50 | 0.002 | 0.003 | 0.005 | 0.002 | 0.002 | 0.003 |
| 40 | 0.009 | 0.011 | 0.009 | 0.013 | 0.006 | 0.007 |
| 30 | 0.015 | 0.013 | 0.015 | 0.017 | 0.006 | 0.008 |
| 20 | 0.016 | 0.013 | 0.017 | 0.015 | 0.01 | 0.006 |
| 15 | 0.015 | 0.013 | 0.015 | 0.013 | 0.01 | 0.008 |

pH

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 6.99 | 6.98 | 6.97 | 6.99 | 6.98 | 6.97 |
| 60 min | 7.01 | 6.96 | 6.93 | 6.96 | 6.9 | 6.85 |

## **Addition of $K^+$**

MLSS data:

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1275 | 0.1272 | 0.1267 | 0.1267 | 0.127 | 0.126 |
| Filter pap.+ sludge wt ( | 0.1412 | 0.1405 | 0.1401 | 0.1402 | 0.1404 | 0.140 |
| Sludge wt (g) | **1.37** | **1.33** | **1.34** | **1.35** | **1.34** | **1.32** |
| Avg MLSS (g/l) | | | | | | |

Sludge settling data:

| Adde | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | | | | | | |
| 1 | 47 | 47 | 47 | 48.5 | 43 | 46.5 |
| 2 | 40 | 41 | 40 | 42.7 | 36 | 39.6 |
| 3 | 33 | 34 | 33 | 35 | 29 | 33 |
| 4 | 25.5 | 26 | 26 | 28.5 | 22 | 25 |
| 5 | 18 | 17.8 | 19.5 | 21 | 16.5 | 18.5 |
| 6 | 14.5 | 14.6 | 15.5 | 16.5 | 14 | 14.5 |
| 7 | 12.4 | 12.4 | 13.2 | 13.7 | 12 | 12.3 |
| 8 | 11.2 | 11.4 | 11.8 | 12 | 11.3 | 11.4 |
| 9 | 10 | 10.3 | 10.9 | 11.3 | 10.3 | 10.5 |
| 10 | 9.2 | 9.4 | 10 | 10 | 9.2 | 9.9 |
| 11 | 8.4 | 8.6 | 9.2 | 9.3 | 9 | 8.9 |
| 12 | 7.9 | 8 | 8.8 | 8.5 | 8.4 | 8.6 |
| 14 | 5.9 | 6.4 | 7.7 | 7.7 | 7.5 | 7.8 |
| 17 | 5.3 | 6.1 | 6.9 | 6.8 | 6.2 | 6.4 |
| 20 | 5.1 | 5.8 | 6.1 | 5.8 | 5.5 | 5.9 |
| 22 | 5 | 5.5 | 5.7 | 5.4 | 5 | 5.3 |
| 25 | 4.8 | 5 | 5.4 | 5.1 | 5 | 5 |
| 28 | 4.5 | 4.6 | 5 | 4.6 | 4.6 | 4.7 |
| 30 | 4.4 | 4.5 | 4.9 | 4.6 | 4.5 | 4.7 |
| SSVI | 64.233576 | 67.669172 | 73.134328 | 68.148148 | 67.16417 | 71.21212 |
| SISV | 4.41 | 4.86 | 4.11 | 4.26 | 4.2 | 4.38 |

Supernatant turbidity data:

| Added d | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidit | ABS | ABS | ABS | ABS | ABS | ABS |
| Depth | | | | | | |
| 50 | 0.011 | 0.007 | 0.009 | 0.011 | 0.009 | 0.012 |
| 40 | 0.025 | 0.02 | 0.019 | 0.02 | 0.018 | 0.018 |
| 30 | 0.033 | 0.02 | 0.019 | 0.019 | 0.02 | 0.021 |
| 20 | 0.026 | 0.02 | 0.02 | 0.02 | 0.023 | 0.026 |
| 15 | 0.029 | 0.027 | 0.021 | 0.02 | 0.025 | 0.027 |

pH

| Added dose (me | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.4 | 7.39 | 7.41 | 7.46 | 7.43 | 7.44 |
| 60 min | 7.47 | 7.49 | 7.43 | 7.44 | 7.4 | 7.41 |

