DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

IMPROVING OF DEWATERING CAPACITY OF AEROBIC AND ANAEROBIC STABILIZED SLUDGES

by
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September, 2005
İZMİR

IMPROVING OF DEWATERING CAPACITY OF AEROBIC AND ANAEROBIC STABILIZED SLUDGES

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by
Elif GÖKNİL

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"IMPROVING OF DEWATERING CAPACITY OF AEROBIC AND ANAEROBIC STABILIZED SLUDGES"** completed by **Elif GÖKNİL** under supervision of **Prof. Dr. Ayşe FİLİBELİ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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IMPROVING OF DEWATERING CAPACITY OF AEROBIC AND ANAEROBIC STABILIZED SLUDGES

ABSTRACT

Sludge is one of the constituents removed in wastewater treatment plants and persists to be a major problem in various operations in wastewater treatment because its largest volume, complexer processing and the disposal problem according to the other constituents removed by treatment. Sludge dewatering is preceded by a conditioning process to enhance water removal efficiency. In the conditioning process, chemical coagulants or polymers are added to promote sludge particle aggregation for easier dewatering.

In this study, dewaterability of aerobic and anaerobic stabilized sludges was extensively investigated. The experimental studies were carried out using aerobic stabilized sludge samples taken from Manisa Organised Industrial District Wastewater Treatment Plant and anaerobic stabilized sludge samples taken from Pakmaya/Kemalpaşa.

To determine the sludge characteristics, parameters as pH, electrical conductivity, sludge volume index (SVI), capillary suction time (CST), specific resistance to filtration (SRF), suspended solids content, dry solids content, organic matter, and turbidity were analyzed on both aerobic and anaerobic stabilized raw sludge samples.

Sludge samples were conditioned separately with alum ($Al_2(SO_4)_3.18H_2O$) and different amounts of polyelectrolytes such as cationic polyelectrolyte (KWD 3500, SNF 5980, 5980 SB), anionic polyelectrolyte (KWD A-0055) and nonionic polyelectrolyte (KWD-20LT) to investigate their dewatering capacity of each type of sludges. After this experiment, alum ($Al_2(SO_4)_3.18H_2O$) was used as additive conditioner before and after polyelectrolyte addition to investigate the dewatering capacity of sludge.

To determine dewatering capacity of conditioned sludge samples, parameters like supernatant turbidity, dry solids content and turbidity of centrate and filtrate, specific resistance to filtration, centrifugal settleability index (CSI), specific resistance to filtration (SRF), capillary suction time (CST), suspended solids concentration, organic matter, dry solids content of cake were tested.

Keywords: Aerobic stabilized sludge, anaerobic stabilized sludge, conditioning, dewatering, centrifugal settleability index (CSI), specific resistance to filtration (SRF), capillary suction time (CST), polyelectrolyte.

AEROBİK VE ANAEROBİK STABİLİZE ÇAMURUN SUSUZLAŞTIRMA KAPASİTESİNİN GELİŞTİRİLMESİ

ÖZ

Çamur, atıksu arıtma tesislerinin çıktılarından birisi olup, diğer çıktılara göre büyük hacim kaplaması, işlenmesi ve bertaraf edilmesi için kompleks işlemler gerektirmesi dolayısıyla, atıksu arıtma tesislerinde karşılaşılan en büyük problemlerden biridir. Çamur susuzlaştırma ünitelerinin verimini arttırmak için, bu ünitelerden önce çamur şartlandırma işlemi uygulanmaktadır. Şartlandırma işlemi, daha kolay susuzlaşmanın gerçekleşmesi için koagulantların ve polimerlerin eklenmesiyle partiküllerin bir araya gelmesini sağlayarak gerçekleşir.

Bu çalışmada aerobik ve anaerobik stabilize çamurların susuzlaştırılabilirliği araştırılmıştır. Deneysel çalışmalarda kullanılan aerobik stabilize çamur numuneleri Manisa Organize Sanayi Bölgesi Atıksu Arıtma Tesisi'nden, anaerobik stabilize çamur numuneleri Pakmaya/Kemalpaşa Atıksu Arıtma Tesisi'nden alınmıştır.

Aerobik ve anaerobik stabilize ham çamur numunelerinde, pH, elektriksel iletkenlik, çamur hacim indeksi, kapiler emme süresi, özgül filtre direnci, santrifüj çökebilirlik indeksi, askıda katı madde, toplam katı madde, organik madde ve bulanıklık gibi parametreler analizlenmiştir.

Her iki tipteki çamurun susuzlaştırma kapasitesini görebilmek için çamur numuneleri katyonik polielektrolit (KWD 3500, SNF 5980, 5980 SB), anyonik polielektrolit (KWD A-0055), ve noniyonik polielektrolit (KWD-20LT) gibi farklı polielektrolitlerle; ve alum ($Al_2(SO_4)_3.18H_2O$) ile ayrı ayrı şartlandırılmıştır. Alüm, polielektrolit ilavesinden önce ve sonra yardımcı şartlandırıcı olarak da kullanılarak susuzlaştırmaya etkisi gözlemlenmiştir.

Şartlandırma işlemi sonrasında, üst su bulanıklığı, santrifüj üst suyunda ve filtrasyon alt suyunda bulanıklık ve askıda katı maddesi, özgül filtre direnci, santrifüj çökebilirlik indeksi, kapiler emme süresi, askıda katı madde, organik madde, toplam katı madde ve kek katı maddesi parametreleri analizlenerek kullanılan şartlandırıcıların çamurun susuzlaştırma kapasitesi üzerindeki etkisi incelenmiştir.

Anahtar kelimeler: Aerobik stabilize çamur, anaerobik stabilize çamur, şartlandırma, susuzlaştırma, santrifüj çökelebilirlik indeksi, özgül filtre direnci, kapiler emme süresi, polielektrolit.

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CHAPTER ONE
INTRODUCTION

Sludge is one of the constituents removed in wastewater treatment plants and Lee et al. expressed as a major problem in various operations in wastewater treatment because its largest volume, complexer processing and the disposal problem according to the other constituents removed by treatment. For this reason, dewatering capacity of different type of sludges is investigated in this study. The sludge resulting from wastewater treatment operations and processes is defined by Tchobanoglous as: usually in the form of a liquid or semisolid liquid that typically contains from 0,25 to 12 percent solids by weight, depending on the operations and processes used. (Lee et al. 2000, p.4430, Tchobanoglous, 1995, 3rd ed.).

The main process in sludge treatment is the water removal. Basic parameters in process design and operation is the characterization, dewaterability and volume of the sludge. The specific resistance to filtration (SRF) parameter has been widely used to evaluate sludge dewaterability. The capillary suction time (CST) apparatus has been used for a quick determination of filterability.

The purpose of both the SRF and CST tests is to see the evaluation of sludge dewaterability. Using SRF or CST vs. dosage curves, the optimal dose of a sludge conditioner (defined as the dosage that yields minimal resistance to filtration) can be estimated. However, the effect of particle sedimentation on the determination of the optimal dose has not yet been properly addressed. Sedimentation effects may became more apparent when conditioning close to the optimal dose, since the flocs produced will be large and will settle easily.

Sludge dewatering is preceded by a conditioning operation to enhance water removal efficiency. In the conditioning operation, chemical coagulants or polymers are added to promote sludge particle aggregation for easier dewatering. In this study, dewaterability of aerobic and anaerobic stabilized sludges was extensively investigated.

CHAPTER TWO

SLUDGE CONDITIONING

2.1 General Consideration

The conditioning of sludge involves pretreatment in order to facilitate water removal during subsequent thickening and/or dewatering operations. During the conditioning process small and amorphous gel like particles are transformed into larger and stronger aggregates, thereby increasing the rate and/or extend of water drainage and solid separation. Separation of sludge components either by filtration, centrifugation, etc. can be enhanced by mixing additives to the sludge and/or by subjecting these solids to specific chemical and physical processes.

Dentel, et al., (2005) indicated that in the classical representation of sludge, the particles in sludge have often been conceptualized as rigid and uniform spheres; and added that coagulation and flocculation in water treatment and conditioning in sludge treatment could be explained with this traditional approach. *In water and wastewater treatment, conditioning may be applied with polymers (generally cationic) and inorganic conditioners such as ferric chloride. Charge neutralization plays a crucial role in conditioning. Polymers also have an important conditioning advantage called "bridging effect"* (Dentel et al., 2005, p 78).

Only recent has the impact of the selected sludge-handling system on total wastewater treatment plant performance and economics been realized. Methods of sludge thickening, dewatering including conditioning techniques, can significantly affect preceding and succeeding unit operations, particularly with respect to the liquid treatment portion of the plant (Eckenfelder & Santhanam, 1981, pp. 66-67).

"Sludge is conditioned expressly to improve its dewatering characteristics" (Metcalf & Eddy, 1995, p.850). *Sludge conditioning is an essential component of sludge management and can represent a significant proportion of the costs. Where*

conditioning agents are used, it is desirable, for both financial reasons and arising from the potential impact of residuals in the environment (e.g. monoacrylamide), that the conditioning agents are used with maximum efficiency (Papavasilopoulos et al., 1998, p.3173).

"Polymers are used for sludge conditioning to improve sludge dewaterability" (Abu-Orf & Dentel,1997). "Sludge conditioned with a polymer generates less solid cake after sludge dewatering because of the lower dosage required as compared to the addition of fly ash and inorganic chemicals. The cost of the polymer accounts for almost half of the overall sludge dewatering and disposal costs" (Chitikela & Dentel, 1998). "Effective sludge conditioning is thus important in sludge dewatering" (Lee et al., 2001, p.129).

"Many factors affect sludge conditioning, which is an important step prior to dewatering of sludges. These factors may broadly be categorized as physical, chemical, and biological, and are discussed as follows"(Lue-Hing, et al., 1992, p.247).

2.2 Factors Affecting Sludge Conditioning

2.2.1 Physical Factors Influencing Sludge Conditioning

Perhaps the single most significant factor that influences sludge conditioning is the particle size distribution of the sludge suspended solids. As the particle size decreases, the surface area of the suspended solids mass increases. This mean greater hydration and increased resistance of the suspended solids conditioning, which is intended to aid in the release of bound water and aggregation of suspended solids.

Any processes that reduce the size of the suspended sludge particles will have a negative effect on conditioning, since it will increase the degree of conditioning required and/or limit the effect produced. Pumping of sludge, for example, subjects

the sludge suspended material to shear forces and thus reduces the size of sludge particles. The level of shear stress imparted on sludge suspended solids is a function of the type of pump used, flow rate, and the geometry of the piping network used for the transport of sludge. Shear stress, which causes particle size reduction, is also imparted by mixing and agitation of the sludge, and, is a function of the intensity of turbulence created by the mixing equipment used. Sludge storage and aging also have a negative effect on conditioning of sludge, although it is not a severe. These issues concerning the effect of shear stress on particle size are of even more significant after sludge conditioning is achieved by chemicals, as different chemicals may produce flocs of varying floc strength or fragility. Obviously, sludges containing flocs that are more fragile will dewater poorly in comparison to sludges having flocs that are less fragile.

Sludge origins and the nature of the solids matrix from a certain unit process also influence sludge conditioning. For example, primary sludge requires less conditioning than secondary sludge (e.g. waste activated sludge). Primary and secondary sludges from biological wastewater treatment plants usually require cationic polymer conditioning while chemical sludges often require anionic polymer conditioning.

The degree of mixing in the preparation of solutions of organic conditioning agents is an important factor because high-speed mixing tends to cut or fracture long polymer chains into shorter, less effective fragments. A proper degree of mixing is needed to achieve solution blending. Excessive mixing, however, results in polymer degradation. Another major factor is the degree of mixing required to distribute chemical conditioners in the sludge. The intensity of mixing must be such that it provides uniform dispersal of the conditioning agent throughout the sludge, which allows for good floc formation. However, it should not be excessive to destroy the flocs that are formed. The degree and/or the intensity of mixing is related to the viscosity of the chemical conditioner solution and the suspended solids concentration of the sludge. As these two factors increase, it becomes more difficult

to achieve effective dispersal of the conditioner in the sludge (Lue-Hing, et al., 1992, pp. 247-248)

2.2.2 Chemical Factors Influencing Sludge Conditioning

The alkalinity and pH of sludge are perhaps the most important of the chemical factors influencing its conditioning. The charge densities on the surface of the suspended sludge particles and on a conditioning agent are functions of pH. Both of these charge densities affect the surface chemistry of particles involved in conditioning, depending on the sludge type and conditioner. The pH of sludge also governs the ionization state of other chemical species in the sludge. The charge type and geometry of these species, the degree of particle hydration, and the nature of the bound water matrix may in turn influence the dewaterability of sludges. Thus, pH determines the floc structure and affects its properties. Organic conditioners tend to be effective over a broader pH range than inorganic conditioners. However, the effect of pH may also be specific to a given situation and is difficult to generalize.

Alkalinity is an important sludge property that modifies conditioning requirements and the pH of sludge affects alkalinity. High alkalinities tend to have detrimental effects on the performance of both inorganic and organic conditioning agents and tend to increase the dosage requirements of a conditioning agent. Also, a high ionic strength of the sludge liquid phase and of the makeup water tends to have a detrimental effect on floc stability, conditioning agent performance, and dosage requirements of both inorganic and organic conditioners. Moreover, some species of dissolved organic salts that are balanced in anion and cation charge (e.g., NaCl, $CaSO_4$) impair conditioning by reducing zeta potential toward zero. Thus, a high concentration of such dissolved materials tends to multify the effectiveness of conditioners that utilize charge as their principal mechanism of floc formation. Some organic acids also inhibit conditioning. Fulvic acid and humic acid, for example, impair floc formation with both organic and inorganic conditioning agents (Lue-Hing, et al., 1992, pp248-250).

The concentration of the sludge suspended solids is an important factor the increases the dosage of as conditioner in proportion to the suspended solids concentration

The ash or fixed solids content of sludge affects the charge type of the conditioner that is effective with a given sludge. In general, sludges with fixed solids less than 50% require cationic conditioners while sludges with fixed solids greater than 50% require anionic or nonionic conditioners (Lue-Hing, et al., 1992, pp248-250).

The charge density and molecular weight of a conditioning agent govern its performance. In general, as the charge density and molecular weight of a conditioning agent increase, so does its effectiveness in forming good flocs. However, it will be progressively more difficult to prepare solutions of conditioning agents as their molecular weight and charge density increase. The charge density is associated with the neutralization of repellent electrical forces, which inhibit floc formation. The molecular weight (i.e., length of molecular chain) is associated with particle bridging that results in floc formation. The charge type of the conditioner is also a factor and the demand for the conditioner is related to the effective particle charge in the sludge(Lue-Hing, et al., 1992, pp248-250).

The concentration of a conditioning agent is an important factor in the dewatering of sludges and is related to the viscosity of its solution. The concentration and dose of a conditioning agent must be sufficient to meet the requirement for sludge conditioning within a given flow and pumping rate of the sludge and conditioning agent, and yet not so concentrated that the viscosity of the solution hinders its effective distribution in the sludge. Water used for diluting the conditioner may often be applied close to the mixing point of the sludge and conditioner, in order to obtain effective distribution of the conditioner.

Organic conditioning agents, in addition to being fragile and difficult to mix into solution, also require a specific waiting period (aging time) in order to activate fully

in the diluted state. Initially, long-chain polymers are coiled and ineffective for conditioning. In solution, a waiting period (aging) allows the coils to unwind and expose the many charged sites along each molecule. Thus, the conditioning agents become more effective during the electrokinetic and bridging mechanisms of floc formation. Low molecular weight polymers may only require a few seconds to activate while high molecular weight polymers may require as much as an hour to activate. Dilute organic polymer solutions, however, begin to deteriorate in performance after several hours. Mannich type polymers are the most rapid in their degradation rate in comparison to emulsion or other powder type of polymers (Lue-Hing, et al., 1992, pp248-250).

2.2.3 Biological Factors Influencing Sludge Conditioning

The biological solids content of sludge is a significant factor in influencing conditioning. In general, biological sludges have different conditioning requirements than chemical sludges. Processed biological sludges have different conditioning requirements than raw and primary sludges. Anaerobically digested sludges tend to have lower requirements for charge neutralization than the raw sludges from which they are derived, and hence can be dewatered by conditioning agents with a moderate cationic charge. Anaerobically digested sludges, however, tend to require more highly charged cationic conditioning agents. Biological sludges from activated sludge processes with long solids retention times tend to have lower conditioner requirements for charge neutralization than those with short solids retention times. This affects the charge requirement on the conditioning agent to be utilized for effective floc formation. Cationic polymers, in general, are the most efficient in conditioning biological sludges.

“Factors such as an increase in the concentration and geometry of biocolloids, degree of filamentous growth, concentration of pinpoint flocs, and production of exocellular biopolymers, will increase polymer dosage requirement for conditioning biological sludges” (Lue-Hing, et al., 1992, p.250).

2.3 Sludge Conditioning Methods

2.3.1. General Considerations

"American sludge conditioning experience is generally related to methods specific for sludge dewatering by vacuum filtration" (Eckenfelder & Santhanam, 1981, p.66). As shown by Table 2.1 (U.S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal, EPA 6251/1-74-006, Cincinnati,Ohio (October 1974).) , however, many conditioning methods exists with the objectives of each dependent on a particular solids concentration process. For example, in most dewatering operations the ability of sludge to form and maintain a porous structure under an applied vacuum or pressure is of prime concern; however, and in contrast, with thickening processes, compressibility is desired.

"Water and wastewater sludges consist of a mixture of compressible « macroscopic » (larger than 100 μm) and colloidal particles" (Eckenfelder & Santhanam, 1981, p.66). The physical, chemical, and biological mechanisms influencing conditioner requirements to enhance agglomeration of these particles are exceedingly complex. Hence, optimal conditioning methods must be determined for a particular sludge by applying empirical laboratory techniques. Various conditioning agents must be evaluated based on the nature of the sludge to be treated and the thickening and/or dewatering process to be employed.

Table 2.1 Conditioning Methods and Purposes

Conditioning Method	***Unit Process***	***Function***
Polymer addition	*Thickening*	*Improve loading rate, degree of concentration, and solids capture*
Polymer addition	*Dewatering*	*Improve production rate, cake solids content, and solids capture*
Inorganic chemical addition	*Dewatering*	*Improve production rate, cake solids content, and solids capture*
Elutriation	*Dewatering*	*Decrease acidic chemical conditioner demand ; increase degree of concentration*
Heat treatment	*Dewatering*	*Eliminate or decrease chemical use ; improve production rate, cake solids content, and stabilization ; some conversation also possible*
Ash addition	*Dewatering*	*Provide improved cake release from belt-type vacuum filters ; facilitate filter pressing ; higher filter yields and reduced chemical requirements also possible*

(U.S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal, EPA 6251/1-74-006, Cincinnati, Ohio (October 1974).

The two major classes of sludge conditioners are physical conditioners (fly ash, diatomaceous earth, etc.) and chemical conditioners (polyvalent metal ions and synthetic organic polyelectrolytes). Physical conditioners generally have an

advantage in that they are subjected to fewer variables than chemical conditioners. They also have the distinct disadvantage of appreciably increasing the volume of sludge to be subsequently dewatered and disposed of. Required conditioner dose is established by two separate demands, that is, the liquid demand of the carriage water(pH, alkalinity, polyvalent cation concentration , ionic strength, etc.) and the solid's demand of the sludge particles (solids concentration, surface charge, particle size, etc.). Physical conditioners are generally influenced to a lesser degree by the liquid demand of the sludge than are chemical conditioners.

Ferric chloride addition with or without lime has until recently been the principal chemical method for sludge conditioning. Presently, metal salts are employed as supplements to polymer addition or where polyelectrolytes have been demonstrated to be ineffective or uneconomical. Polymers are also widely employed as conditioning agents for both flotation and gravity thickening.

Heat treatment methods while facilitating dewatering also solubilize a portion of the treated sludge. Recirculation of supernatant liquor can result in severe organic overloading and solids accumulations within biological secondary treatment processes.

Sludge elutriation of anaerobically digested sludge by dilution with low-alkalinity water and subsequent decantation reduces both the liquid and solid demand of a sludge since both dissolved chemical species and small or finely sludge particles will leave with the decanted elutriate solution. This particle is declining in popularity due to serious side stream effects (Eckenfelder & Santhanam, 1981, p.66).