## Addition of Ca$^{2+}$

MLSS data:

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1214 | 0.1203 | 0.1202 | 0.1188 | 0.1206 | 0.120 |
| Filter pap.+ sludge wt (g | 0.1378 | 0.1385 | 0.1395 | 0.1391 | 0.1382 | 0.139 |
| Sludge wt (g) | **1.64** | **1.82** | **1.93** | **2.03** | **1.76** | **1.93** |
| Avg MLSS (g/l) | | | | | | |

Sludge settling data:

| Added dos | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | | | | | | |
| 1 | 48.5 | 48.6 | 48 | 47.5 | 48.5 | 48.6 |
| 2 | 44.5 | 44 | 44.5 | 43.7 | 43.5 | 43.4 |
| 3 | 41 | 40.5 | 40 | 39.2 | 39.8 | 39 |
| 4 | 36.6 | 36 | 35 | 34.3 | 35 | 33.6 |
| 5 | 32.7 | 31.5 | 30.9 | 29.8 | 30 | 28.8 |
| 6 | 28.6 | 27.4 | 26.8 | 25.9 | 26 | 24.7 |
| 7 | 25.4 | 24.4 | 23.6 | 23 | 22.9 | 21.5 |
| 8 | 22.9 | 22 | 21.4 | 20.9 | 20.5 | 19 |
| 9 | 20.6 | 19.9 | 19.7 | 19 | 18.5 | 17.3 |
| 10 | 19 | 18.5 | 18 | 17.7 | 17.5 | 16 |
| 11 | 18 | 17 | 16.8 | 16.5 | 16.3 | 15 |
| 12 | 16.9 | 16 | 15.9 | 15.6 | 15.5 | 14.1 |
| 14 | 15 | 14.1 | 14.5 | 15.6 | 13.8 | 12.9 |
| 17 | 12.9 | 12.3 | 12.2 | 12 | 12.4 | 11.3 |
| 20 | 11.6 | 10.9 | 10.9 | 10.7 | 10.9 | 10 |
| 22 | 10.9 | 10 | 10.4 | 10 | 10.2 | 9 |
| 25 | 10 | 9.4 | 9.4 | 9.2 | 9 | 8.5 |
| 28 | 9.3 | 8.8 | 8.9 | 9 | | |
| 30 | 9 | 8.5 | 8.7 | 8.4 | 8.5 | 7.5 |
| SSVI | 109.7561 | 93.4065 | 90.15544 | 82.75862 | 96.59091 | 77.72021 |
| SISV | 2.466 | 2.532 | 2.748 | 2.82 | 2.94 | 3.06 |

Supernatant turbidity data:

| Added dos | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Depth | | | | | | |
| 50 | 0.017 | 0.014 | 0.02 | 0.019 | 0.038 | 0.033 |
| 40 | 0.019 | 0.014 | 0.024 | 0.02 | 0.04 | 0.034 |
| 30 | 0.023 | 0.016 | 0.024 | 0.024 | 0.039 | 0.036 |
| 20 | 0.026 | 0.017 | 0.025 | 0.024 | 0.039 | 0.039 |
| 15 | 0.028 | 0.018 | 0.026 | 0.026 | 0.04 | 0.042 |

pH

| Added dose (me | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 6.93 | 6.9 | 6.94 | 6.91 | 6.92 | 6.94 |
| 60 min | 6.94 | 6.75 | 6.8 | 6.78 | 6.77 | 6.75 |

## Addition of $Mg^{2+}$

MLSS data:

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1235 | 0.1201 | 0.1215 | 0.1227 | 0.1178 | 0.123 |
| Filter pap.+ sludge wt ( | 0.1366 | 0.1333 | 0.1342 | 0.1357 | 0.1312 | 0.135 |
| Sludge wt (g) | 1.31 | 1.32 | 1.27 | 1.3 | 1.34 | 1.28 |
| Avg MLSS (g/l) | | | | | | |