2.3.2 Chemical Conditioning Methods

2.3.2.1 Conditioning Mechanism

The effective application of chemical conditioning techniques requires an understanding of primary sludge characteristics and the relationship of these

characteristics to basic interactions among sludge particles. A significant factor affecting conditioner effectiveness is the predominance of sludge fines which process large surface areas and numerous chemically active sites. Condition requirements as determined by solids characteristics are consequently greatly influenced by two reactions :

1. water and solutes are adsorbed to the surface of the sludge particle, thereby reducing its effective specific gravity ;

2. the surface of the particle tends to acquire an electrical charge by preferential adsorption of ions from the solution or by ionization of component functional groups.

Wastewater sludges generally possess a negative charge which may be due to preferential adsorption of hydroxide ions or by ionization of carboxyl groups.(Water Pollution Control Federation, Sludge Dewatering, Manual of Practice 20, Washington, D.C. (1969)). *One of the objectives of sludge conditioning is adjustment of physico-chemical conditions to reduce particle charge with a resultant release of water and aggregation of particles.*

There are generally considered three mechanisms of sludge conditioning :

1. the neutralization of the charged sludge particulate ;

2. the binding of dispersed particles into aggregates ;

3. auxiliary factors.

The classical double-layer model is an attempt to explain colloidal charge neutralization. In essence, most dispersed particles in wastewater carry a net negative charge. These charged particles tend to attract a layer of positively charged ions which tightly surround the particle (fixed or stern layer). Outside of this layer is a loose and mobile layer of negative and positively charged ions (diffuse layer). The two predominant forces affecting particle interactions are electrostatic repulsive and attractive Van der Waals forces. Reduction of colloidal charge is accomplished primarily by the addition of a polyelectrolyte and/or inorganic chemical with charges opposite to that of the colloidal. This reduction in charge alters the equilibrium between the electrostatic forces of repulsion and those of mass attraction so that Van der Waals forces predominate. (see figure 2.1.).

Particulate aggregation is thereby promoted, as is the desorption and of bound water.

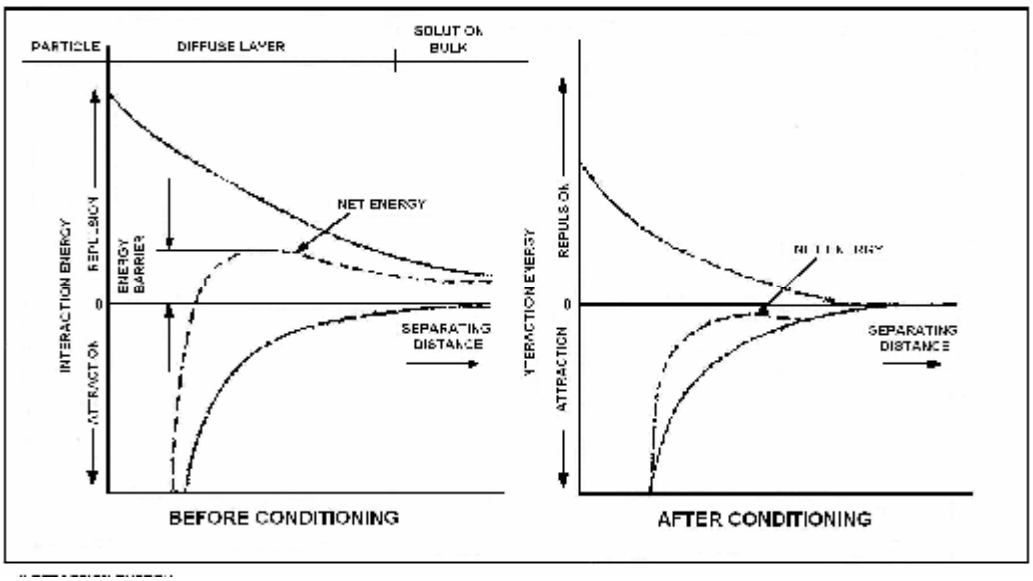


Fig. 2.1. Representation of the Classical Double-Layer Theory of particle coagulation.

Following charge neutralization, particulate aggregation or flocculation may be enhanced by the addition of other conditioners. The introduction of a flocculent generally results in a strong floc lattice structure which is a prerequisite for efficient dewatering.

Auxiliary factors affecting conditioning effectiveness are pH, dissolved oxygen, redox potential, and the concentration of carbonate detergents, oil and greases, and degradable organics (Eckenfelder & Santhanam, 1981, pp.66-68).

2.3.2.2 Chemicals Used for Conditioning

Suspended solids and colloidal solids in water are separated from the area with precipitation, flotation or filtration processes. « Big granulated and high specific weighted solids can collapse but colloidal solids cannot because of their very little particle diameters (10^{-7}-10^{-9}mm) and their low precipitation rates (approx 30cm/year) »(ATTIK – II, Tijen TUNCA). Natural colloids generally have negative charge and this fact is the main effect which causes their stability. It is very difficult

to precipitate stabile particles. Positive charged ions in area, supplies charge neutralization and the particles can easily be coagulate.

2.3.2.2.1 Coagulants

There is two types of coagulants : 1) organic coagulants ; 2) inorganic coagulants. For charge neutralization +3 charged inorganic chemicals are preferred. More the ion's charge is high more the neutralization capacity is effective. « In Schultz-Hardy theory +3 charged ions are 10 times effective then +2 charged ions. » (ATTIK – II, Tijen TUNCA).

« In Turkey, the most preferred coagulant is aluminum sulfate but for some advantages polyaluminum chloride is more popular in other world's countries ». (ATTIK – II, Tijen TUNCA).

Organic coagulants, cationic polyelectrolytes can be used single or dual (with another inorganic coagulant used in pretreatment). « In that case, inorganic coagulant's dose can increase in the range of %40-%80 » (ATTIK – II, Tijen TUNCA). The advantage of the organic coagulants is their very low sludge cake volume because of the organic coagulant's low neutralization capacity. But the sludge cake is very viscous and sticky that's why organic coagulants are not used in all cases.

Lime is another coagulant used in treatment systems. Lime is alkaline contrary to other iron or aluminum based coagulants. It is generally used in pretreatment before aluminum and iron based coagulants, to prepare them a nucleus.

2.3.2.2.2 Flocculants

The pushing forces between particles disappear with coagulation and particles became bigger with flocculant's effect. Negative charged flocculants cannot be dosed with coagulants at the same time because the charge neutralization between them will decrease the flocculation effect. That is why flocculants must be dosed

after 1 to 4 minutes then the usage of the coagulants, after the coagulation effect is well done.

There are two types of flocculants: 1) inorganic flocculants ; 2) organic flocculants : a)natural organic flocculants ; b) synthetic organic flocculants.

Activated silica was first used as inorganic flocculent. It is very effective when used after aluminum based coagulation process but it is not employed in these days.

Natural organic flocculants are plant or animal based. These flocculant's molecular weights are between 10^4 and $2x10^5$. They are used as auxiliary flocculants to iron and aluminum salt treated wastewaters.

Synthetic organic flocculants are made from synthetic monomers and they are long-chained macromolecules. Their molecular weights are between 10^6-10^7g and they show high flocculation performance. They are categorized into 3 groups with respect to their charge:

a) anionic polymers
b) cationic polymers
c) nonionic polymers.

2.3.2.3 Use of Organic Polymers

Organic polymers are typically classified as long-chain organic molecules with molecular weights varying from 10^4 to 10^6. Polymers are added to settled effluent to bring about the formation of larger particles by bridging. Because the chemistry of the wastewater has a significant effect on the performance of a polymer, the selection of a type of polymer for use as a filter aid generally requires experimental testing. (Metcalf & Eddy, 1995, p.851).

Because of the variability of sludge characteristics, optimum polymer dosage can be determined by trial-error full-scale plant testing. Tests used for selecting chemical dosage include the Buchner Funnel test for the determination of specific

resistance of sludge, Capillary Suction Time test (CST), and the Standard Jar test, these methods will be discussed separately in Chapter 3, 3.1 Determination of Optimum Conditioning Chemicals.

2.3.3 Physical Conditioning Methods

Filter aids are relatively inert materials which when added to sludge facilitate the formation of a porous, permeable, and rigid lattice structure which allows for an increase in filtration rate. These materials are generally employed during vacuum or pressure filtration when compressible sludges would otherwise blind or slime the filter media. Reduced chemical conditioning requirements, an increase in cake solids concentration, an improvement in cake release are other advantages offered by physical conditioners. In addition, these additives being relatively inert are subjected to fewer variables than chemical conditioners. Their use, however, can significantly increase the volume of sludge to be dewatered and ultimately disposed of. It should be noted that calculations of true filter yield when employing filter aids must be based on kg(lb) sludge solids removed as cake/m^2/h (cake/ft^2/h) and not on total solids removed. Thermal content of sludges may be significantly reduced by the incorporation of inorganic filter aids.

An assortment of materials have been employed prior to dewatering as physical conditioners, including diatomaceous earth, perlite, fly ash, clay, crushed coal, ground blast furnace slag, activated carbon, paper pulp, sawdust, ground oyster shell, and decomposed granite. (Eckenfelder & Santhanam, 1981, p.83).

Freeze/thaw treatment is generally accepted as a physical sludge conditioning method that can significantly enhance sludge dewatering characteristics, transform the floc structure into a more compact form, and reduce the sludge bound water content. Some of the advantages of freeze/thaw conditioning are its simplicity, low cost at moderate cold climates, and effectiveness with certain type of sludge. Freezing is achieved either natural or with mechanical freezing processes. Mechanical sludge freezing devices categorized into bulk freezers, freeze crystallizers and layer freezer (Aslan et al., 2005).

CHAPTER THREE
CHEMICAL CONDITIONING

3.1. Determination of Optimum Conditioning Chemicals

The chemical dosage required to condition a given sludge is determined in the laboratory. Tests used for selecting chemical dosage include the Buchner Funnel Test for the determination of specific resistance of sludge, Capillary Suction Time Test (CST), Filter Leaf Testing, Centrifugal Settleability Index and the Standard Jar Test. The Buchner Funnel Test is a method of testing sludge drainability or dewatering characteristics using various conditioning agent. The Capillary Suction Time relies on gravity and the capillary suction of a piece of thick filter paper to draw out water from a small sample of conditioned sludge. The standard jar test, the easiest method to use, consists of testing standard volumes of sludge samples with different conditioner concentrations, followed by rapid mixing, flocculation, and settling using standard jar test apparatus.

3.1.1. Jar Test

The Jar Test is used to screen conditioning agents especially when the designer faces a wide variety of potentially effective products. This test is performed by taking four to six large beakers of about 1 liter capacity and filling them with about 600 mL of the sludge. Solutions of different types of conditioning chemicals are prepared in accordance with the manifacturer's introductions. The beakers are then placed on a gang stirrer with the filter pan in position beneath the oversize paddle. The paddle should just clear the bottom of the pan. The stirrer should be set to 75 rpm. The diluted chemical is then poured into the pan and mixed for 30 seonds. The operator then stops the gang stirrer, removes the paddle, and observes the floc formation and settling.

3.1.2. Filter Leaf Testing

The Filter Leaf Test is usually used for evaluating dewaterability, primarily by a vacuum filter. Further, in some cases, this test hes been used to size a vacuum filter. Assembling a filter leaf apparatus as shown in figure 3.1 performs the test. The filter cloth should be the fabric intended for use or monofilament filter cloth.

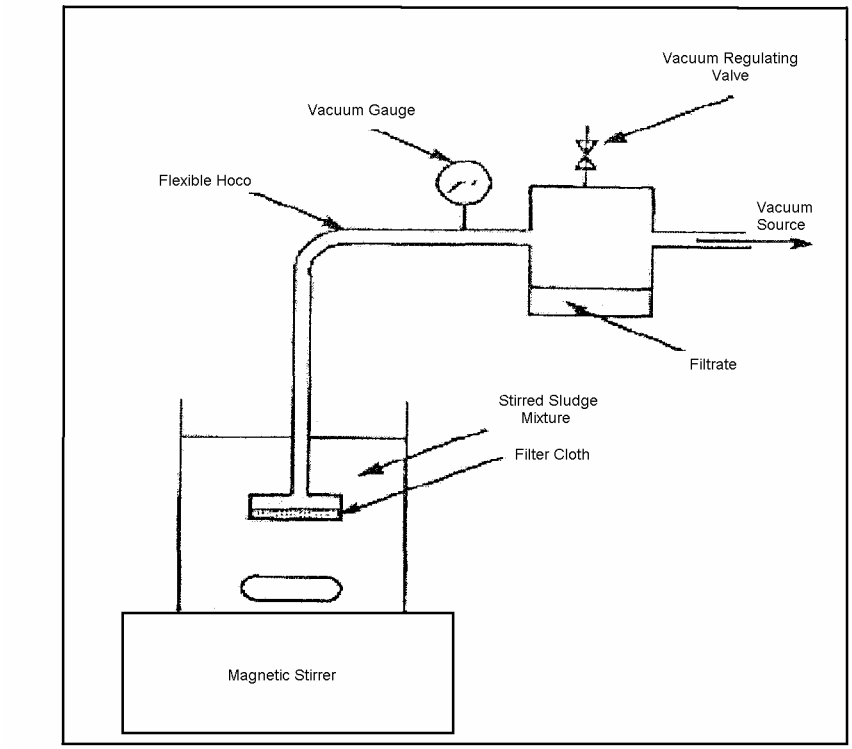


Figure 3.1 Example of a filter leaf apparatus (EPA, 1987)

A jar test apparatus as described in section 3.1.1., is used to prepare chemically conditioned sludge in at least two liter batches for each filtration cycle. The conditioning chemicals are placed in the jar test apparatus, allowing for 2 to 4 minutes of mixing and flocculation time. The mixing should be slow (about 10 rpm). Flash mixing will adversely affect the test results.

Two liters of the chemically conditioned sludge area transferred to a beaker, its temperature is measured and the filter is submerged in it about 5 cm (2 in) below the

surface. Then 51cm (20 in) Hg of vacuum is applied to the filter leaf and timing begins. After 45 seconds of form time, the eaf is withdrawn and dried 90 seconds.

The cake thickness is measured and the cake is scraped into a previously weighed dish. The dish and cake are weighed and transferred to a drying oven. After air-drying , the cake should be desiccated, weighed, volatilized, desiccated again and weighed again.

The following determinations should be made for each run:

- Volume of filtrate,mL
- Temperature of filtrate, °C
- Wet weight of filter cake, g
- Dry weight of filter cake, g
- Dry weight of ash, g
- Total solids concentration of cake, Ts, percent of wet weight
- Volatile solids concentration of cake solids, Vs, percent of total solids

This test simulates a 3 minute cycle time, divided into 45 seconds of form time, 90 seconds of drying time, and 45 seconds of discharde time. It may be desirable to use a longer cycle time. Typically, cake thickness with cycle time and cake total solids content will increase. Cake solids content can be further increased by decreasing the ratio of form time to drying time. Subsequently, experiments might be conducted to determine yield as a function of percent solids concentration and/or a function of cycle time. Also for each run the filter yield, in pounds of cake solids per square foot of filter per hour, can be calculated with Equation 3.1:

$$\text{Filter yield} = \{\text{Dry Weight of cake(g)} \times \text{Cycles/hr}\} / \{453{,}6 \times \text{Filter area } (ft^2)\} \quad \textbf{(3.1.)}$$

One of the advantages of the filter leaf test is that it stimulates actual behaviour on a vacuum filter. Ease of cake release from the filter cloth can be estimated, and the percent moisture of the final cake can be determined.

NOTE: The actual sizing of vacuum filter would require a series of leaf tests, employing one or more controls in which no characteristics are added.

3.1.3. Specific Resistance or Buchner Funnel Test

The Specific Resistance Test is another method of predicting conditioning agent performance. A detailed theoretical description is contained in below. Specific resistance is used to compare filtration characteristics of different types of sludges and to determine the optimum conditioning chemical requirements for a specific sludge. Specific resistance value of a sludge is determined by appliying the Buchner Funnel Test to the sludge. The Buchner Funnel Test equipment consist of a graduated cylinder, Buchner Funnel and a vacuum pump as shown in Figure 3.2.

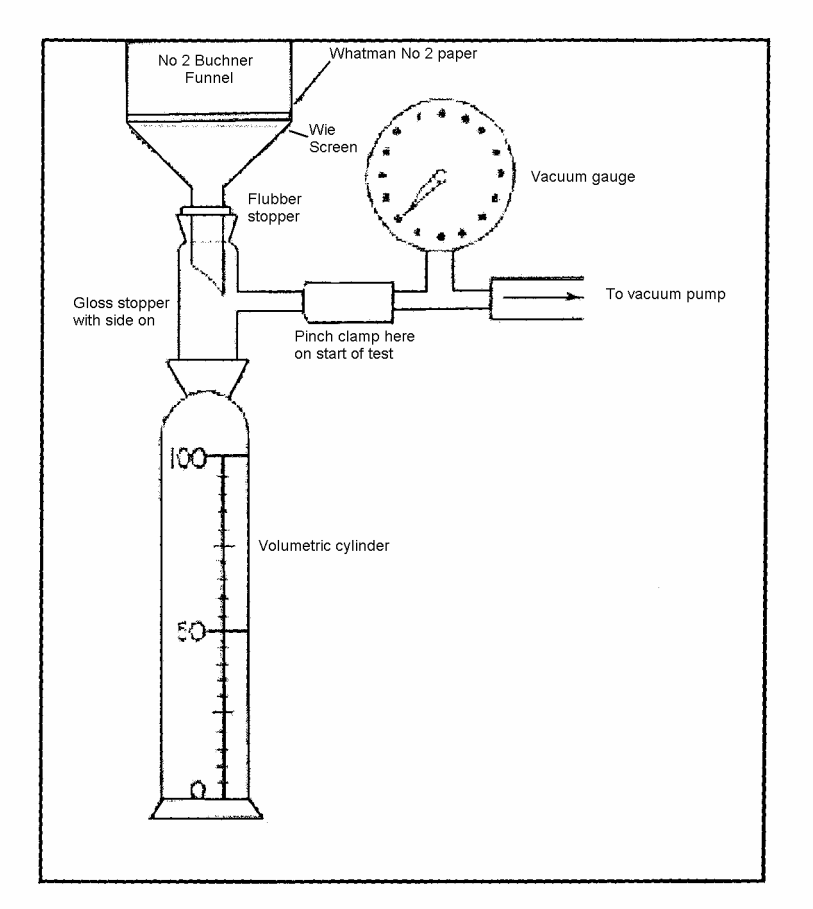


Figure 3.2 Buchner funnel apparatus (EPA, 1987)

Series of conditioned sludge samples are prepared in large beakers. First about 200 mL of the thickened sludge is placed into the beakers. The sludge tested should be representative of the sludge to be used on the dewatering units. This sludge can be sampled from a pilot-plant or a similar full-scale treatment plant.

A Buchner Funnel is mounted on top of the graduated cylinder and the funnel is fitted with a Whatman No 2 filter paper, then 100 mL of conditioned sludge is poured into the funnel. After 2 minutes gravity drainage, the vacuum pump is turned on (2 bar). At about 10 seconds intervals, the filtrate volume is measured and recorded untill additional water can not be removed. After this period, the sludge cake is removed from the filter and placed in a weighed dish. The wet weight of the cake is measured and then after drying at 180 °C, the dry weight is measured and dry solids content of the sludge cake (%) is determined. In addition, total suspended solids as the units of mg/L and % is also determined on the filtrate.