Sludge settling data:

| Added d | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | | | | | | |
| 1 | 48.5 | 49 | 47.5 | 48 | 47 | 46.9 |
| 2 | 45 | 45.2 | 44 | 44.1 | 42 | 42.3 |
| 3 | 40 | 40.5 | 39.4 | 39.5 | 36.6 | 37 |
| 4 | 35 | 34.1 | 34.8 | 34.6 | 31 | 31.8 |
| 5 | 30 | 29.5 | 29.4 | 29.5 | 26 | 26.4 |
| 6 | 25.5 | 24.8 | 25.5 | 25.7 | 22.4 | 22.8 |
| 7 | 22 | 21.5 | 22 | 22.4 | 19 | 19 |
| 8 | 19.9 | 19.1 | 19.8 | 20.3 | 16.8 | 16.6 |
| 9 | 18 | 17.5 | 18.3 | 18.8 | 15.8 | 15.8 |
| 10 | 17 | 16.2 | 17 | 17.4 | 14.9 | 14.9 |
| 11 | 15.9 | 15.4 | 16 | 16.4 | 14 | 14 |
| 12 | 15 | 14.6 | 14.9 | 15.2 | 13.4 | 13.2 |
| 14 | 13.5 | 13.4 | 13.3 | 14.1 | 12 | 12 |
| 17 | 11.7 | 11.9 | 12.1 | 12.9 | 10.8 | 10.6 |
| 20 | 10.5 | 10.7 | 10.9 | 11.4 | 10 | 9.5 |
| 28 | 8.7 | 9 | 9.7 | 10 | 9 | 8.5 |
| 30 | 9 | 8.6 | 8.9 | 9 | 8 | 7.8 |
| SSVI | 137.4046 | 130.303 | 140.1575 | 138.4615 | 119.403 | 121.875 |
| SISV | 3 | 3.102 | 3 | 3 | 3.18 | 3.18 |

Supernatant turbidity data:

| Added do | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS | ABS | ABS |
| Depth | | | | | | |
| 50 | 0.01 | 0.008 | 0.005 | 0.008 | 0.007 | 0.004 |
| 40 | 0.015 | 0.011 | 0.008 | 0.007 | 0.009 | 0.008 |
| 30 | 0.013 | 0.011 | 0.011 | 0.009 | 0.011 | 0.01 |
| 20 | 0.016 | 0.012 | 0.009 | 0.009 | 0.014 | 0.013 |
| 15 | 0.016 | 0.013 | 0.01 | 0.009 | 0.014 | 0.015 |

pH

| Added dose (meq | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 6.96 | 6.97 | 6.94 | 6.92 | 6.93 | 6.95 |
| 60 min | 6.93 | 6.55 | 6.49 | 6.47 | 6.38 | 6.35 |

## Addition of $Cu^{2+}$

MLSS data:

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1214 | 0.1203 | 0.1202 | 0.1188 | 0.1206 | 0.1201 |
| Filter pap.+ sludge wt ( | 0.1378 | 0.1385 | 0.1395 | 0.1391 | 0.1382 | 0.1394 |
| Sludge wt (g) | **1.64** | **1.82** | **1.93** | **2.03** | **1.76** | **1.93** |
| Avg MLSS (g/l) | | | | | | |

Sludge settling data:

| Added | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | | | | | | |
| 1 | 46.2 | 40 | 41 | 43.5 | 45 | 44 |
| 2 | 42 | 31 | 33 | 36 | 36 | 35.5 |
| 3 | 35 | 22 | 23.7 | 27 | 27 | 27.5 |
| 4 | 30 | 17.8 | 18.4 | 20.5 | 21 | 21.5 |
| 5 | 24 | 15 | 15 | 16.6 | 17.5 | 17.6 |
| 6 | 20 | 13 | 13.5 | 14 | 15 | 15.1 |
| 7 | 17.9 | 12 | 11.5 | 13 | 12.9 | 12.6 |
| 8 | 16 | 10.5 | 10.5 | 11.6 | 12.1 | 12 |
| 9 | 15 | 9.5 | 9.3 | 10 | 11.1 | 11 |
| 10 | 14 | 8.7 | 8.5 | 9.1 | 10 | 10 |
| 11 | 13 | 8.1 | 7.9 | 8.2 | 9.2 | 9 |
| 12 | 12.3 | 7.6 | 7 | 7.5 | 9 | 8.6 |
| 14 | 11 | 7.1 | 6.8 | 7 | 7.5 | 7.6 |
| 17 | 9.4 | 6.6 | 6.5 | 6.2 | 6.7 | 6.9 |
| 20 | 8.6 | 6 | 6.2 | 6 | 6 | 6.9 |
| 22 | 8 | 6 | 6.2 | 6 | 6 | 6.5 |
| 25 | 7.8 | 6 | 6.1 | 6 | 6 | 6.4 |
| 28 | 7 | 5.6 | 5.6 | 5.8 | 5.9 | 6.4 |
| 30 | 6.6 | 5.6 | 5.6 | 5.8 | 5.9 | 6.3 |
| SSVI | 80.4878 | 61.53846 | 58.03109 | 57.14286 | 67.04545 | 65.28497 |
| SISV | 3.54 | 5.4 | 5.19 | 4.95 | 5.4 | 4.95 |

Supernatant turbidity data:

| Added d | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidit | ABS | ABS | ABS | ABS | ABS | ABS |
| Depth | | | | | | |
| 50 | 0.01 | 0.065 | 0.071 | 0.073 | 0.077 | 0.082 |
| 40 | 0.015 | 0.067 | 0.075 | 0.075 | 0.077 | 0.085 |
| 30 | 0.019 | 0.073 | 0.076 | 0.075 | 0.088 | 0.088 |
| 20 | 0.019 | 0.072 | 0.08 | 0.08 | 0.087 | 0.099 |
| 15 | 0.019 | 0.077 | 0.08 | 0.08 | 0.087 | 0.099 |

pH

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 6.96 | 6.97 | 6.94 | 6.92 | 6.93 | 6.95 |
| 60 min | 6.93 | 5.77 | 5.38 | 5.47 | 5.4 | 5.41 |

## Addition of Zn$^{2+}$

MLSS data:

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | 10 | 10 | 10 | 10 | 10 |
| Filter paper wt (g) | 0.1194 | 0.124 | 0.1198 | 0.1192 | 0.1195 | 0.118 |
| Filter pap.+ sludge wt ( | 0.1367 | 0.1425 | 0.1387 | 0.1377 | 0.1376 | 0.137 |
| Sludge wt (g) | 1.73 | 1.85 | 1.89 | 1.85 | 1.81 | 1.9 |
| Avg MLSS (g/l) | | | | | | |

Sludge settling data:

| Added | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | | | | | | |
| 1 | 47 | 47.2 | 46.5 | 47.5 | 45.5 | 48 |
| 2 | 42.5 | 41 | 39.5 | 40.5 | 38 | 42 |
| 3 | 37 | 33.5 | 32 | 33 | 29.5 | 34.5 |
| 4 | 31.6 | 26 | 24.5 | 25.6 | 22.5 | 27 |
| 5 | 26.7 | 20.8 | 19.5 | 20 | 18.5 | 20.7 |
| 6 | 22.5 | 16.7 | 16.6 | 17 | 16 | 17.8 |
| 7 | 20 | 15.6 | 14.8 | 15.1 | 13.9 | 15.8 |
| 8 | 17.8 | 13.8 | 12.5 | 13 | 13 | 14 |
| 9 | 16.5 | 12.5 | 12 | 12.2 | 12 | 13 |
| 10 | 15 | 11.5 | 11 | 11 | 11 | 11.8 |
| 11 | 14.2 | 10.8 | 9.8 | 10.4 | 10 | 10.9 |
| 12 | 13.5 | 10 | 9.5 | 10 | 9.5 | 10.2 |
| 14 | 11.9 | 9 | 8.3 | 8.9 | 8.5 | 9 |
| 17 | 10.5 | 7.9 | 7 | 7.8 | 7 | 8.2 |
| 20 | 9 | 7 | 6.5 | 6.8 | 6.6 | 7.2 |
| 22 | 8.9 | 6 | 6.1 | 6.5 | 6 | 6.8 |
| 25 | 7.6 | 6 | 5.9 | 6.2 | 6 | 6.3 |
| 28 | 7 | 5.9 | 5.6 | 6 | 5.8 | 6.2 |
| 30 | 7 | 5.9 | 5.6 | 6 | 6 | 6 |
| SSVI | 80.92486 | 63.78378 | 59.25926 | 64.86486 | 66.29834 | 63.15789 |
| SISV | 3.168 | 4.5 | 4.5 | 4.47 | 4.65 | 4.23 |

Supernatant turbidity data:

| Added d | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Turbidit | ABS | ABS | ABS | ABS | ABS | ABS |
| Depth | | | | | | |
| 50 | 0.016 | 0.067 | 0.052 | 0.059 | 0.079 | 0.094 |
| 40 | 0.017 | 0.071 | 0.062 | 0.068 | 0.088 | 0.096 |
| 30 | 0.021 | 0.071 | 0.066 | 0.072 | 0.087 | 0.097 |
| 20 | 0.021 | 0.082 | 0.07 | 0.083 | 0.089 | 0.103 |
| 15 | 0.024 | 0.086 | 0.07 | 0.082 | 0.091 | 0.104 |

pH

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | | 6.97 | 6.94 | 6.92 | 6.98 | 6.9 |
| 60 min | 6.94 | 5.8 | 5.45 | 5.6 | 5.55 | 5.57 |

## Addition of rain water

MLSS data

| Added rain water (volume %) | 0 | | 25% | |
|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | |
| Filter paper wt (g) | 0.1238 | 0.124 | 0.1269 | 0.124 |
| Filter pap.+ sludge wt (g) | 0.1431 | 0.1432 | 0.1452 | 0.146 |
| Sludge wt (g) | 1.93 | 1.92 | 1.83 | 2.2 |
| Avg MLSS (g/l) | 1.925 | | **2.015** | |

| Added rain water (volume %) | 50% | | 75% | |
|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | |
| Filter paper wt (g) | 0.1235 | 0.122 | 0.1262 | 0.1252 |
| Filter pap.+ sludge wt (g) | 0.1417 | 0.1408 | 0.1453 | 0.1448 |
| Sludge wt (g) | 1.82 | 1.88 | 1.91 | 1.96 |
| Avg MLSS (g/l) | **1.85** | | 1.935 | |

Sludge settling data:

| Added rain water (volume %) | 0 | 25% | 50% | 75% |
|---|---|---|---|---|
| Time | | | | |
| 1 | 48.5 | 48 | 48.1 | 48.6 |
| 2 | 46 | 45.6 | 46 | 46.5 |
| 3 | 40.7 | 43.5 | 44 | 39.5 |
| 4 | 36.1 | 40.5 | 41.3 | 37.3 |
| 5 | 33.5 | 37 | 38.3 | 35 |
| 6 | 32.01 | 34 | 35.5 | 34.02 |
| 7 | 30 | 31 | 32.8 | 32 |
| 8 | 28 | 28.2 | 30 | 30 |
| 9 | 26 | 26.5 | 28 | 27.9 |
| 10 | 24.4 | 24.4 | 25.8 | 25.2 |
| 11 | | | | |
| 12 | | | | |
| 15 | 18 | 17.1 | 18 | 19.8 |
| 17 | | | | |
| 20 | 15.8 | 15.1 | 16 | 17.2 |
| 22 | | | | |
| 25 | 13.9 | 13 | 13.9 | 15 |
| 28 | | | | |

|  |  |  |  |  |
|---|---|---|---|---|
| 30 | 12.5 | 12.02 | 13 | 13 |
| SSVI | 131.5789 | 122.9668 | 141.3043 | 136.1257 |
| SISV | 1.862914 | 1.729286 | 1.692 | 1.564114 |