After these experimental procedure, a plot was made of time/filtrate volume, as shown in Figure 3.3. the slope of the straight line portion of the graph is “b” and is used to calculate the specific resistance (r) from equation 3.2.

$$r = (2PA^2b)/\mu w \qquad (3.2.)$$

Where,

r = specific resistance, m/kg

P = pressure of filtration, N/m^2

A = area of filter, m^2

b = slope of time/volume vs volume curve, sec/m^6

μ = viscosity of filtrate, $N(sec)/m^2$

w = weight of dry solids/volume of filtrate, kg/m^3

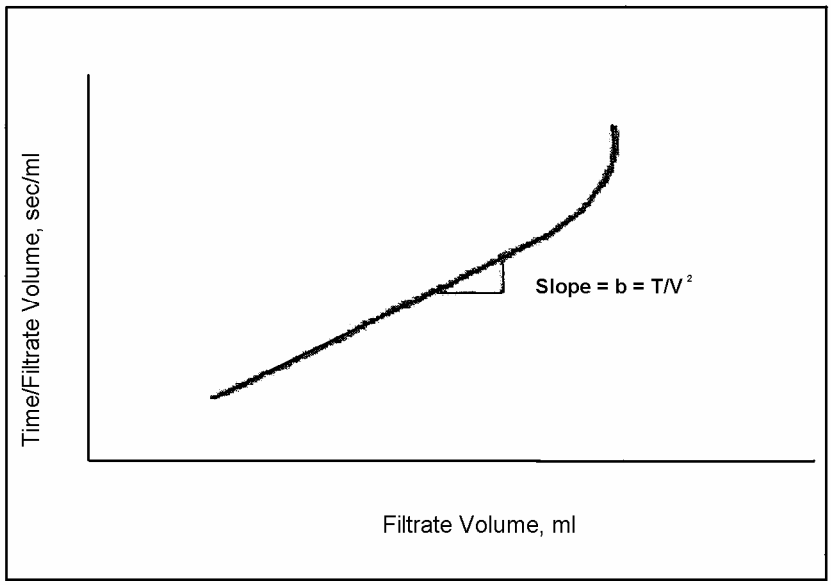


Figure 3.3. Time/filtrate vs filtrate volume plot. (EPA, 1987)

Figure 3.4. shows a plot of specific resistance versus conditioning chemical dose. This plot is constructed with specific resistance data from a sludge conditioned with different levels of the same chemical, in this case a polyelectrolyte. From a plot such as this, the designer can determine optimum polymer dose. The optimum conditioner chemical dosage is that which produces the lowest specific resistance.

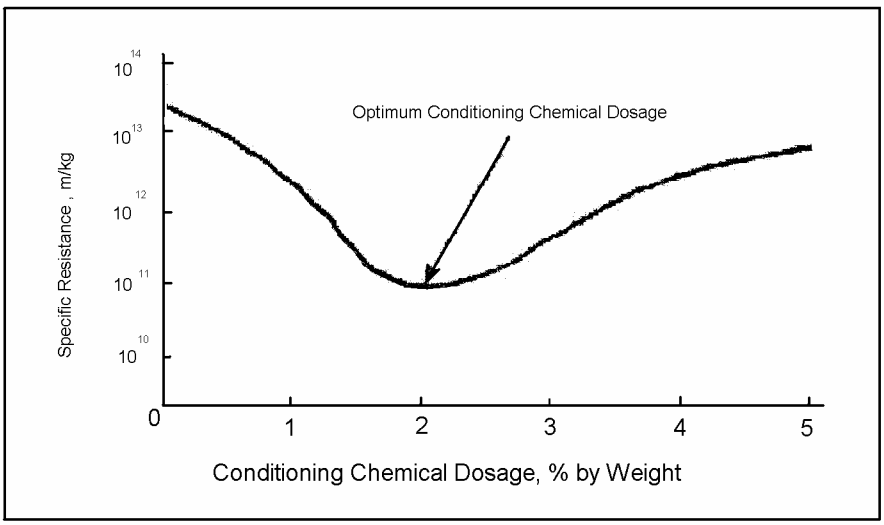


Figure 3.4. Plot of specific resistance vs conditioning chemical dosage (EPA, 1987)

3.1.4. Capillary Suction Time Test

The time the filtrate requires to travel a fixed distance in the filter paper is reffered to as capillary suction time (CST). The whole purpose of Capillary Suction Time Test is to determine dewatering characteristics of a given sludge rapidly and easily. The advantages of this test is to be simple, inexpensive, and easy. A large CST is usually indicator of a poor sludge dewaterability. (EPA, 1987, p.50; Eckenfelder et al., 1981, p.77; Vesilind, 1988, p.216)

To optimize the operation of chemical sludge conditioning, CST parameter has beeb widely used bt many researchers. (Christensen et al., 1993; Chikitela et al., 1998; Wu et al., 2000; Lin et al., 2001; Wu et al., 2003).

The apparatus (Figure 3.5 and 3.6.) consists of a timing device, an upper plate containing probes that activate and deactivate the timing device, and a lower plate that holds the filter paper and a metal sample container.

A sample of conditioned sludge is placed in the sample container. As water migrates through the paper and reaches the first probe, it activates the timer. When the water reaches the second probe, the timer deactivates. The time interval between

timer activation and deactivation is the capillary suction time and is a measure of the dewaterability of the conditioned sludge. Capillary suction time is plotted versus chemical dosage. The dosage that gives the fastest time is the optimum chemical and dosage is found for a particular dewatering system. (EPA, 1987, p.50; Eckenfelder et al., 1981, p.77)

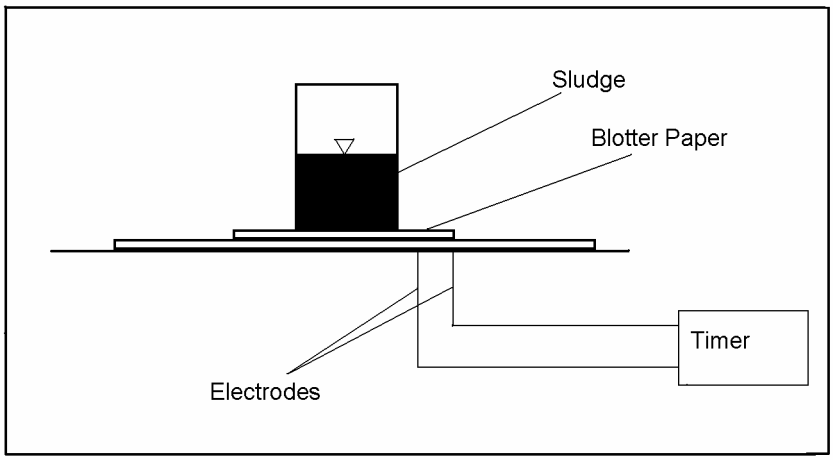


Figure 3.5. Capillary suction time apparatus (EPA, 1987)

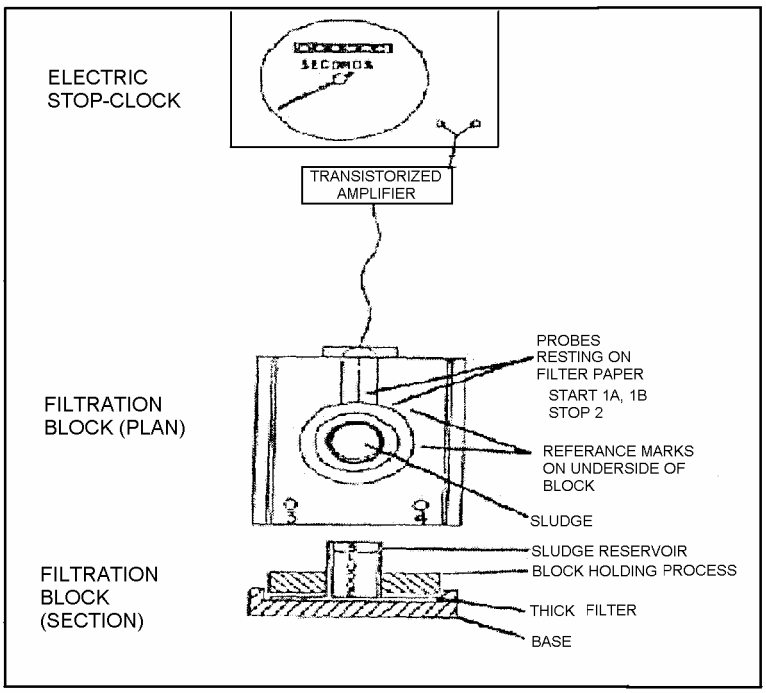


Figure 3.6. Capillary suction time appararus (EPA, 1987)

3.1.5. Centrifugal Settleability Index

Centrifugal Settleability Index (CSI) is used to determine the performance of centrifugation on conditioned sludge. It is termed as percent recovery by Vesilind in 1979 can be used as an indicator of a sludge performance on centrifugal dewatering processes. (Vesilind, 1979).

Centrifugal Settleability Index (CSI) is measured by centrifuging 50 mL of conditioned sludge at 3500 rpm for 15 minutes. Suspended solid concentration is determined in the initial sludge sample and in the resulting centrate water. The mathematical expression for CSI is given in Equation 3.3:

$$CSI\ (\%) = (C_0\text{-}C_C/C_0) \times 100\% \qquad (3.3)$$

Where,

C_0 = initial sludge suspended solids concentration (mg/L)

C_C = centrate suspended solids concentration (mg/L). (Cheung et al., 1998)

CHAPTER FOUR
LITERATURE REVIEW

Sludge dewatering is preceded by a conditioning operation to enhance water removal efficiency. In the conditioning operation, chemical coagulants or polymers are added to promote sludge particle aggregation for easier dewatering. Lin et al., (2001) have reported that sludge volume reduction or dewatering is an important operation for the solid stream in a wastewater treatment plant. An increase in solid content of sludges can promote savings in facility space as well as treatment and disposal costs. To enhance water removal efficiency, sludge conditioning is an essential procedure before the dewatering process. Normally, sludge conditioning is operated by adding chemical coagulants or polymers to flocculate the sludge particles to form larger aggregates which allows easier formation of concentrated solid cakes. To optimize the operation of chemical conditioning, several test parameters such as capillary suction time (CST), specific resistance to filtration (SRF), and sludge viscosity have been developed to evaluate the effectiveness of conditioning on sludge dewatering ability.

The efficacy of solid/liquid separation that is essential process in sludge management is enhanced by conditioning processes, which take place on subsequent sludge thickening. Eckenfelder et al., 1981 have reported that during the chemical conditioning process, small and amorphous gellike particles are transformed into larger and stronger aggregates. This leads to increasing the rate and/or extent of water drainage and solid separation. Dentel (2001) have stated the process is intended to alter sludge properties in important ways to provide both environmental and economic benefits.

Dohanyos et al., 2004 stated that anaerobic stabilization which is already widely used, will become even more important in the future, since it guarantees that reduced sludge volume can be stored and handled easily without strong odor nuisances. In future, for any type of agricultural reuse, sludge stabilization has to be a part of the

treatment. Even power station operators nowadays often demand stabilized sludges for co-combustion, in order to safely prevent odor nuisances.

Ayol et al., 2004 reported that treatment with low molecular weight oxidizing agents can produce filter cakes which are quite high in solids and lower in volume, while also circumventing later use of high lime doses for stabilization. The organic oxidants cannot function as flocculants so the oxidation of extracellular organic substances, which act to stabilize biological sludges, is the most likely mode of action.

“Sludge dewaterability characteristics take an important role in the selection of the optimal dewatering method. Many characteristics are reported to influence the dewaterability of sludges such as particle size distribution, bound water content, viscosity, structure and composition of the flocs.” (S.Çetin et al., 2004)

“In order to obtain a high degree of separation in a short period of time and a relatively small process volume, conditioning step should be very effective since the dewatering process heavily depends on it” (S.K. Dentel, 2001, p.278).

Vesilind et al., 1979 have reported that the simple jar test is the most widely used method to evaluate chemical conditioning. This method uses 500 mL of sludge sample into each of six jars in the jar test apparatus. Different amounts of polymer solutions are then poured into the beakers using a syringe. The polymer and sludge are then mixed at approximately 200 rpm for about two minutes. The speed is then inspected for formation of strong flocs and the clarity of free water above the settled sludge. These would be indicative of the polymer’s ability to condition the sludge. The test results are based on visual observation of floc formation. Dentel et al., 1998 have stated the main disadvantage of the jar test is that it does not provide quantitative information. In addition, while this test provides information only on the degree of flocculation, it does not indicate actual dewaterability.

Novak et al., 1980 evaluated the effect of polymer dosing and mixing on the sludge dewaterability and floc stability and reported that the optimal dose of cationic polymer depended upon the sludge solids concentration, mixing speed, and mixing time.

Novak et al., 2004 studied the estimation of conditioning and dewatering characteristics following both anaerobic and aerobic digestion from initial sludge characteristics and reported that as the percent solids destruction increases due to digestion, the specific resistance to filtration increases along with chemical conditioning requirements and that based on the cation content of waste activated sludges, conditioning and dewatering properties can be estimated providing a tool for determining sludge handling costs prior to construction of a digestion facility.

Filibeli et al., 2005 determined that conditioning processes done with cationic polymers has importantly positive effect on sludge dewaterability and reported that over-dosage or insufficient dosage of polymer is increasing the dewatering efficiency.

Werle, et al., 1984 expressed that the polymer conditioning has been widely employed to improve the dewatering characteristics of sludge and mechanical dewatering efficiency and over-intensive shear and insufficient polymer results in floc breakage and deterioration of dewaterability. In the same study, they determined the effects of polymer dose, mixing time, and mixing energy on the relative filterability of water and wastewater sludges. It was shown that jar testing devices using low mixing energies inclined to under-predict polymer dose requirements in cases where sludges, especially primary sludge, were to be subjected to high stress dewatering. The product of the mean velocity gradient (G) and the mixing time (t), was found to be a critical factor in determining optimal polymer dose. Increase in mixing energy input (Gt) was found to result in an increase of optimum polymer requirements while conditioning alum, activated and primary sludges.

"Specific resistance is a primarily useful to compare the filtration characteristics of different sludges and to determine the optimum coagulant requirements for a specific sludge" (Eckenfelder et al., 1981, p.76).

"An evaluation technique referred to as the capillary suction time (CST) been found to be a rapid, easy, inexpensive, and reproducible method of characterizing the dewaterability of a given sludge" (Eckenfelder et al., 1981, p.77).

Baskerville et al., 1968 reported that the properties of the paper, surface tension, temperature, and suspended solid content of the sludge are the factors affecting the CST.

"The CST test is a purely empirical test and is not based on a theorical analysis of sludge dewaterability" (Vesilind, 1998, p.216).

Huang et al., 2000 demonstrated that the purpose of the capillary suction time (CST) and specific resistance to filtration (SRF) tests is the evaluation of slurry filterability and using SRF or CST vs. dosage curves, optimal dose of a sludge conditioner (defined as the dosage that yields minimal resistance to filtration) can be estimated.

The correlation between the variations in SRF and the CST measurement has been observed in several studies. Cristensen et al., 1993 showed that there is a relationship between the CST and SRF:

$$CST = c_1 \times SRF \times \mu_f \times w + c_2 \times \mu_f$$

in which c_1 and c_2 are coefficients related to CST, μ_f is the viscosity of the filtrate, and w is the solid content in volume of the filtrate.

Huang et al., 2000 investigated the determination of the optimal dose of a cationic polyelectrolyte sludge conditioner using leaf and Buchner Funnel tests and

CST measurement, and the effect of the particle sedimentation on the determination of optimal polyelectrolyte dose in a kaolin suspension and an alum sludge. They reported that filter orientation during the leaf tests and the stirring during the Buchner Funnel tests affected the SRF, and the optimal dose of the polyelectrolyte sludge conditioner, as determined by the leaf test, was not affected by filter orientation, and the optimal dose as determined by the Buchner Funnel test was not affected by stirring. However, the optimal dose was found the vary depending on the type of test used. They also reported that the optimal dose of a conditioner was, therefore, an operationally defined value, and depended on the geometry of the filter chamber and fluid/particle interactions, such as particle sedimentation.

Wu et al., 2001 studied the floc strength requirement of the alum sludge which is applied on vacuum filtration. In order to improve the sludge dewaterability, cationic polyelectrolyte were used and sludge dewaterability was evaluated by the capillary suction time (CST) and the specific resistance to filtration (SRF). From the experimental results, it was shown that the addition of polymer does substantially enforce the floc strength, even in the over dosage, and therefore reduces the floc breakage of alum sludge.

Chikitela et al., 1998 demonstrated that waste activated sludge pre-conditioned with iron salt or cationic surfactant shows better dewaterability when conditioned with cationic polyelectrolyte.

Lai et al., 2004 studied on the co-conditioning and dewatering of alum and waste activated sludge and summarized that alum sludge acted as skeleton builder and rendered dewatering process more effective. Enhancements in settling and dewatering could be achieved through co-conditioning so lower polyelectrolyte dosage was required. It implied practical solution to treat the waste activated sludge more effectively.

Akça et al., 2005 studied on conditioning and co-conditioning of alum sludge and observed that it was more effective to co-condition by using first anionic

polyelectrolyte then cationic polyelectrolyte the to co-condition by using cationic polyelectrolyte then cationic polyelectrolyte. It is also summarized in the study that a possible bridging mechanism could occur at first part of the co-conditioning; then with the addition of cationic polyelectrolyte at second part, with an electrical attractive force, a better flocculation could occur.

Christensen et al., 1993 reported that good control of polyelectrolyte dose is critical in sludge conditioning, since overdosing will increase cost and reduce sludge dewaterability. The optimal polyelectrolyte dosage is usually associated with the colloidal surface of minimum surface charge and a tendency to aggregate to form large floc.

Pan et al., 2003 investigated the correlation between dewatering index and dewatering performance of three mechanical dewatering devices. In that study, sludges were conditioned with both synthetic and natural polymers, and their dewatering characteristics after three different mechanical dewatering devices, the filter press, belt press, and the centrifuge were compared. The results showed that the traditionally used dewatering index may not reflect sludge conditioning properly. Correlation between sludge conditioning indices and dewaterability depends upon both the type of sludge and the means of sludge conditioning and dewatering. It is therefore concluded that dewatering index must be properly chosen for optimum sludge conditioning.

Huang et al., 2000 elucidated the filterability of a kaolin suspension and an alum sludge using leaf and Buchner Funnel tests and CST measurements. Filter orientation during the leaf tests and stirring during the Buchner Funnel tests affected the SRF. The optimal dosage of the polyelectrolyte sludge conditioner, as determined by the leaf test was not affected by filter orientation, and the optimal dosage as determined by the Buchner Funnel test was not affected by stirring. However, the optimal dosage was found to vary depending on the type of test used. The optimal dose of a conditioner is, therefore, an operationally defined value and depends on the geometry of the filter chamber and fluid particle interactions, such as particle sedimentation.

The effect of floc strength on the dewatering efficiency of alum sludge was studied in another work. 0-30 mg/L cationic polyelectrolyte were used in conditioning experiments and sludge dewaterability was evaluated by the capillary suction time (CST) and specific resistance to filtration (SRF). In centrifugation, settled sludge samples were centrifuged at 1000 to 12000 rev./min for 1 minute. From the experimental results, it was shown that addition of polymer strengthens the floc structure of the sludge, which reduces floc breakage and sludge dewaterability. A confined floc strength growth benefits the filterability, although the strongest floc structure does not guarantee maximal dewatering efficiency. For centrifugal dewatering, increasing floc strength can not reduce the moisture content of the sludge cake when the centrifugal *G* value is under 7000. At high *G*, a strong structure is necessary to reduce cake blinding from floc deformation, and the lowest moisture content is found in sludge cake with the highest floc strength. Therefore, floc strength should be included with other traditional dewaterability indices in determining sludge dewatering. Centrifugation is suggested for the dewatering of sludge with high floc strength, and vacuum filtration for middle floc strength (Wu et al., 2003)

Chang et al., 2001 were investigated the sludge conditioning behavior and improving sludge conditionability. The effects of calcium ion with and without polyelectrolyte conditioning behavior on two industrially activated sludge systems were studied via Capillary Suction Time (CST) tests. Experimental results indicated that the calcium ion can strongly enhance the conditionability of the industrial biological sludge system. The good conditionability of calcium ion added system could have possibly resulted from the interaction of polysaccharide from activated sludge with calcium ion. Additionally, adding polyelectrolyte solution first would produce more suitable conditioning in a situation in which calcium ion is involved with polyelectrolyte.

Wu et al., 2001 were studied the effect of charge neutralization on dewatering performance on alum sludge by polymer conditioning. Different doses of cationic

and anionic polymers with the same molecular weight were used in conditioning experiments. After conditioning, floc density and zeta-potential of sludge were measured and then remaining sludge was allowed to settle for 2 hours, after which, the supernatant was removed. Next, bound water content and dry solid content of the settled sludge were measured. Sludge dewaterability was evaluated according to the capillary suction time (CST). During the experiments, CST values corresponding to cationic polymer doses decreased substantially at the beginning, then decreased gradually to a minimum value at a dose of 10 mg/L, which was defined as the optimal dose. At doses over 20 mg/L, CST value increased significantly relative to the optimal state. Anionic polymer dosing resulted in a gradual decrease of CST at first and a stable thereafter. A re-increase in CST was defined as evidence of over-dosing, then no over-dosing condition was found during the anionic polymer conditioning. As a result of CST measurement, it was reported that it is easier to determine the optimal dose for a cationic polymer than for an anionic polymer when the optimal dose is determined according to the lowest value of CST.

CHAPTER FIVE
MATERIALS AND METHODS

5.1 Materials

5.1.1 Raw Sludge Samples and Their Properties

In the experimental studies, chemical conditioning was applied to aerobic stabilized sludge samples taken from Manisa Organized Industrial District and to anaerobic stabilized sludge samples taken from Pakmaya/Kemalpaşa Inc. for investigation of dewatering performance. Raw sludge samples were collected seven times and kept at 4°C during the experiments. pH, electrical conductivity (EC), dry solid content (DS), organic matter (OM), total suspended solid (TSS), capillary suction time (CST), centrifugal settleability index (CSI), sludge volume index (SVI) and supernatant turbidity were analyzed for raw sludge samples. The physico-chemical characteristics of raw sludge samples are reported in Table 5.1.

Table 5.1 The physico-chemical characteristics of raw sludge samples

Parameter	Units	Sample Numbers							
		I	II	III	IV	V	VI	VII	VIII
pH	-	7,95	7,89	8,01	8,00	7,98	7,72	6,68	7,41
EC	µmho/cm	13000	11900	11500	13500	16800	15000	350	210
DS	%	3	-	1,23	2,82	1,53	3,24	1,58	0,49
	mg/L	3000	-	1230	2820	1530	3240	1580	492
OM	%	37,22	-	41,06	41,01	39,66	41,02	58,92	26,20
	mg/L	3722	-	4106	4101	3966	4102	5892	2620
TSS	mg/L	-	-	19000	10666	5000	50900	100000	4300
CST	Second	617,6	1022	184,3	717,4	344,5	820,4	76	12,5
CSI	%	-	-	92,1	96,24	89,6	99,8	99,7	96,04
SVI	mL/g	750	89	210	900	190	960	925	140
Turbidity	JTU	12300	5000	5000	13000	6000	22000	5000	4500

Raw sludge samples could not be filtrated and there were any sludge cake formation for these samples. For this reason there is any SRF parameter data in this thesis for these raw sludge samples.

5.1.2 Conditioners

Materials used as conditioning agents in chemical conditioning trials were; commercially available three types of cationic polyelectrolyte (KWD 3500, 5980 SB and SNF 5980), Alum ($Al_2(SO_4)_3.18\ H_2O$), non-ionic polyelectrolyte (KWD 20LT and anionic polyelectrolyte (KWD A 0055). The polyelectrolyte solutions were prepared as 0,1% stock solution, and alum solution was prepared as 10% stock solution using distilled water. Dosages of polyelectrolytes varied between 5 to 450 mg/L, and the dosage of alum varied 100 to 1000 mg/L. The properties of conditioners used in conditioning experiments are given in Table 5.2.

5.2 Methods

5.2.1 Analytical Methods

Dry solids content (DS, %), water content (WC,%), organic matter content (OM,%), pH, electrical conductivity (EC, µmhos/cm), capillary suction time (CST), specific resistance to filtration (SRF), and centrifugal settleability index (CSI) parameters were analyzed for raw and conditioned sludge samples in laboratory studies. DS, WC, OM, pH, EC, CST and SRF were measured according to procedures given in Standard Methods (APHA, AWWA, 1992). pH measurements were carried out by using a 890 MD pH meter; electrical conductivity was measured by using a YSI Model 33 conductivity-meter.

For conditioning studies, Jar Test Method was applied to sludge samples. Different amounts of conditioners were added to 500 mL of sludge samples in 1000 mL beakers. The samples were mixed at 200 rev/min for 1 minute, and then 25 rev/min for 30 minutes. After 30 minutes of settling time, settled sludge volume (mL) and supernatant turbidity (JTU) were determined. Floc structures of settled sludges were observed for each trial. Turbidity parameter was measured using a Hach model spectrophotometer with a standard 4445 color filter.

Table 5.2 Properties of conditioner agents

5.2.2 Evaluation Methods of Chemical Conditioning

5.2.2.1 Specific Resistance to Filtration (Buchner Funnel) Test

Specific Resistance to Filtration (SRF) test was applied to conditioned sludge samples for evaluation of dewatering characteristics. For this aim, SRF test procedure was performed using a Buchner Funnel with a Whatman # 2 filter paper applying 2 bar of vacuum suction. Dry solids contents of sludge cake and filtrate samples obtained from Buchner Funnel test applications were measured according to the procedures given in Standard Methods (APHA, 1995). Viscosities of filtrate samples were also measured using Brookfield RVDV III Rheometer.

5.2.2.2 Capillary Suction Time Test

Capillary Suction Time Test (CST) was also used as another method for the evaluation of the dewatering performances of conditioned sludge samples. CST values were analyzed using Triton A 304 M CST-meter. A standard CST sample cylinder of 1,8 cm diameter was used during experiments with Whatman # 17 filter paper. All CST measurements were conducted in triplicates and average of three values was taken into consideration for standard deviation to be less than 1 second. (APHA, 1995).

5.2.2.3 Centrifugal Settleability Index Measurement

In the study, centrifugal settleability index (CSI) was measured for raw and conditioned sludge samples using the procedure given in Chapter 3.1.5 Centrifugal Settleability Index. To calculate this index, suspended solids concentrations were measured according to Standard Methods (APHA, 1995).

CHAPTER SIX
EXPERIMENTAL RESULTS AND DISCUSSION

6.1 Conditioning Results of KWD 3500 Cationic Polyelectrolyte Applications to Aerobic Stabilized Sludge Samples

6.1.1 Jar Test Results of KWD 3500 Cationic Polyelectrolyte Applications

In the jar test trials using KWD 3500 cationic polyelectrolyte, different amounts of the polyelectrolyte ranged from 5 to 450 mg/L were dosed to the aerobic stabilized sludge samples applying the jar test procedure defined in Chapter 5.2.1. The experimental results evaluating settled sludge volume, floc structure of aerobic stabilized sludges and supernatant turbidity are given in Table 6.1.

Then different amounts of KWD 3500 cationic polyelectrolyte ranged from 150 to 300 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 50 mg/L alum (aluminum hydroxyde 18 hydrate) dosage, and after then different amounts of KWD 3500 cationic polyelectrolyte were added to the sample and mixed at 25 rev/min for 30 minutes.

Different amounts of alum ranged from 200 to 800 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 240 mg/L KWD 3500 cationic polyelectrolyte dosage, using the same method defined above.

According to the results summarized in Table 6.1, it was observed that there is no relationship between supernatant quality and KWD 3500 dosage. Furthermore, results indicate that settled sludge volume obtained from jar test applications is not a critical parameter for sludge conditioning.

Table 6.1 Jar test results of KWD 3500 cationic polyelectrolyte

Dosage		**Settled sludge volume**	**Supernatant turbidity**	**Sludge properties**
mg/L	mg/kg DS	mL	JTU	
5	500	-	-	-
10	1000	-	-	-
15	1500	-	-	-
20	2000	-	-	-
50	5000	-	-	-
100	10000	-	-	-
150	15000	-	-	Very thin flocs
200	20000	-	-	Thin flocs
210	21000	-	-	Middle flocs
220	22000	-	-	Middle flocs
230	23000	400	150	Big flocs
240	24000	500	120	Big flocs
250	25000	-	-	Middle flocs
300	30000	-	-	Big flocs
350	35000	-	-	Big flocs
400	40000	-	-	Big flocs
450	45000	-	-	Big flocs
240cp, 200al.	24000cp. 2000al.	-	-	Middle flocs
240cp, 400al.	24000cp. 4000al.	-	-	Middle flocs
240cp, 600al.	24000cp. 6000al.	-	-	Thin flocs
240cp, 800al.	24000cp. 8000al.	-	-	Thin flocs
50al, 150cp.	500al. 15000cp	-	-	Thin flocs
50al, 200cp.	500al. 20000cp.	-	-	Thin flocs
50al, 250cp.	500al. 25000cp.	-	-	Thin flocs
50al, 300cp.	500al. 30000cp.	-	-	Thin flocs

Where, cp: KWD 3500 cationic polyelectrolyte and al.: Alum.

6.1.2 Buchner Funnel Test Results of KWD 3500 Cationic Polyelectrolyte

Buchner Funnel Test was applied to raw and conditioned aerobic stabilized sludge samples. Buchner Funnel Test procedure given in Chapter 3.1.3 was used to calculate the specific resistance to filtration value of the sludge samples.

Filtrate volume (V) versus time (T) were recorded and ratios of T/V were calculated. Obtained filtration data of raw and conditioned aerobic stabilized sludge samples with KWD 3500 cationic polyelectrolyte are given in Appendix A. Obtained T/V ratios versus V were plotted and the slope of linear portion of the curve (b) were determined for each trial. The plots –T/V versus V- for each sample are presented between Figure 6.1 – Figure 6.26.

Dry solids content and viscosity of filtrate, and dry solids content of sludge cake removed from the filter were determined for conditioned samples with KWD 3500 cationic polyelectrolyte. The results of the Buchner Funnel tests for all trials are summarized in Table 6.2.

In order to determine optimum dose range of KWD 3500 cationic polyelectrolyte, the relationship between doses and specific resistance to filtration (r) values were used. Therefore the graph which KWD 3500 dosage versus r values depicted is given in Figure 6.27.

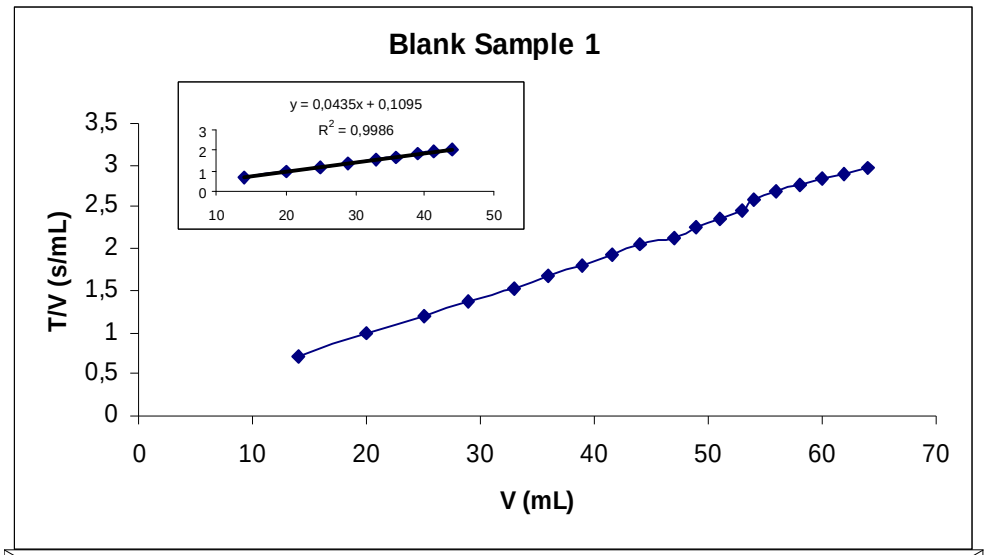


Figure 6.1 T/V values versus filtrate volume (V) for sample I. Inset: The data applied linear regression

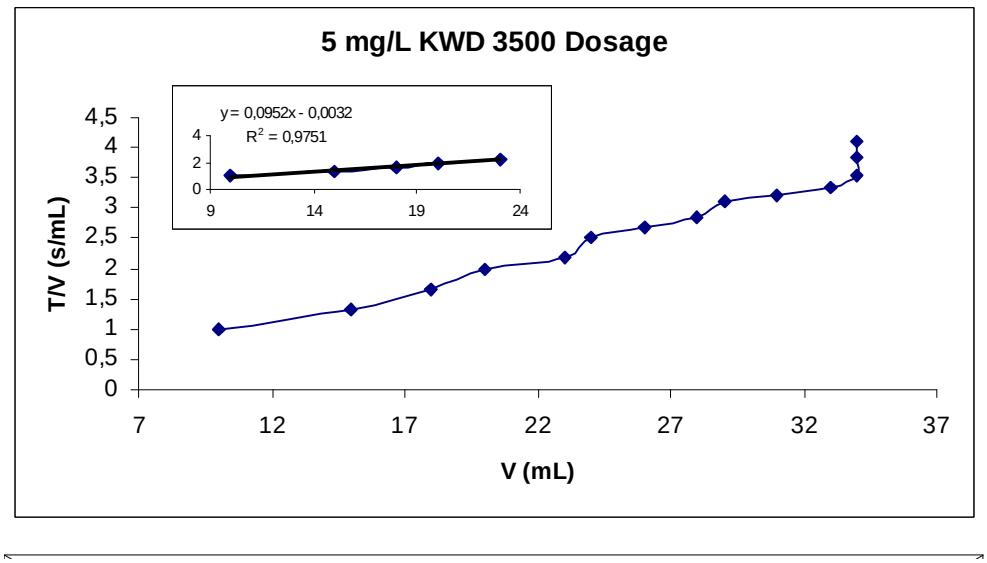


Figure 6.2 T/V values versus filtrate volume (V) for 5 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

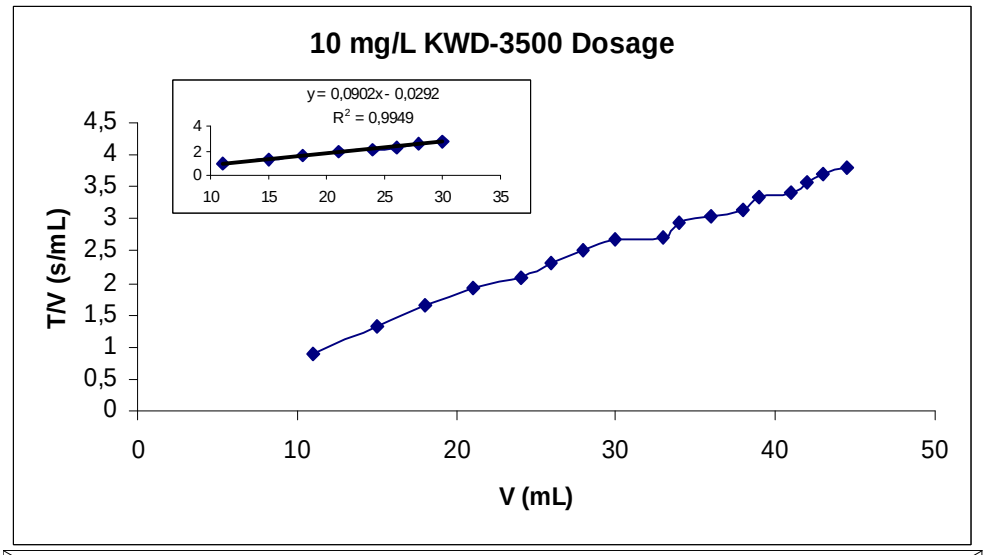


Figure 6.3 T/V values versus filtrate volume (V) for 10 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

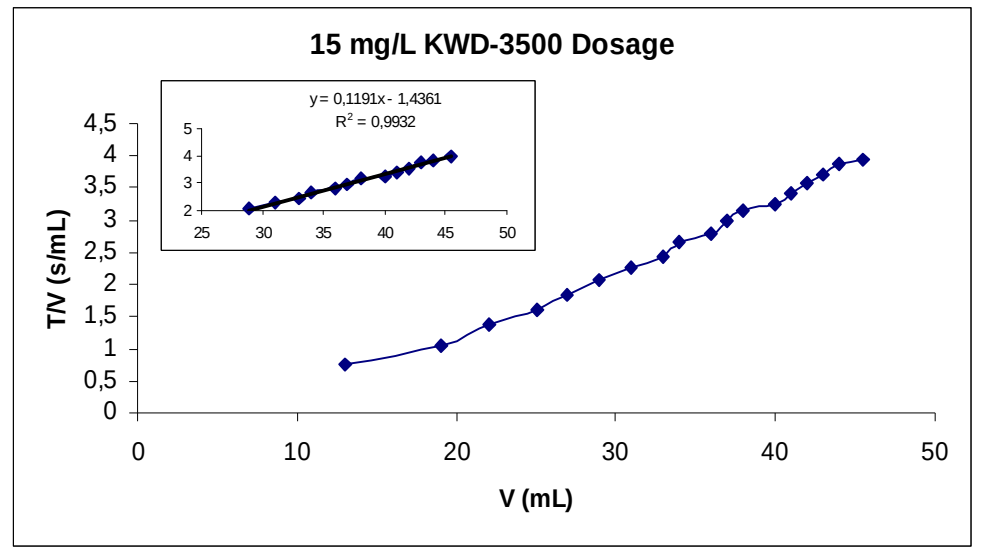


Figure 6.4 T/V values versus filtrate volume (V) for 15 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

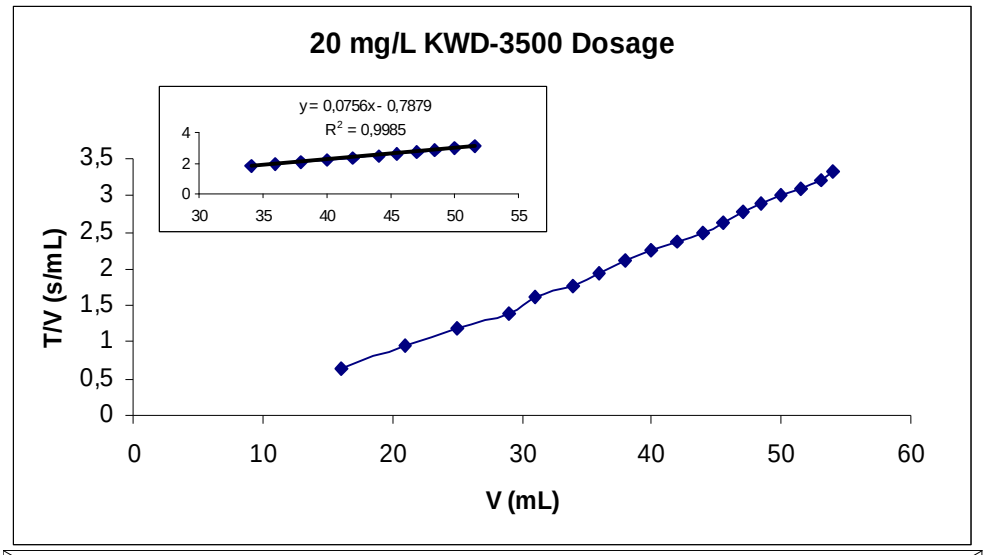


Figure 6.5 T/V values versus filtrate volume (V) for 20 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

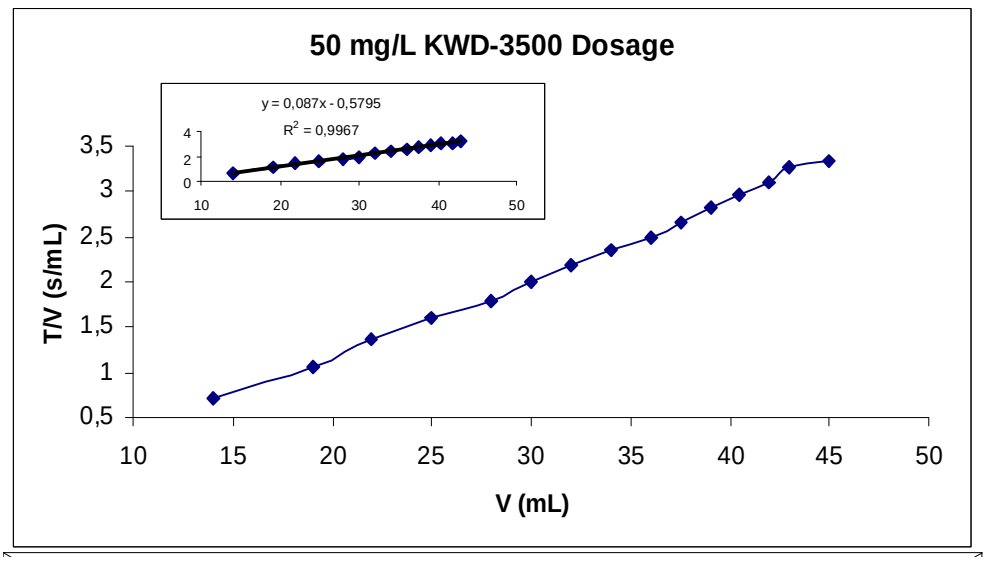


Figure 6.6 T/V values versus filtrate volume (V) for 50 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