Supernatant turbidity data:

| Added rain water (volume %) | 0 | 25% | 50% | 75% |
|---|---|---|---|---|
| Turbidity | ABS | ABS | ABS | ABS |
| Depth |  |  |  |  |
| 50 | 0.015 | 0.02 | 0.019 | 0.018 |
| 40 | 0.018 | 0.022 | 0.019 | 0.024 |
| 30 | 0.018 | 0.022 | 0.022 | 0.026 |
| 20 | 0.021 | 0.023 | 0.026 | 0.035 |
| 15 | 0.021 | 0.025 | 0.028 | 0.035 |

## (III) Dewaterability tests : ( MLSS, CST, pH and conductivity)

### Addition of $Na^+$

MLSS data

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.122 | 0.124 | 0.1257 | 0.1246 | 0.1231 | 0.124 |
| Filter pap.+ sludge w | 0.166 | 0.168 | 0.1748 | 0.174 | 0.1769 | 0.1777 |
| Sludge wt (g) | 4.45 | 4.43 | 4.91 | 4.94 | 5.38 | 5.37 |
| Avg MLSS (g/l) | 4.44 | | 4.925 | | 5.375 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.122 | 0.125 | 0.1258 | 0.126 | 0.1249 | 0.1271 |
| Filter pap.+ sludge w | 0.166 | 0.169 | 0.1718 | 0.1719 | 0.1742 | 0.1739 |
| Sludge wt (g) | 4.47 | 4.46 | 4.6 | 4.59 | 4.93 | 4.68 |
| Avg MLSS (g/l) | 4.44 | | 4.925 | | 4.805 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | Sec | Sec | Sec | Sec | Sec | Sec |
| Test No. | | | | | | |
| 1 | 40.31 | 36.94 | 27.53 | 29.54 | 32.53 | 37.34 |
| 2 | 41.03 | 26.6 | 35.62 | 30.42 | 36.44 | 39.03 |
| 3 | 35.43 | 33.81 | 33.53 | 29.88 | 36.71 | 33.84 |
| 4 | 37.5 | 28.84 | 34.75 | 33.25 | 38.72 | 35 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.21 | 7.2 | 7.22 | 7.21 | 7.2 | 7.18 |
| 60 min | 7.23 | 7.16 | 7.18 | 7.19 | 7.16 | 7.12 |

## **Addition of K$^+$**

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.126 | 0.124 | 0.1235 | 0.1274 | 0.125 | 0.126 |
| Filter pap.+ sludge v | 0.193 | 0.193 | 0.1891 | 0.1931 | 0.1906 | 0.1929 |
| Sludge wt (g) | 6.73 | 6.86 | 6.56 | 6.57 | 6.56 | 6.69 |
| Avg MLSS (g/l) | 6.795 | | 6.565 | | 6.625 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.127 | 0.123 | 0.1286 | 0.123 | 0.1239 | 0.1246 |
| Filter pap.+ sludge w | 0.196 | 0.192 | 0.1977 | 0.1927 | 0.1902 | 0.1906 |
| Sludge wt (g) | 6.89 | 6.85 | 6.91 | 6.97 | 6.63 | 6.6 |
| Avg MLSS (g/l) | 6.87 | | 6.94 | | 6.615 | |

Shear Test :

| Added dose (meq/l | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | Sec | Sec | Sec | Sec | Sec | Sec |
| Test No. | | | | | | |
| 1 | 38.22 | 39.47 | 36.34 | 41.38 | 39.34 | 48 |
| 2 | 38.82 | 35.41 | 36.4 | 38.63 | 43.93 | 45.5 |
| 3 | 32.25 | 31.02 | 34.69 | 47.91 | 48.84 | 38.69 |
| 4 | 34.09 | 35.26 | 37.8 | 43.21 | 41.32 | 43.11 |

pH

| Added dose (meq | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.17 | 7.16 | 7.15 | 7.15 | 7.17 | 7.1 |
| 60 min | 7.17 | 7.2 | 7.38 | 7.31 | 7.2 | 7.1 |

Conductivity (μs/cm)