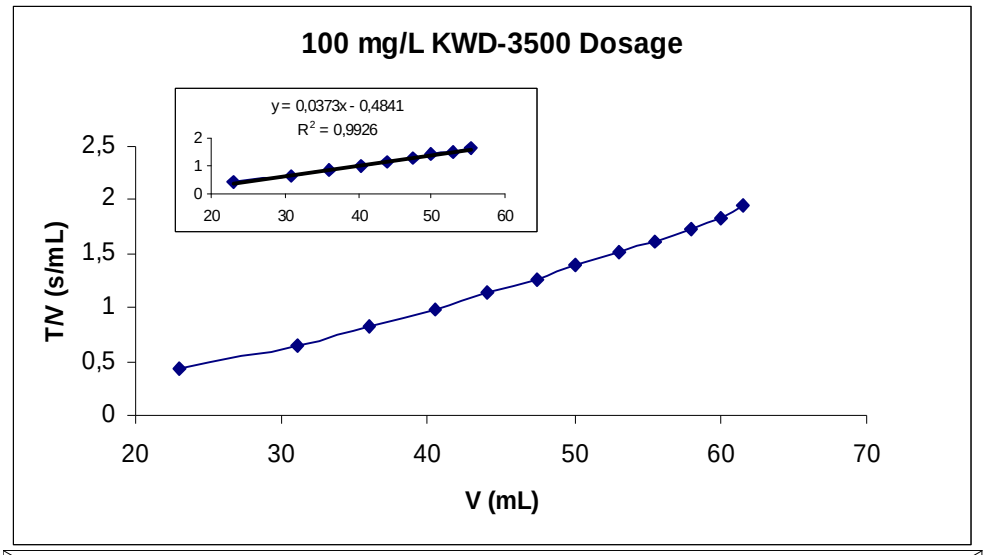


Figure 6.7 T/V values versus filtrate volume (V) for 100 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

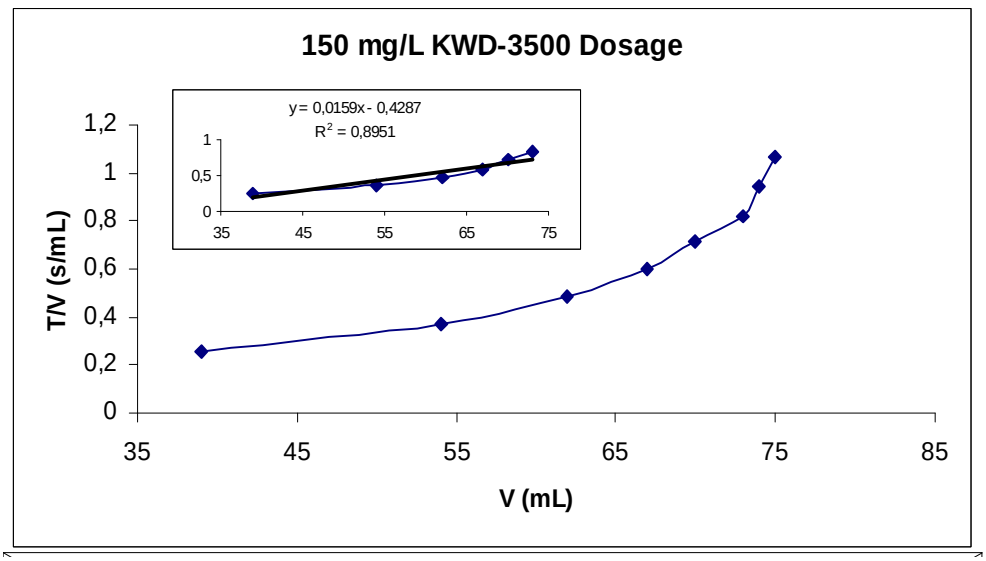


Figure 6.8 T/V values versus filtrate volume (V) for 150 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

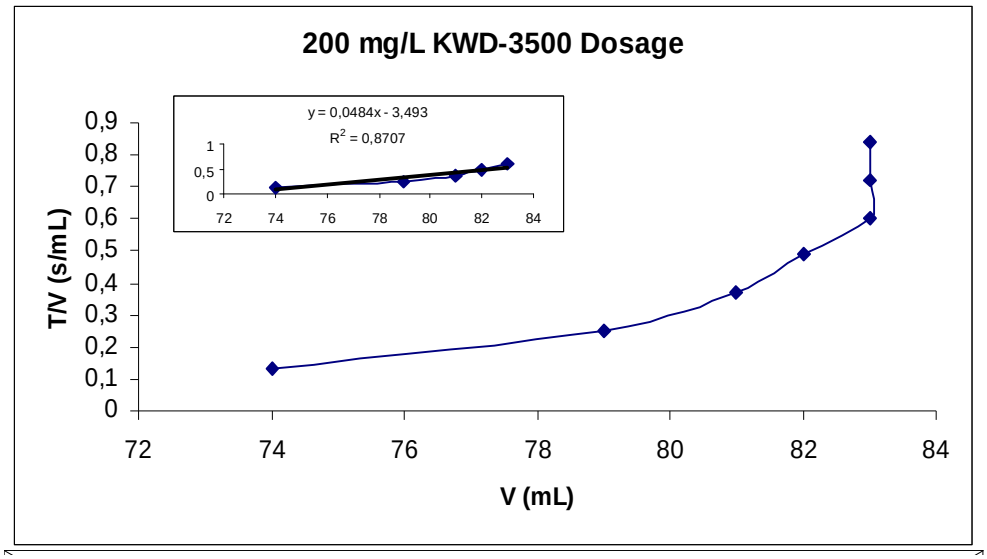


Figure 6.9 T/V values versus filtrate volume (V) for 200 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

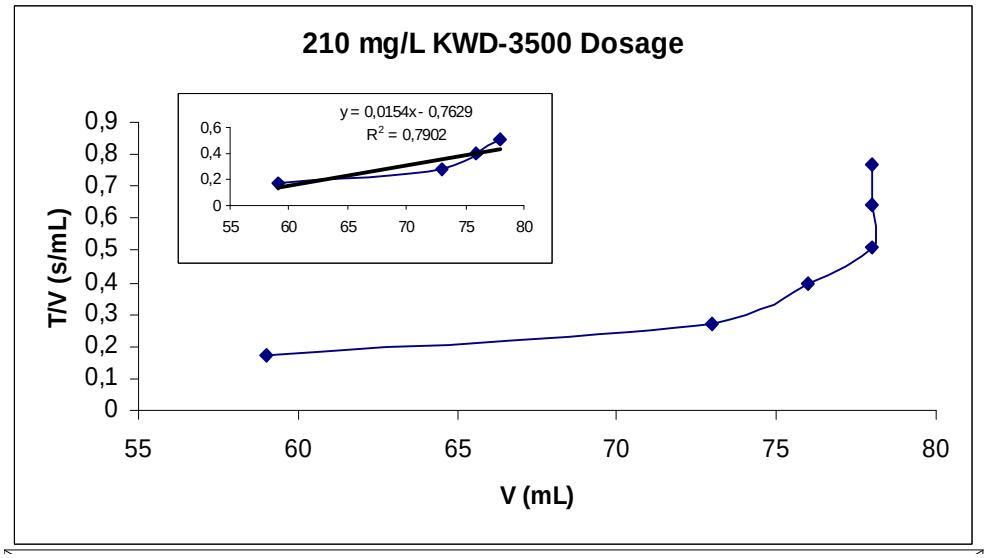


Figure 6.10 T/V values versus filtrate volume (V) for 210 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

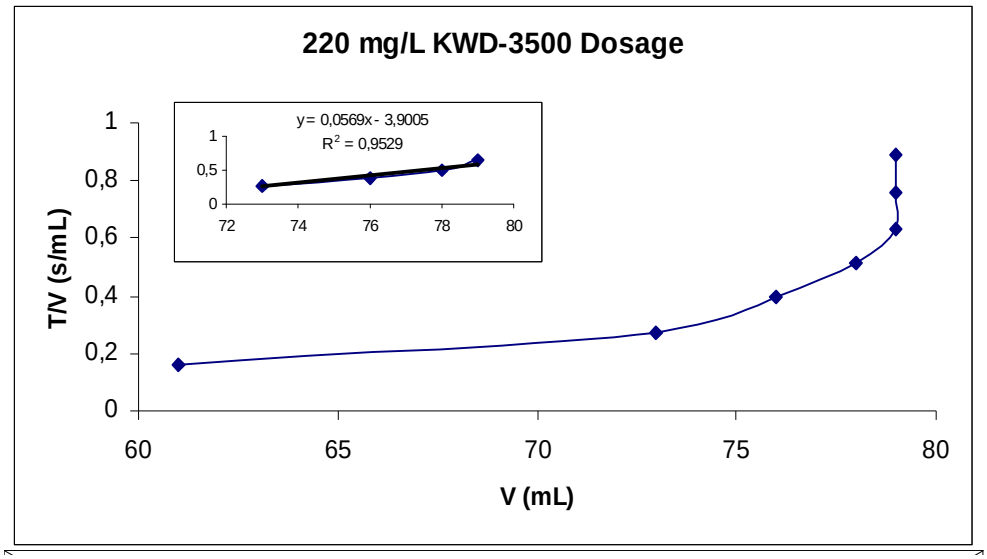


Figure 6.11 T/V values versus filtrate volume (V) for 220 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

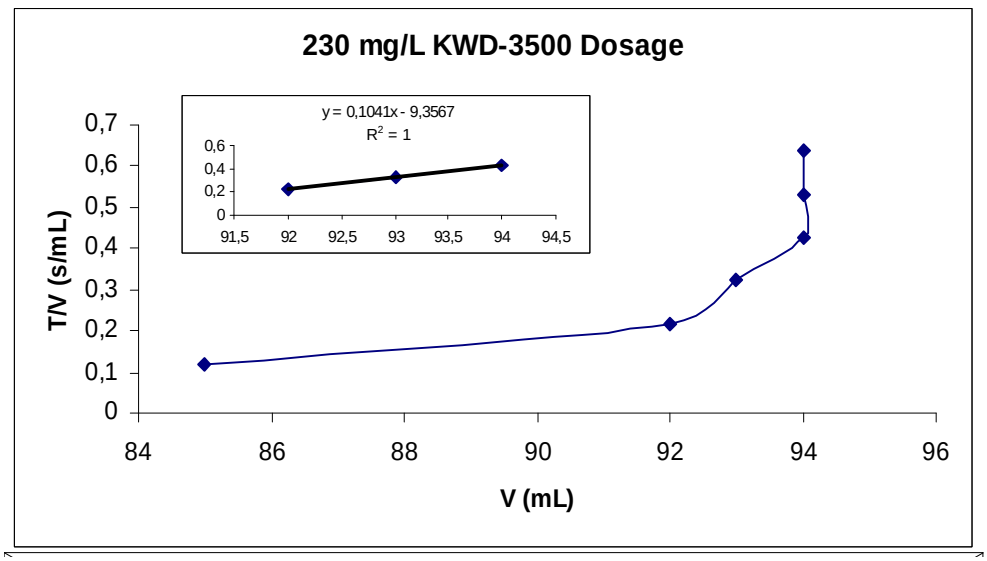


Figure 6.12 T/V values versus filtrate volume (V) for 230 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

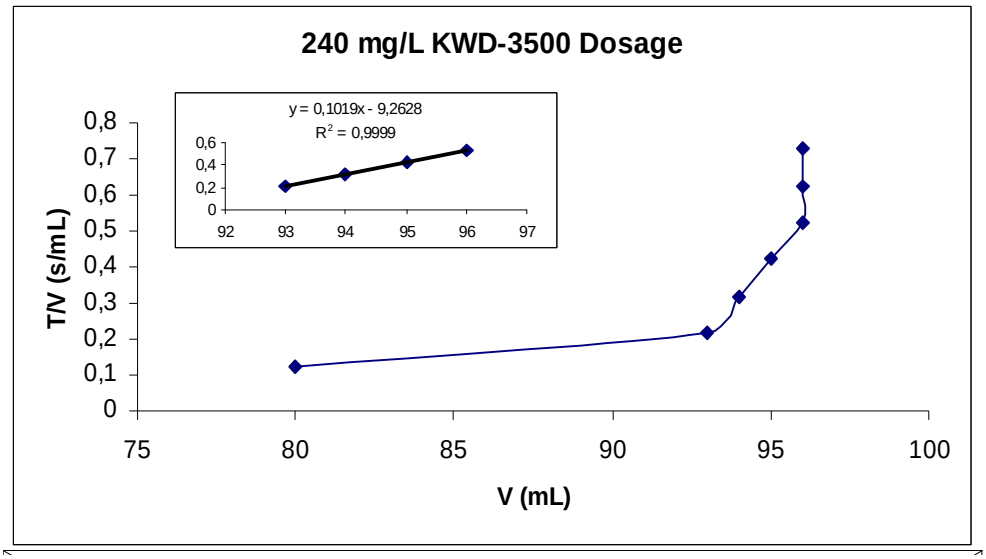


Figure 6.13 T/V values versus filtrate volume (V) for 240 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

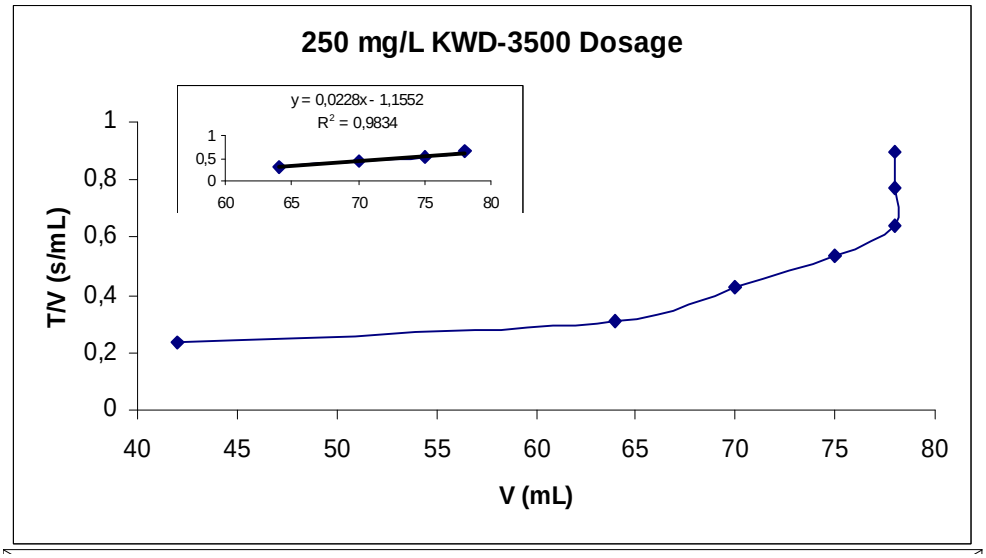


Figure 6.14 T/V values versus filtrate volume (V) for 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

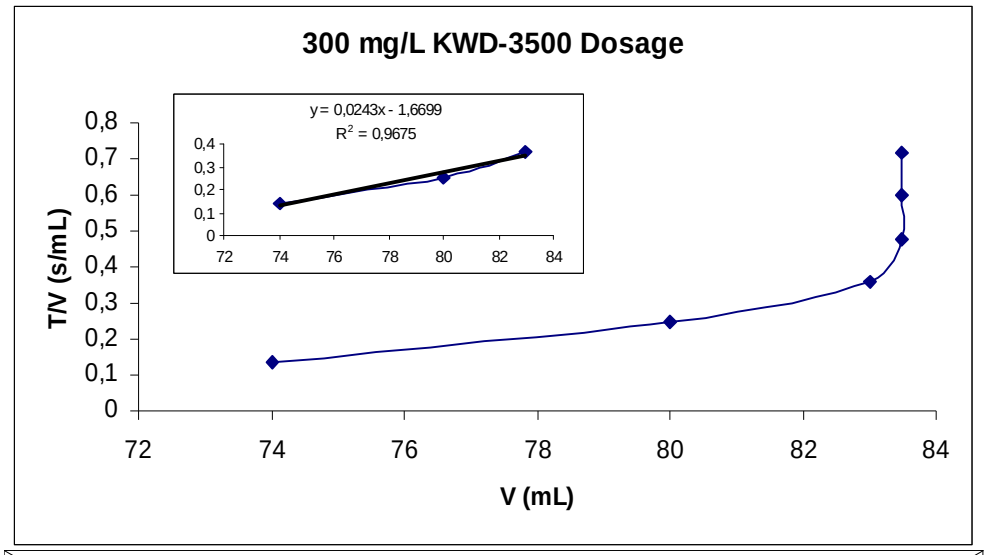


Figure 6.15 T/V values versus filtrate volume (V) for 300 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

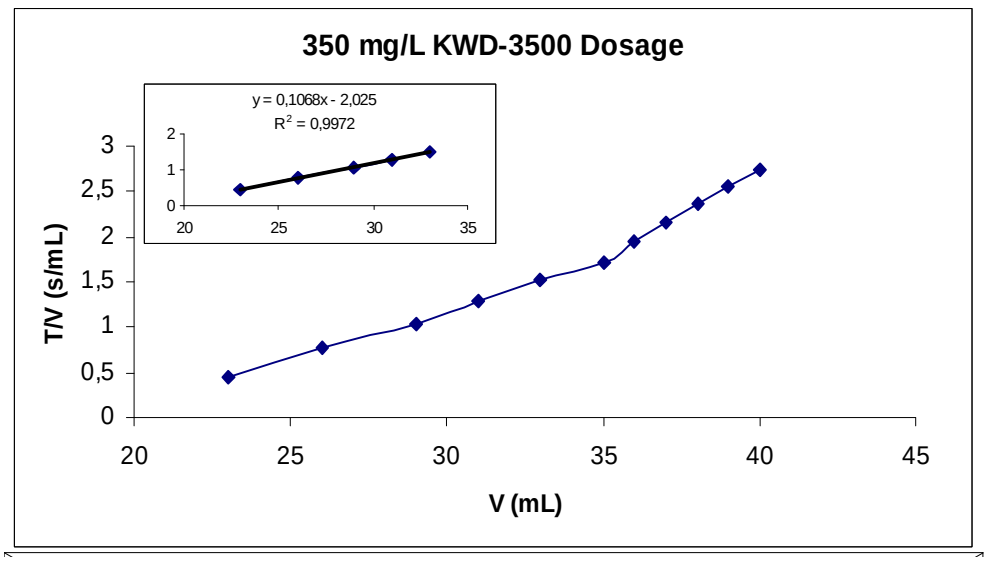


Figure 6.16 T/V values versus filtrate volume (V) for 350 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

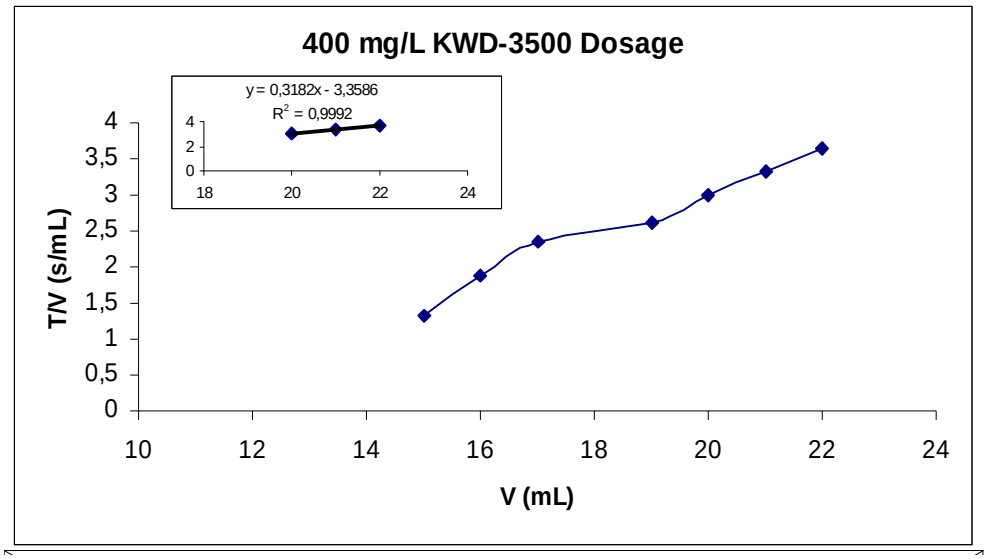


Figure 6.17 T/V values versus filtrate volume (V) for 400 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