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 709 | 753 | 801 | 811 | 701 | 782 |
| 60 min | 712 | 1356 | 1707 | 2500 | 3000 | 330 |

## Addition of $Ca^{2+}$

MLSS data

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.125 | 0.125 | 0.1226 | 0.122 | 0.124 | 0.1245 |
| Filter pap.+ sludge w | 0.179 | 0.179 | 0.1808 | 0.18 | 0.1816 | 0.1818 |
| Sludge wt (g) | 5.4 | 5.38 | 5.82 | 5.8 | 5.76 | 5.73 |
| Avg MLSS (g/l) | 5.39 | | 5.81 | | 5.745 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.123 | 0.125 | 0.1222 | 0.1235 | 0.1265 | 0.125 |
| Filter pap.+ sludge wt | 0.181 | 0.182 | 0.1805 | 0.1815 | 0.183 | 0.184 |
| Sludge wt (g) | 5.82 | 5.79 | 5.83 | 5.8 | 5.65 | 5.9 |
| Avg MLSS (g/l) | 5.805 | | 5.815 | | 5.775 | |

Shear Test :

| Added dose (meq/l | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | Sec | Sec | Sec | Sec | Sec | Sec |
| Test No. | | | | | | |
| 1 | 38.4 | 43.29 | 47.96 | 51.37 | 46.4 | 51.32 |
| 2 | 38.35 | 41.38 | 48.65 | 56.13 | 50.97 | 51.29 |
| 3 | 38.28 | 44.44 | 52.46 | 53.06 | 47.07 | 43.94 |
| 4 | 39.78 | 39.01 | 48.97 | 48.28 | 49.58 | 48.3 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.21 | 7.2 | 7.22 | 7.21 | 7.2 | 7.18 |
| 60 min | 7.04 | 7.01 | 7.01 | 6.99 | 7.05 | 7.03 |

Conductivity (µs/cm)

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 768 | 801 | 750 | 772 | 758 | 802 |
| 60 min | 1347 | 1347 | 2300 | 2900 | 3500 | 4200 |

## Addition of $Mg^{2+}$

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.121 | 0.123 | 0.1235 | 0.1233 | 0.124 | 0.1248 |
| Filter pap.+ sludge w | 0.162 | 0.161 | 0.1611 | 0.1605 | 0.1609 | 0.1614 |
| Sludge wt (g) | 8.1 | 7.68 | 7.52 | 7.44 | 7.38 | 7.32 |
| Avg MLSS (g/l) | 7.89 | | 7.48 | | 7.35 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.123 | 0.122 | 0.121 | 0.123 | 0.123 | 0.1261 |
| Filter pap.+ sludge v | 0.162 | 0.162 | 0.1595 | 0.161 | 0.1601 | 0.164 |
| Sludge wt (g) | 7.78 | 7.9 | 7.7 | 7.6 | 7.42 | 7.58 |
| Avg MLSS (g/l) | 7.84 | | 7.65 | | 7.5 | |

Shear Test :

| Added dose (meq/l | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | Sec | Sec | Sec | Sec | Sec | Sec |
| Test No. | | | | | | |
| 1 | 46.65 | 39.59 | 40.44 | 37.5 | 43.84 | 40.75 |
| 2 | 40.12 | 42.91 | 40.69 | 43.97 | 41.03 | 39.8 |
| 3 | 45.4 | 40.08 | 34.48 | 42.08 | 45.81 | 40.12 |
| 4 | 39.08 | 40.5 | 38.09 | 39.59 | 30.72 | 38.65 |

pH

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 7.02 | 7.1 | 7.15 | 7.15 | 7.18 | 7.15 |
| 60 min | 7.08 | 7.08 | 7.13 | 7.14 | 7.14 | 7.13 |

Conductivity (µs/cm)

| Added dose (meq/ | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 900 | 896 | 876 | 895 | 880 | 850 |
| 60 min | 842 | 1398 | 2000 | 2398 | 2836 | 3200 |