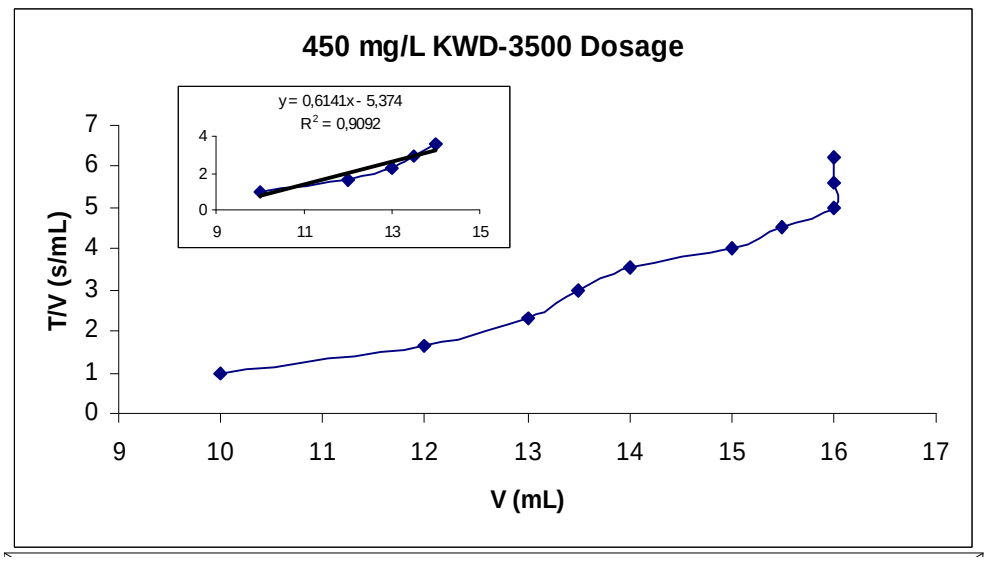


Figure 6.18 T/V values versus filtrate volume (V) for 450 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

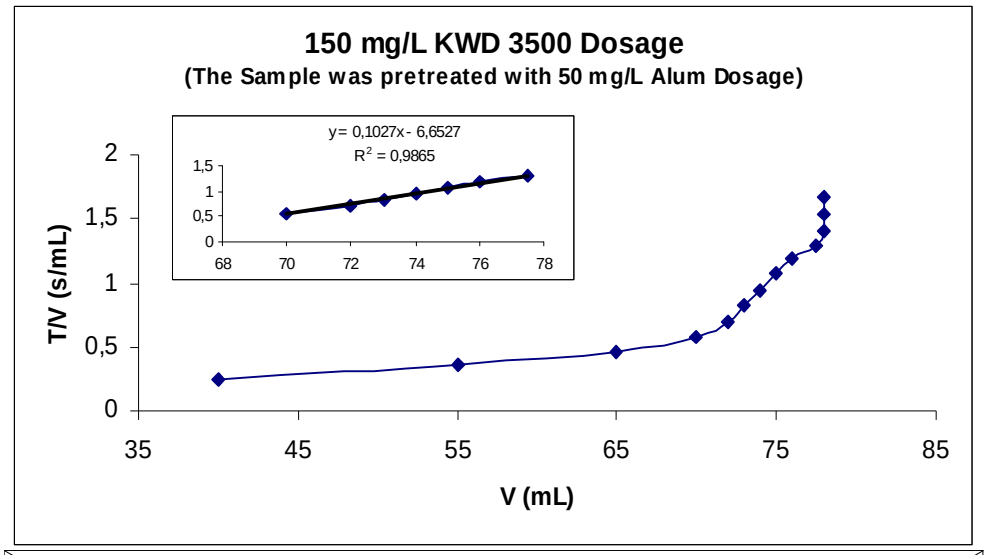


Figure 6.19 T/V values versus filtrate volume (V) for 150 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample pretreated with 50 mg/L alum dosage. Inset: The data applied linear regression

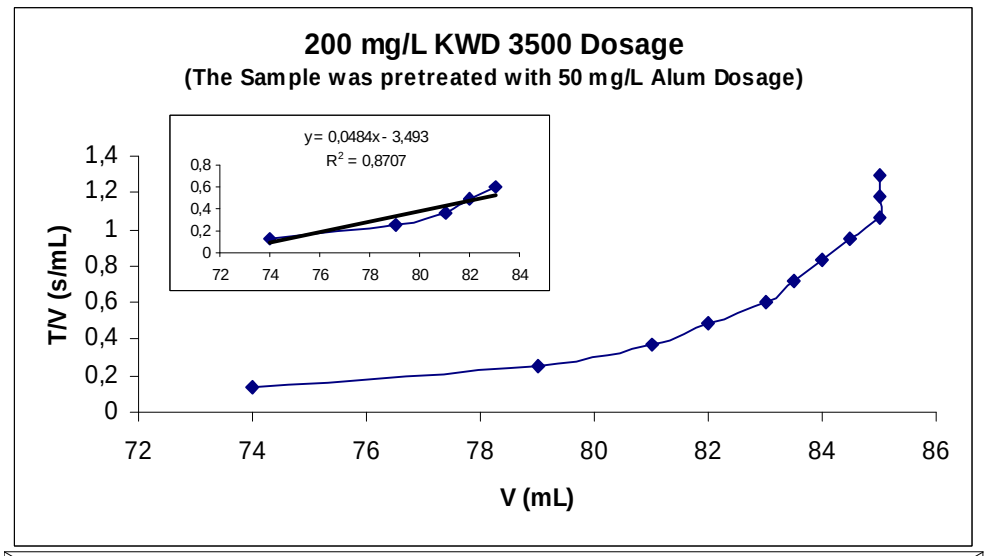


Figure 6.20 T/V values versus filtrate volume (V) for 200 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample pretreated with 50 mg/L alum dosage. Inset: The data applied linear regression

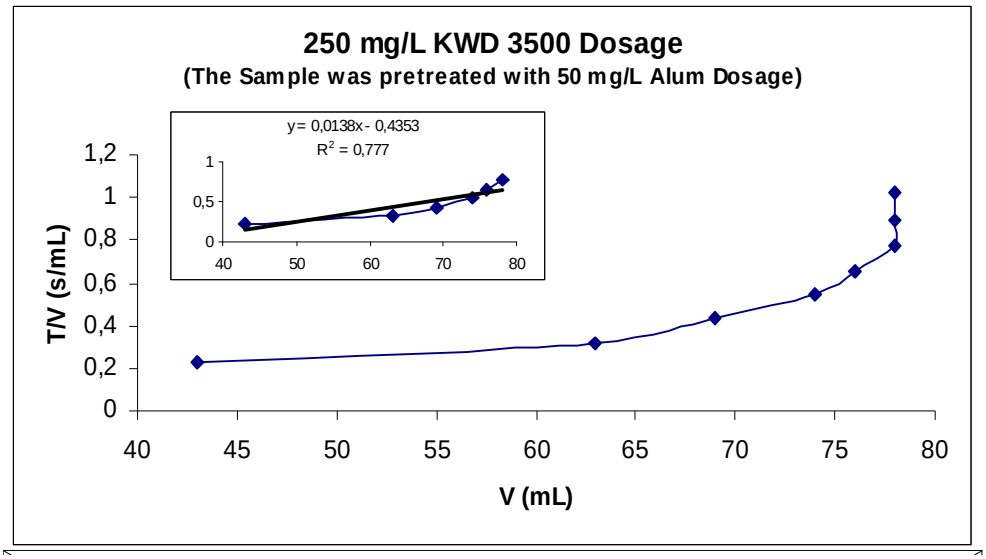


Figure 6.21 T/V values versus filtrate volume (V) for 250 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample pretreated with 50 mg/L alum dosage. Inset: The data applied linear regression

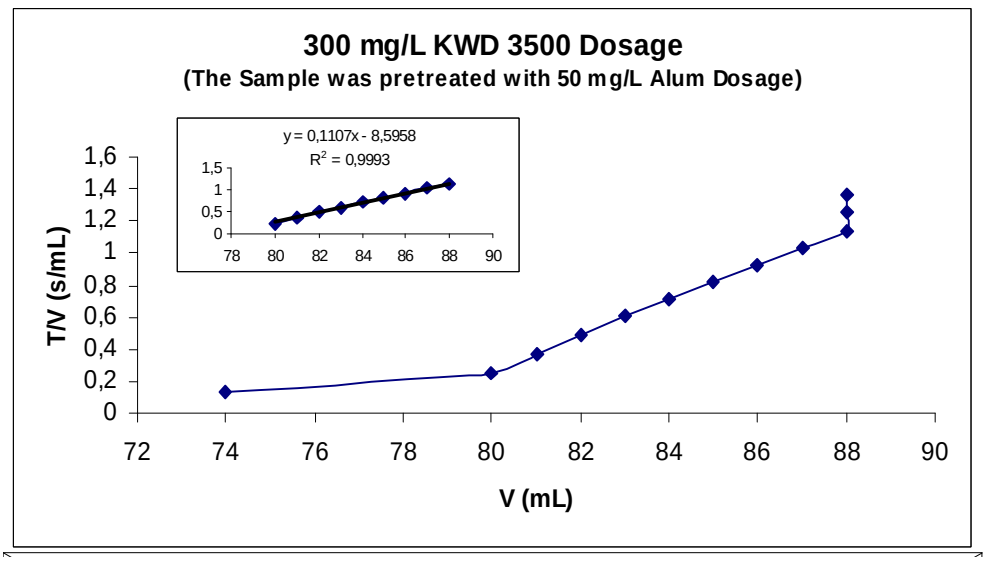


Figure 6.22 T/V values versus filtrate volume (V) for 300 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample pretreated with 50 mg/L alum dosage. Inset: The data applied linear regression

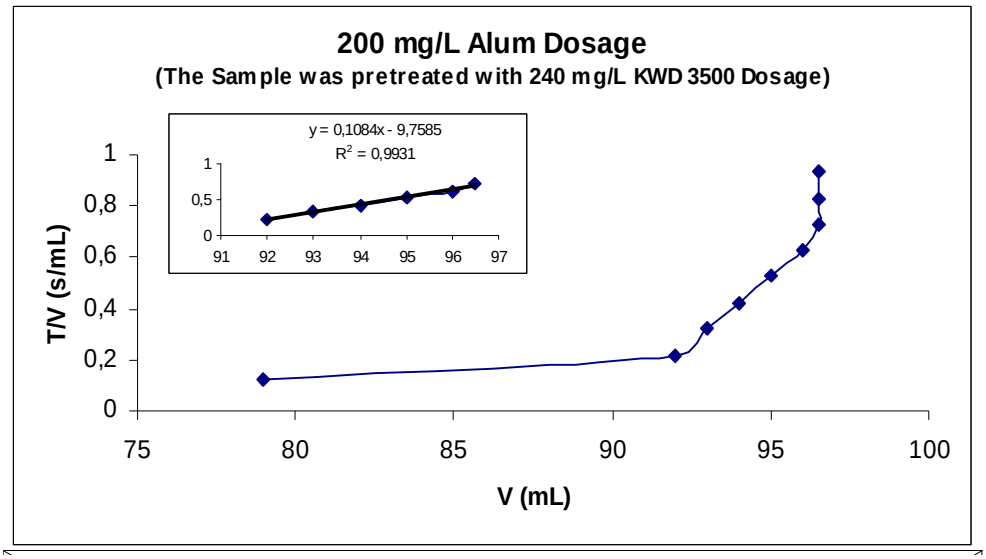


Figure 6.23 T/V values versus filtrate volume (V) for 200 mg/L alum dosage applied to the sludge sample pretreated with 240 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

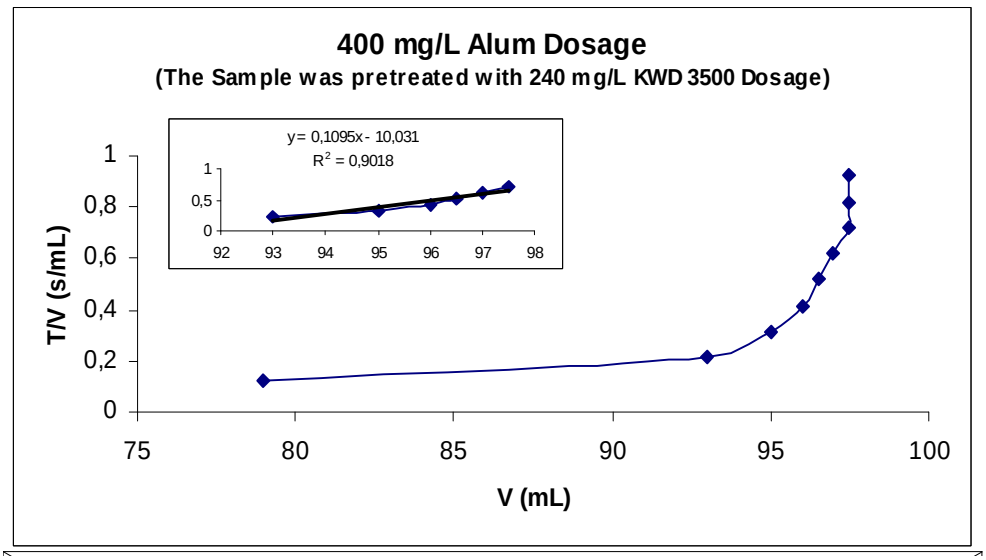


Figure 6.24 T/V values versus filtrate volume (V) for 400 mg/L alum dosage applied to the sludge sample pretreated with 240 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

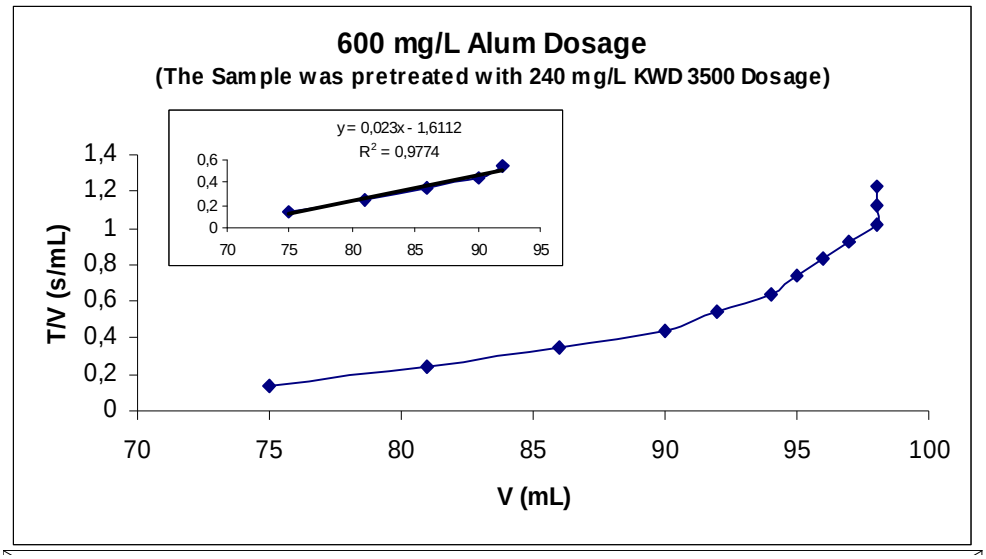


Figure 6.25 T/V values versus filtrate volume (V) for 600 mg/L alum dosage applied to the sludge sample pretreated with 240 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

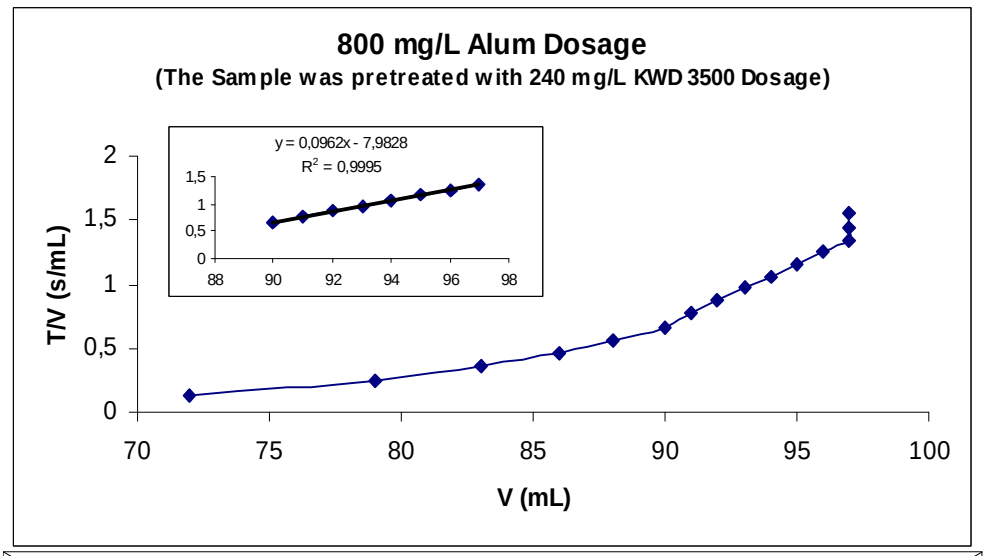


Figure 6.26 T/V values versus filtrate volume (V) for 800 mg/L alum dosage applied to the sludge sample pretreated with 240 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

Table 6.2 Buchner Funnel Test results of raw and conditioned sludge samples with different dosages of KWD 3500 cationic polyelectrolyte.

Dosage		**Dry Solids Content of Filtrate**		**Organic Solids Content of Filtrate**		**Dry Solids Content of Cake (%)**	**b (s/cm^6)**	**Filtrate Viscosity (mPa.s)**	**r (m/kg)**
mg/L	**mg/kg DS**	**mg/L**	**%**	**mg/L**	**%**				
0	0	15388	1,58	5892	58,92	13,14	0,0435	1,25	8,58E+13
5	500	44768	4,47	6405	64,05	-	0,0952	1,25	-
10	1000	37443	3,73	6347	63,47	20,54	0,0902	1,25	1,14E+14
15	1500	43192	4,31	6399	63,99	27,25	0,0915	1,25	8,70E+13
20	2000	37064	3,7	6350	63,5	15,93	0,0756	1,25	1,23E+14
50	5000	47004	4,7	6411	64,11	14,31	0,087	1,25	1,58E+14
100	10000	42311	4,23	6399	63,99	14,53	0,0373	1,25	6,65E+13
150	15000	38540	3,85	6366	63,66	17,37	0,0159	1,25	2,37E+13
200	20000	29074	2,9	6378	6378	18,22	0,0484	1,25	6,89E+13
210	21000	31728	3,17	6569	65,69	16,42	0,0154	1,25	2,43E+13
220	22000	34198	3,41	6381	63,81	17,65	0,0569	1,25	2,36E+13
230	23000	17078	1,7	6106	61,06	20	0, 0109	1,25	1,32E+13
240	**24000**	**11234**	**1,12**	**5694**	**56,94**	**20,64**	**0,0104**	**1,25**	**1,31E+13**
250	25000	41397	4,13	7217	7217	15,85	0,0228	1,25	3,73E+13
300	30000	12520	1,25	6556	65,56	17,35	0,0243	1,25	3,63E+13
350	35000	22576	2,25	6409	64,09	7,92	0,1068	1,25	3,50E+14
400	40000	19433	1,94	6274	62,74	-	0,3182	1,25	-
450	45000	28688	2,86	6905	69,05	-	0,6141	1,25	-
240K 200A	24000K 2000A	31098	3,1	6112	61,12	19,98	0,1084	1,25	1,41E+14
240K 400A	24000K 4000A	38965	3,89	6498	64,98	19,99	0,1095	1,25	1,42E+14
240K 600A	24000K 6000A	37256	3,72	6519	65,19	20,03	0,023	1,25	2,98E+13
240K 800A	24000K 8000A	38972	3,89	6498	64,98	19,83	0,0962	1,25	1,26E+14
50A 150K	500A 15000K	32812	3,28	6521	65,21	18,73	0,1027	1,25	1,42E+14
50A 200K	500A 20000K	33214	3,32	6432	64,32	19,98	0,0484	1,25	6,28E+13
50A 250K	500A 25000K	32008	3,2	6500	65	18,92	0,0138	1,25	1,89E+13
50A 300K	500A 30000K	39087	3,9	6502	65,02	19,01	0,1107	1,25	1,51E+14

As shown in Table 6.2, it can not be obtained any relationship between polyelectrolyte dosages and dry solids content of filtrate. Filtrate viscosity values were measured as 1,25 mPa.s for each sample. Minimum r, $1{,}31 \times 10^{13}$ m/kg, was achieved at 240 mg/L KWD 3500 dosage and dry solids content of the cake was found to be a high value of 20,64%. At higher dosages than 240 mg/L, increased r values obtained with the increases in KWD 3500 doses. Optimum KWD 3500 dosage ranged from 200 to 250 mg/L based on r value results.

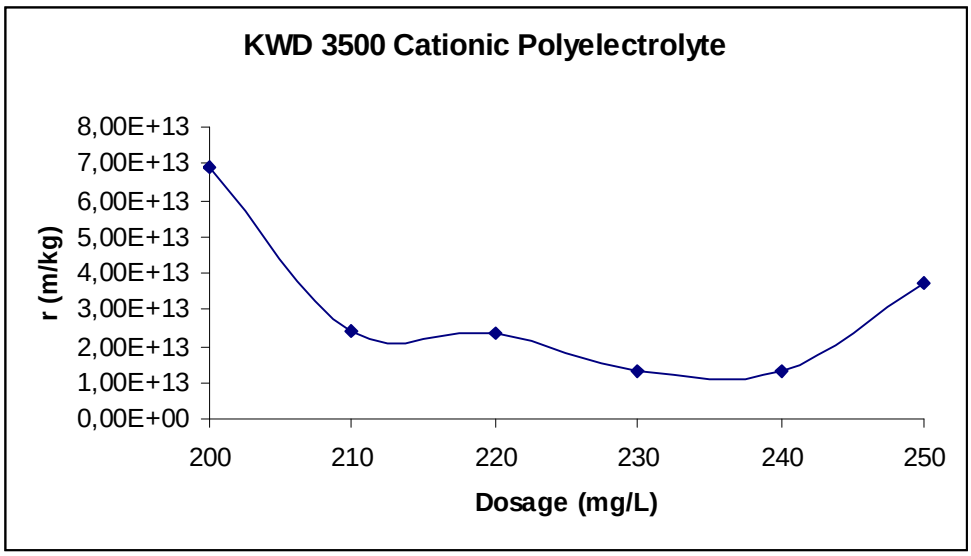


Figure 6.27 Specific Resistance to Filtration (r) values versus KWD 3500 dosage

6.1.3 Capillary Suction Time Test Results of KWD 3500 Cationic Polyelectrolyte

After jar test trials, Capillary Suction Time (CST) test was applied to conditioned sludge samples for evaluation of their dewatering capacity. Results of CST measurements of conditioned sludge samples at different dosages of KWD 3500 cationic polyelectrolyte are shown in Table 6.3 and the CST values as a function of polyelectrolyte dosage is plotted in Figure 6.28.

Table 6.3 Results of Capillary Suction Time measurements of raw and conditioned sludge samples with KWD 3500 cationic polyelectrolyte

Dosage		**Capillary Suction Time**
mg/L	**mg/kg DS**	**s**
0	0	76,0
5	500	115,1
10	1000	103,5
15	1500	120,0
20	2000	77,6
50	5000	126,3
100	10000	25
150	15000	24,4
200	20000	9,1
210	21000	11,6
220	22000	11,6
230	23000	9,0
240	**24000**	**7,8**
250	25000	10,5
300	30000	8,7
350	35000	10,5
400	40000	27,4
450	45000	44,1
240K 200A	24000K 2000A	12,1
240K 400A	24000K 4000A	13,9
240K 600A	24000K 6000A	15,6
240K 800A	24000K 8000A	22,1
50A 150K	500A 15000K	13,1
50A 200K	500A 20000K	14,8
50A 250K	500A 25000K	13,9
50A 300K	500A 30000K	14,1

When 240 mg/L KWD 3500 was added to the sludge sample, minimum 7,8 s of CST was achieved as shown in Table 6.3 and Figure 6.28. Dry solids content of the sludge cake was found to be 19,12% at this dosage. Considering the CST test results, optimum KWD 3500 dose range was determined between 200 mg/L and 250 mg/L.

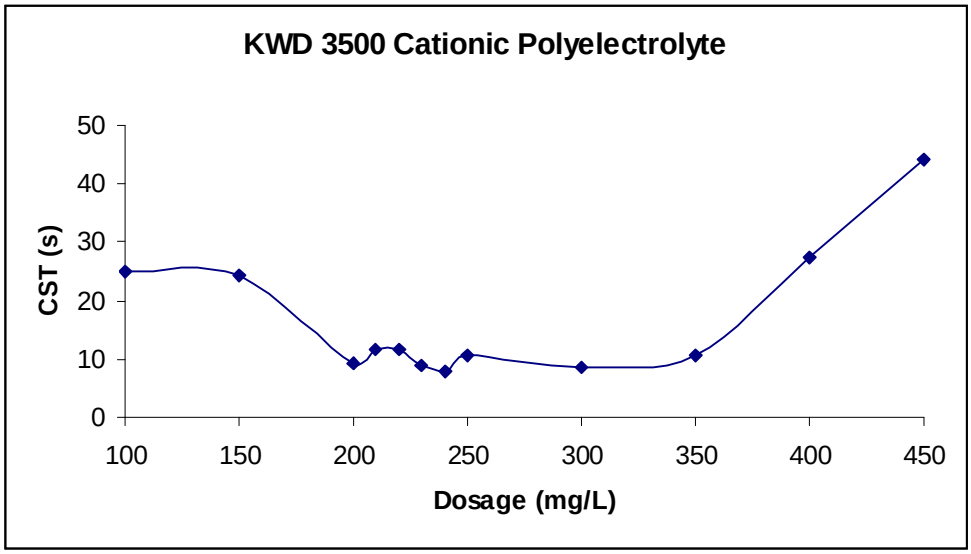


Figure 6.28 Capillary Suction Time (CST) values versus KWD 3500 dosage

6.1.4 Results of Centrifugal Settleability Index Measurements for KWD 3500 Cationic Polyelectrolyte Applications

To evaluate sludge dewaterability for centrifugal dewatering processes, centrifugal settleability index (CSI) parameter was analysed. Suspended solid values of aerobic stabilized sludge and centrate samples and CSI values of aerobic stabilized sludge are given in Table 6.4.

Figure 6.29 shows the CSI values at different dosages of KWD 3500 cationic polyelectrolyte.

Table 6.4 Results of CSI Measurements of raw and conditioned aerobic stabilized sludge samples with KWD 3500 cationic polyelectrolyte

Dosage		**Suspended Solids of Sludge (mg/L)**	**Suspended Solids of Centrate (mg/L)**	**Centrifugal Settleability Index (CSI) (%)**
mg/L	**mg/kg DS**			
0	0	15000	100	99,33
5	500	10000	100	99
10	1000	10000	100	99
15	1500	12000	30	99,75
20	2000	11000	50	99,54
50	5000	47000	1330	97,17
100	10000	88000	2350	97,32
150	15000	59000	1540	97,38
200	20000	22000	600	97,27
210	21000	50000	540	98,92
220	22000	56000	580	98,96
230	23000	34000	340	99
240	**24000**	**34000**	**340**	**99**
250	25000	24000	770	96,79
300	30000	34000	310	99,08
350	35000	36000	416	98,84
400	40000	48000	550	98,85
450	45000	102000	2000	98,03
240K 200A	24000K 2000A	20000	1000	95
240K 400A	24000K 4000A	22000	1800	91,81
240K 600A	24000K 6000A	20000	1500	92,5
240K 800A	24000K 8000A	18000	1800	90
50A 150K	500A 15000K	17500	1500	91,42
50A 200K	500A 20000K	18000	1700	90,55
50A 250K	500A 25000K	19000	1600	91,57
50A 300K	500A 30000K	22000	1800	91,81

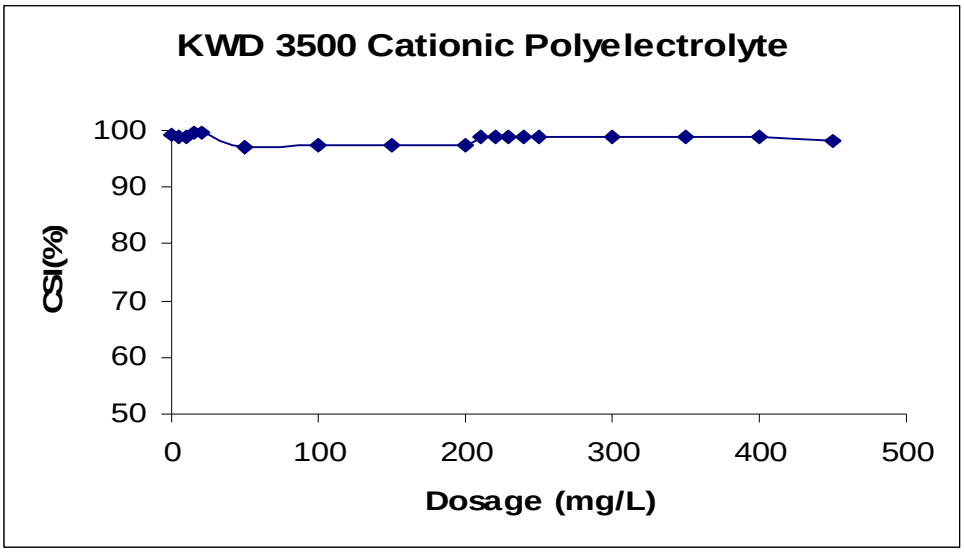


Figure 6.29 CSI values versus KWD 3500 dosage

6.2 Conditioning Experiments of SNF 5980 Cationic Polyelectrolyte Applications to Aerobic Stabilized Sludge Samples

6.2.1 Jar Test Results of SNF 5980 Cationic Polyelectrolyte Applications

In the experiments by using SNF 5980 cationic polyelectrolyte, 5 to 200 mg/L dose range of polyelectrolyte was used to get aerobic stabilized conditioned sludge.

Then different amounts of SNF 5980 cationic polyelectrolyte ranged from 10 to 50 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 50 mg/L alum (aluminum hydroxyde 18 hydrate) dosage by the same method determined in Chapter 6.1.1.

As opposed to the precondition determined in above, different amounts of alum ranged from 200 to 800 mg/L were dosed to aerobic stabilized sludge samples pretreated with 45 mg/L SNF 5980 cationic polyelectrolyte dosage. Results of the jar test experiments are shown in table 6.5.

Table 6.5 Jar test results of SNF 5980 cationic polyelectrolyte

Dosage		**Settled Sludge Volume (mL)**	**Supernatant Turbidity (JTU)**	**Sludge Properties**
mg/L	**mg/L DS**			
5	500	150	40	Thin flocs
10	1000	180	55	Middle sized flocs
25	2500	200	60	Big flocs
30	3000	250	80	Big flocs
35	3500	250	90	Big flocs
40	4000	250	90	Big flocs
45	4500	300	80	Big flocs
50	5000	200	50	Very big flocs
100	10000	200	40	Midlle sized flocs
200	20000	300	75	Big flocs
10 cp, 50 alum	1000, 5000	280	50	Thin flocs
25 cp, 50 alum	2500, 5000	280	45	Thin flocs
50 cp, 50 alum	5000, 5000	300	50	Thin flocs
45 cp, 200 al.	4500, 20000	280	10	Middle sized flocs
45 cp, 400 al.	4500, 40000	280	10	Thin flocs
45 cp, 600 al.	4500, 60000	290	10	Thin flocs
45 cp, 800 al.	4500, 80000	300	10	Very thin flocs

Where, cp: SNF 5980 cationic polyelectrolyte and al.: Alum

6.2.2 Buchner Funnel Test Results of SNF 5980 Cationic Polyelectrolyte Applications

Buchner Funnel Test was applied to aerobic stabilized conditioned sludge samples (between 5 to 200 mg/L dosage of SNF 5980 cationic polyelectrolyte) to calculate the specific resistance to filtration.

In the experiments it was observed that aerobic stabilized raw sludge is not filtrable. As opposed to the observation, the filtration data of aerobic stabilized conditioned sludge samples obtained from the Buchner Funnel Test is reported in Appendix B. T/V ratios versus V were plotted and the slope of linear portion of samples are presented between Figure 6.30 and Figure 6.46.

Dry solids content and viscosity values of filtrate samples and dry matter content of sludge cakes taken from the filter and the slope (b) of linear portion of T/V versus V curve and r values are given in Table 6.6. r values versus SNF 5980 cationic polyelectrolyte dosage are also depicted in Figure 6.47 for determination of optimum polyelectrolyte dosage.

As shown in Table 6.5, it can not be obtained a relationship between polyelectrolyte dosages and dry solids content of filtrate. Filtrate viscosity values were measured as 1,25 mPa.s for each sample. Minimum r, $1{,}17 \times 10^{14}$ mg/kg, was achieved at 45 mg/L SNF 5980 dosage and dry solids content of the sludge cake was found to be a high value of 20,3%. At higher dosages than 45 mg/L, increased r values were obtained with the increases in SNF 5980 dosage ranged from 40mg/L to 45mg/L based on r results.

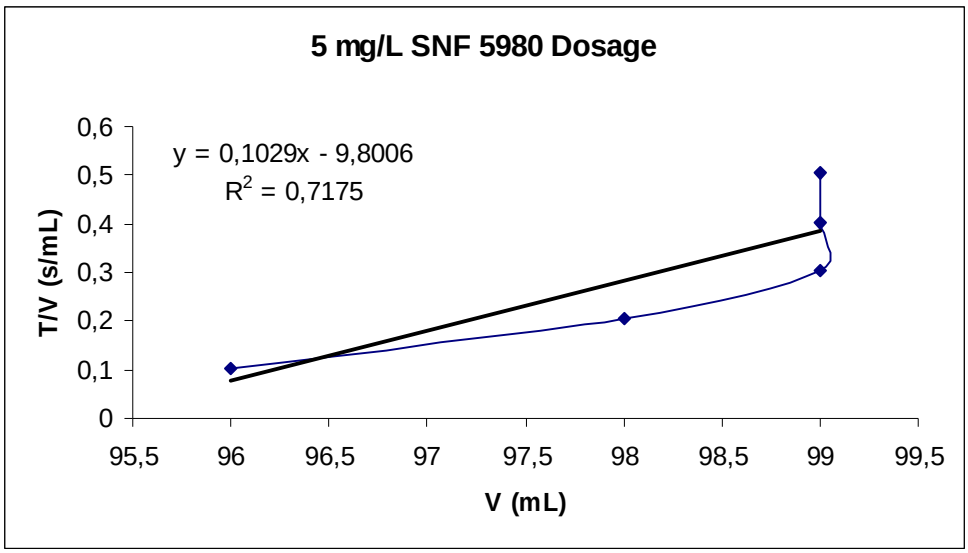


Figure 6.30 T/V values versus filtrate volume (V) for 5mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

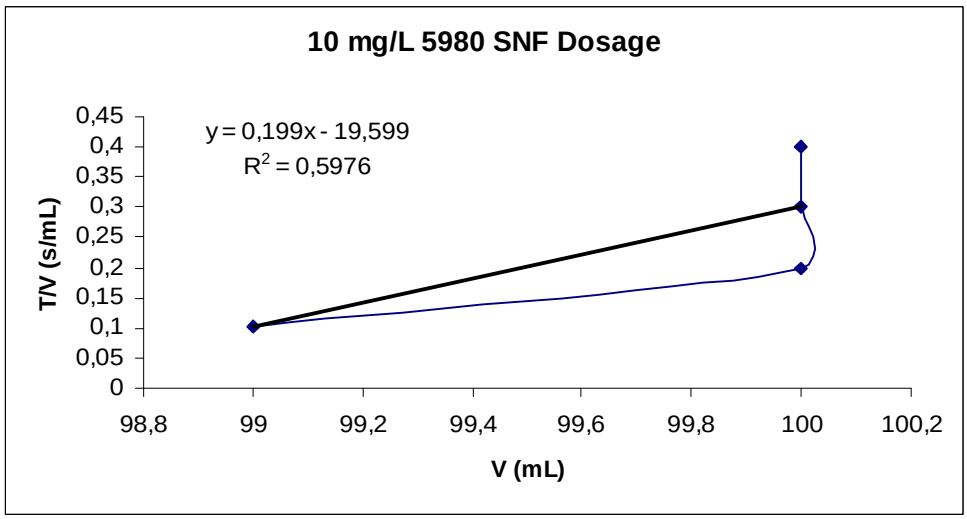


Figure 6.31 T/V values versus filtrate volume (V) for 10mg/L SNF 5980 cationic polyelectrolyte dosage.

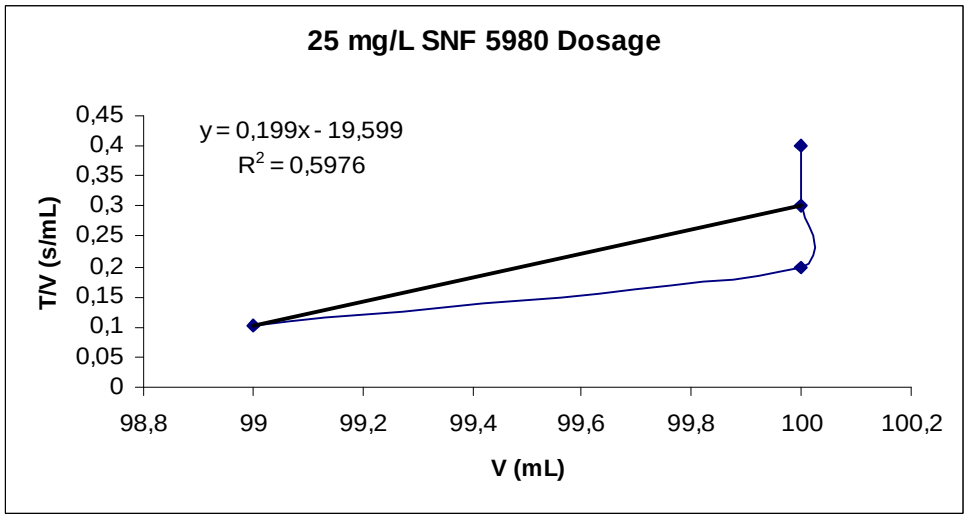


Figure 6.32 T/V values versus filtrate volume (V) for 25 mg/L SNF 5980 cationic polyelectrolyte dosage.