## Addition of $Cu^{2+}$

MLSS data

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.126 | 0.125 | 0.1267 | 0.121 | 0.128 | 0.1291 |
| Filter pap.+ sludge w | 0.195 | 0.195 | 0.2001 | 0.193 | 0.1973 | 0.1982 |
| Sludge wt (g) | 6.98 | 7.01 | 7.34 | 7.2 | 6.93 | 6.91 |
| Avg MLSS (g/l) | 6.995 | | 7.27 | | 6.92 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.127 | 0.125 | 0.1236 | 0.1258 | 0.1246 | 0.1233 |
| Filter pap.+ sludge w | 0.196 | 0.194 | 0.1922 | 0.195 | 0.1947 | 0.1937 |
| Sludge wt (g) | 6.85 | 6.89 | 6.86 | 6.92 | 7.01 | 7.04 |
| Avg MLSS (g/l) | 6.87 | | 6.89 | | 7.025 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | Sec | Sec | Sec | Sec | Sec | Sec |
| Test No. | | | | | | |
| 1 | 37.56 | 35.15 | 37.4 | 35.03 | 34.19 | 32.37 |
| 2 | 40.85 | 40.23 | 31.8 | 35.69 | 31.59 | 31.03 |
| 3 | 39.51 | 38.01 | 41.32 | 33.23 | 40.12 | 34.81 |
| 4 | 40.1 | 37.23 | 35.46 | 30.58 | 31.88 | 33.13 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 6.83 | 6.83 | 6.81 | 6.83 | 6.84 | 6.83 |
| 60 min | 6.82 | 6.02 | 5.73 | 5.61 | 5.62 | 5.47 |

Conductivity (µs/cm)

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 800 | 788 | 812 | 799 | 815 | 830 |
| 60 min | 800 | 1400 | 1700 | 1900 | 2241 | 2500 |

## **Addition of $Zn^{2+}$**

MLSS data:

| Added dose (meq/l) | 0 | | 5 | | 10 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | 10 | | 10 | | 10 | |
| Filter paper wt (g) | 0.127 | 0.126 | 0.1223 | 0.1235 | 0.1266 | 0.125 |
| Filter pap.+ sludge w | 0.196 | 0.195 | 0.1913 | 0.1927 | 0.1924 | 0.1904 |
| Sludge wt (g) | 6.94 | 6.89 | 6.9 | 6.92 | 6.58 | 6.54 |
| Avg MLSS (g/l) | 6.915 | | 6.91 | | 6.56 | |

| Added dose (meq/l) | 15 | | 20 | | 25 | |
|---|---|---|---|---|---|---|
| Sample volume(ml) | | | | | | |
| Filter paper wt (g) | 0.127 | 0.128 | 0.1228 | 0.1249 | 0.127 | 0.1241 |
| Filter pap.+ sludge v | 0.193 | 0.194 | 0.1901 | 0.1916 | 0.1937 | 0.1902 |
| Sludge wt (g) | 6.63 | 6.59 | 6.73 | 6.67 | 6.67 | 6.61 |
| Avg MLSS (g/l) | 6.61 | | 6.7 | | 6.64 | |

Shear Test :

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| Time | Sec | Sec | Sec | Sec | Sec | Sec |
| Test No. | | | | | | |
| 1 | 36.94 | 34.99 | 45.19 | 42.32 | 42.25 | 41.25 |
| 2 | 39.88 | 41.1 | 37.01 | 43.22 | 40.23 | 45.81 |
| 3 | 39.41 | 36.92 | 39.11 | 43.03 | 38.11 | 42.97 |
| 4 | 41 | 38.01 | 41.21 | 40.43 | 42.2 | 40.08 |

pH

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 6.75 | 6.75 | 6.77 | 6.76 | 6.77 | 6.77 |
| 60 min | 6.74 | 6.7 | 6.52 | 6.44 | 6.4 | 6.37 |

Conductivity (µs/cm)

| Added dose (meq/l) | 0 | 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|---|
| 0 min | 788 | 788 | 780 | 799 | 775 | 770 |
| 60 min | 775 | 1200 | 1600 | 2100 | 2600 | 2900 |