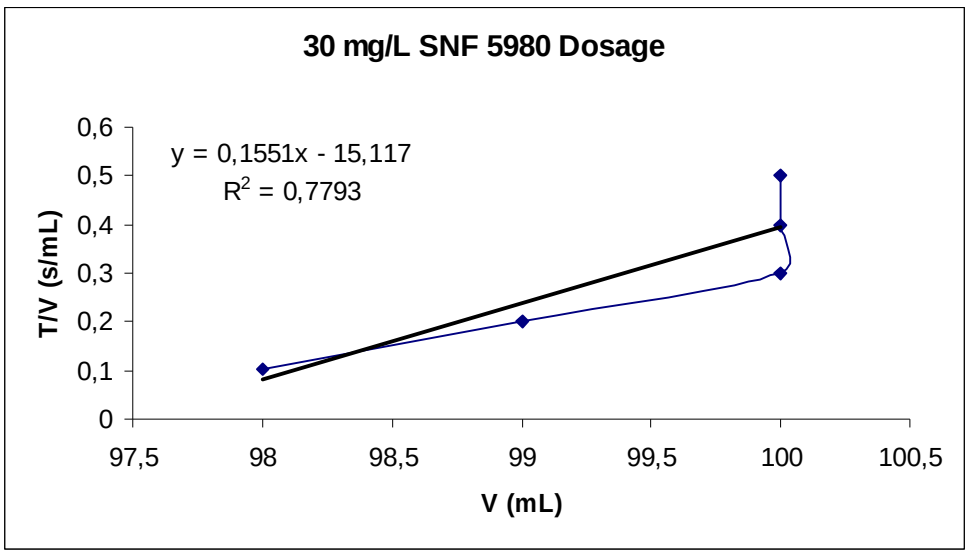


Figure 6.33 T/V values versus filtrate volume (V) for 30 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

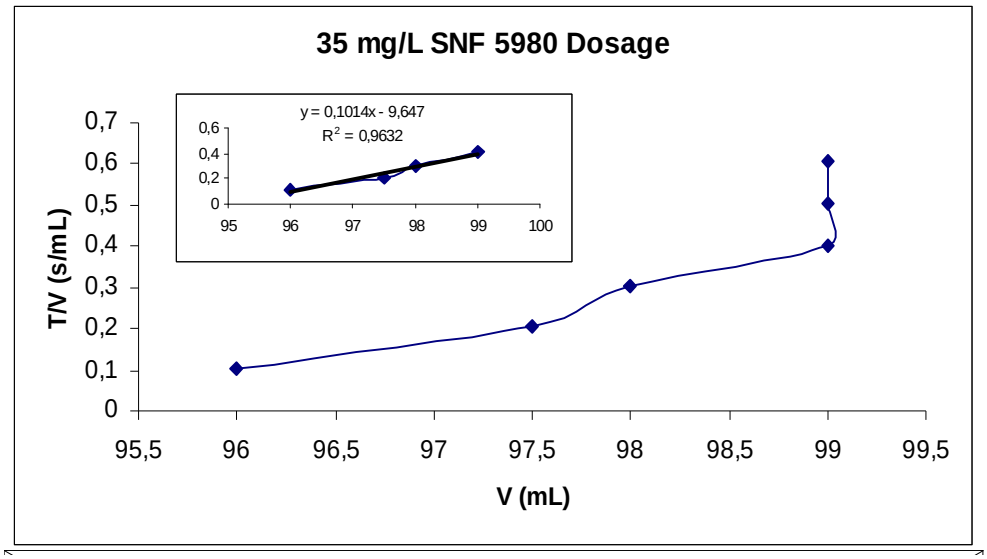


Figure 6.34 T/V values versus filtrate volume (V) for 35 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

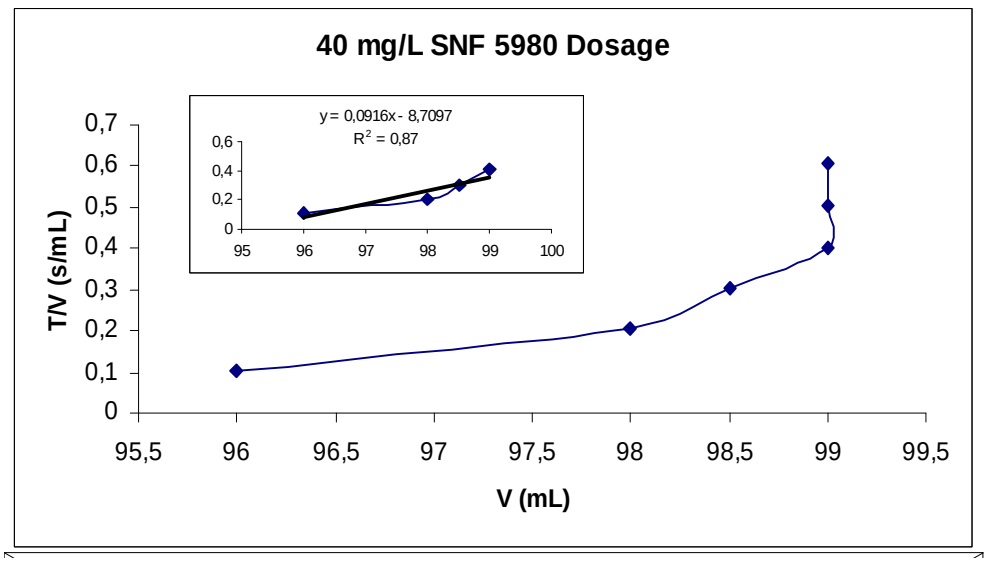


Figure 6.35 T/V values versus filtrate volume (V) for 40 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

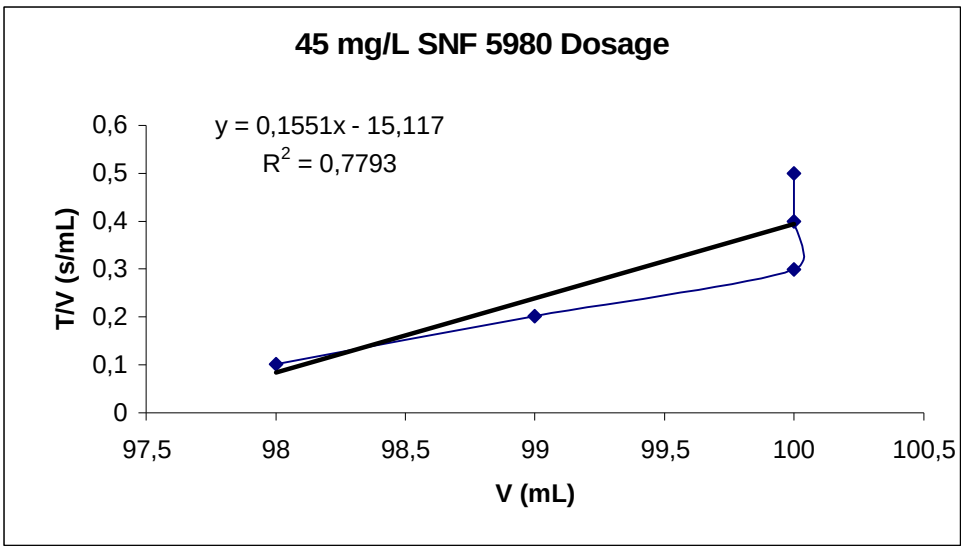


Figure 6.36 T/V values versus filtrate volume (V) for 45 mg/L SNF 5980 cationic polyelectrolyte dosage.

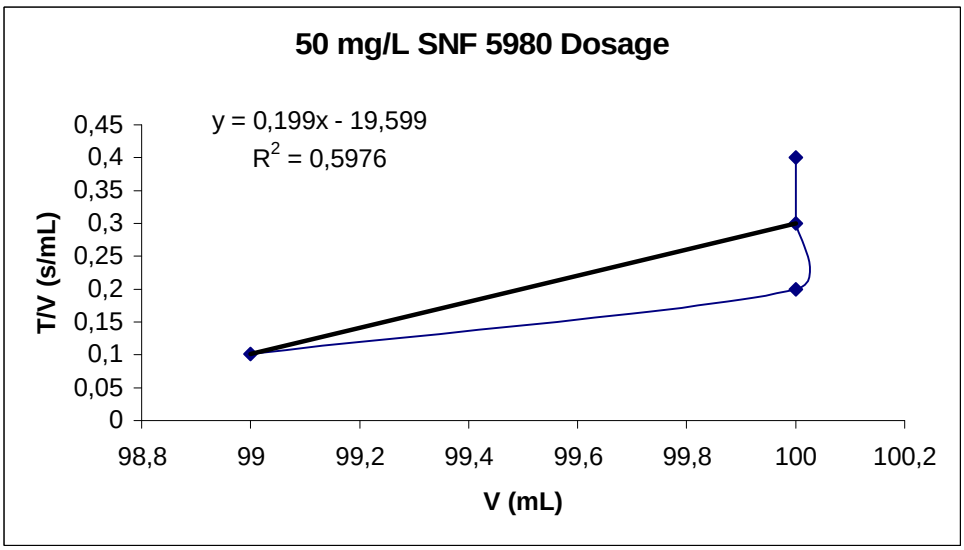


Figure 6.37 T/V values versus filtrate volume (V) for 50 mg/L SNF 5980 cationic polyelectrolyte dosage.

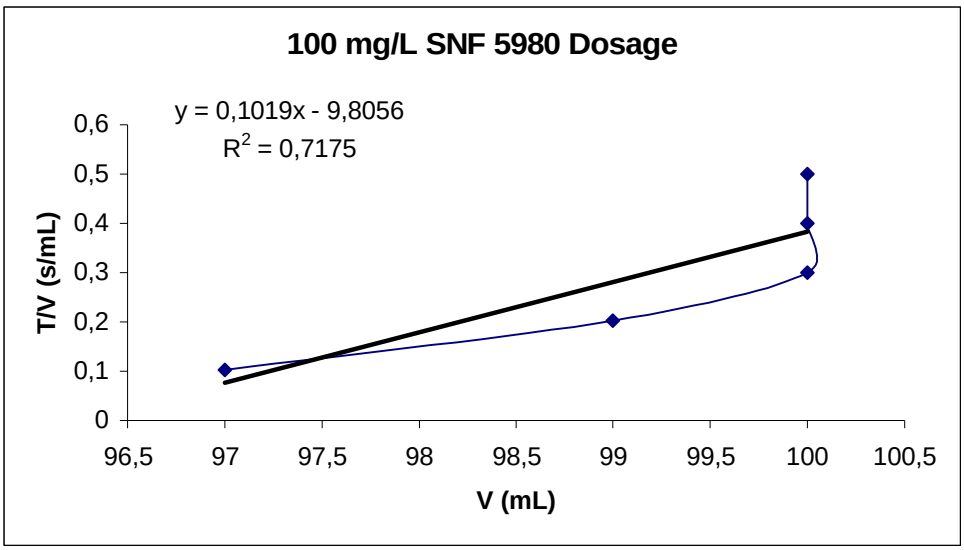


Figure 6.38 T/V values versus filtrate volume (V) for 100 mg/L SNF 5980 cationic polyelectrolyte dosage.

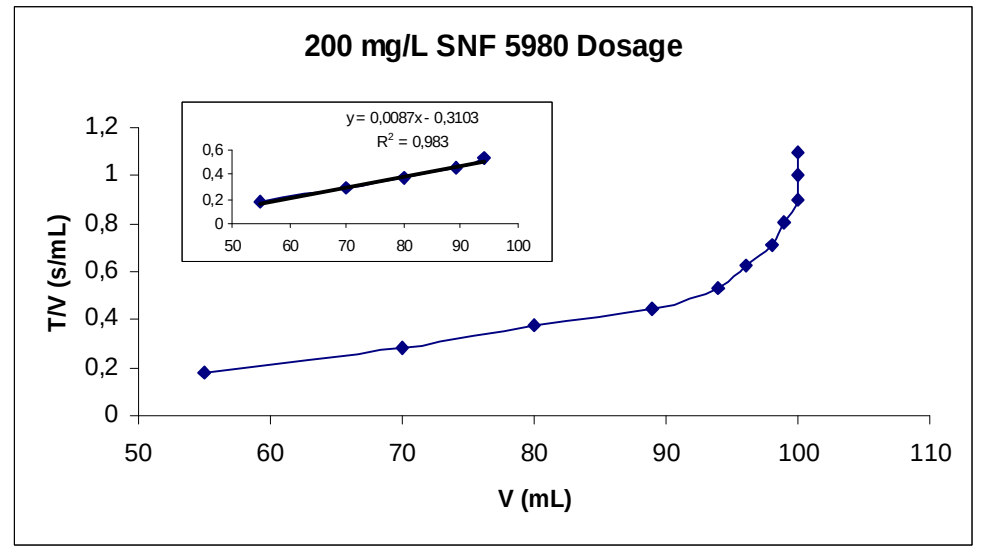


Figure 6.39 T/V values versus filtrate volume (V) for 200 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

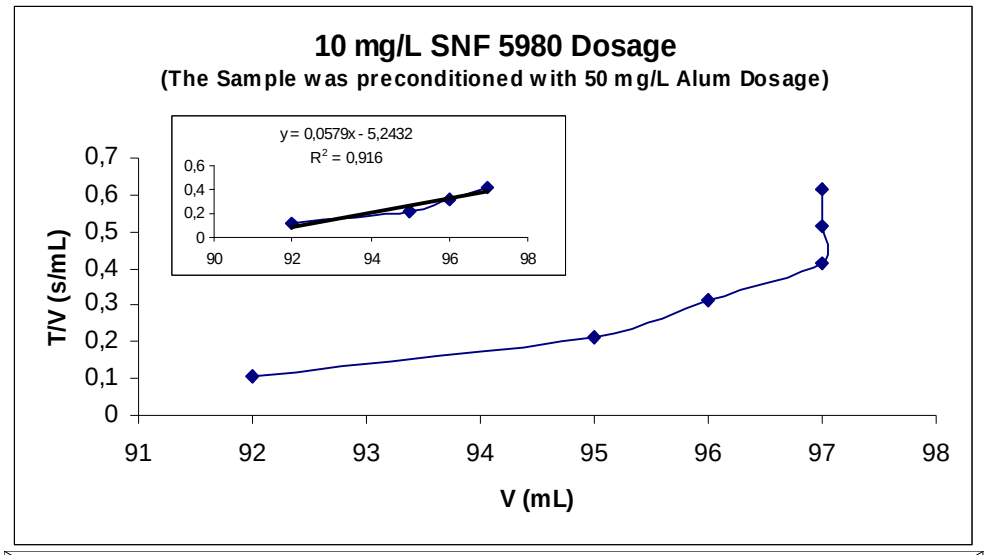


Figure 6.40 T/V values versus filtrate volume (V) for 10 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

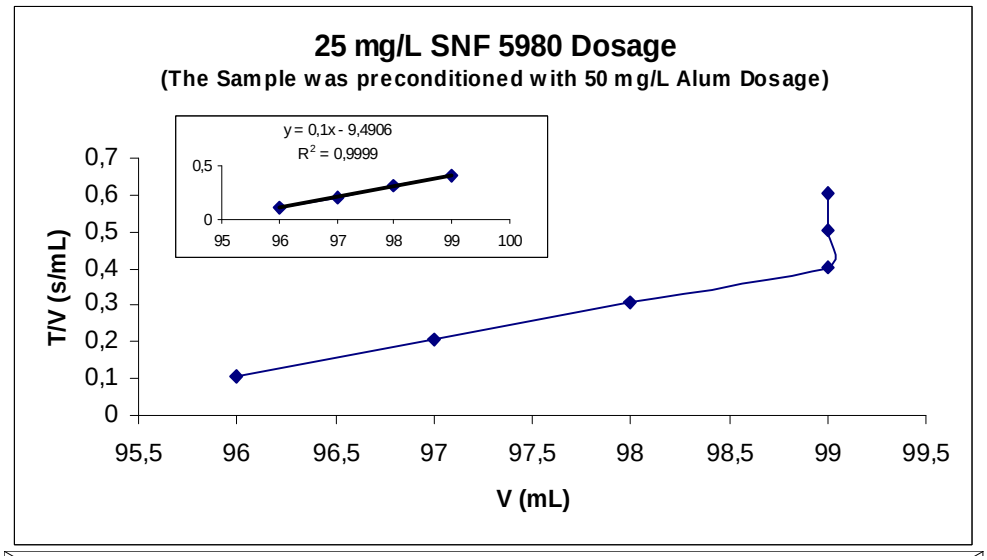


Figure 6.41 T/V values versus filtrate volume (V) for 25 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

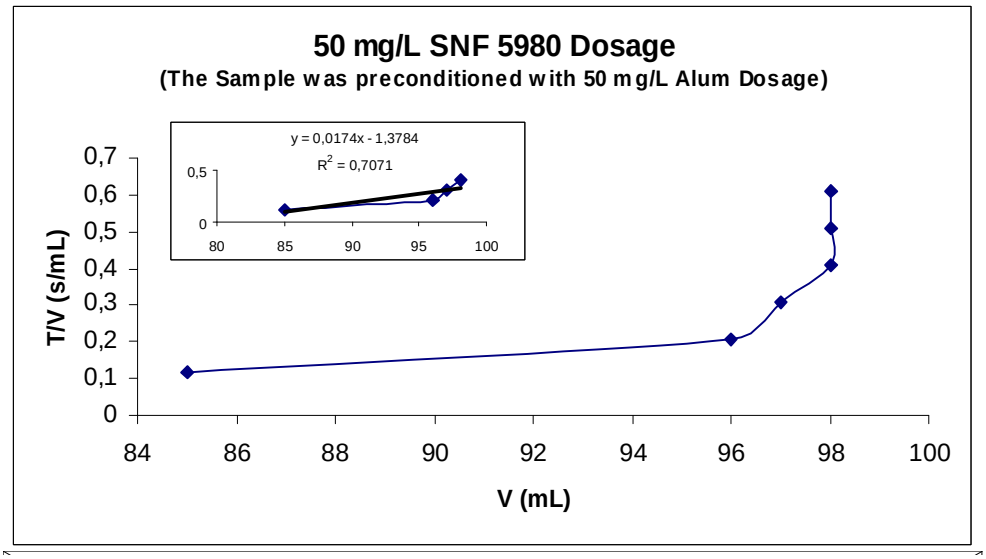


Figure 6.42 T/V values versus filtrate volume (V) for 50 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

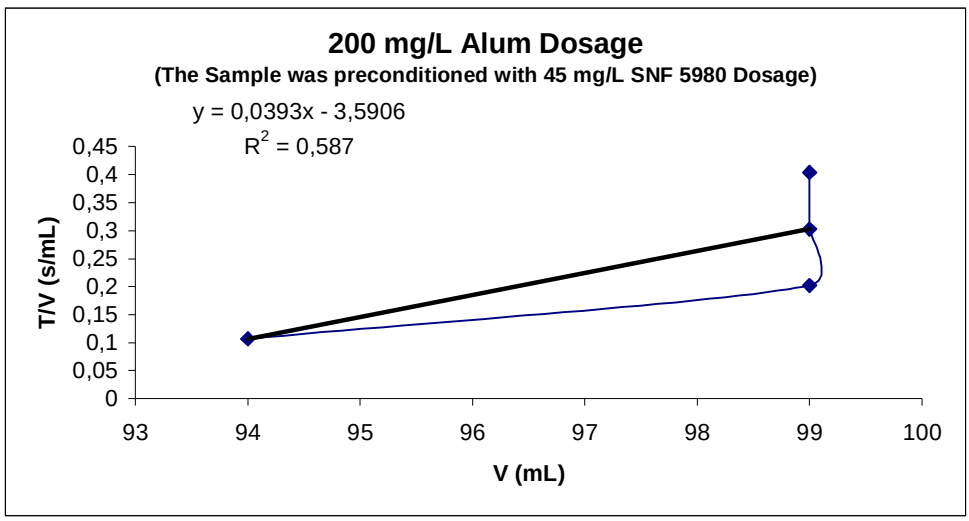


Figure 6.43 T/V values versus filtrate volume (V) for 200 mg/L alum dosage applied to the sludge sample preconditioned with 45 mg/L SNF 5980 cationic polyelectrolyte dosage.

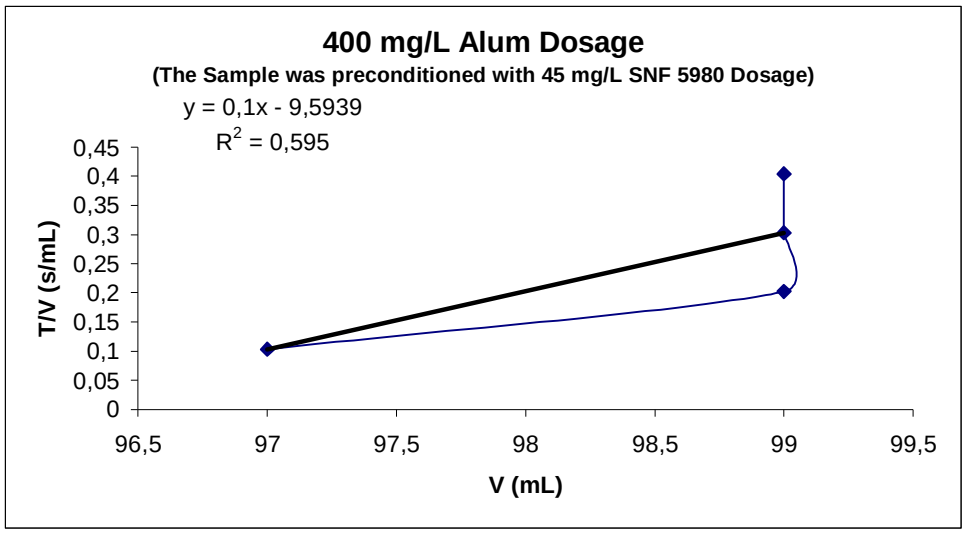


Figure 6.44 T/V values versus filtrate volume (V) for 400 mg/L alum dosage applied to the sludge sample preconditioned with 45 mg/L SNF 5980 cationic polyelectrolyte dosage.

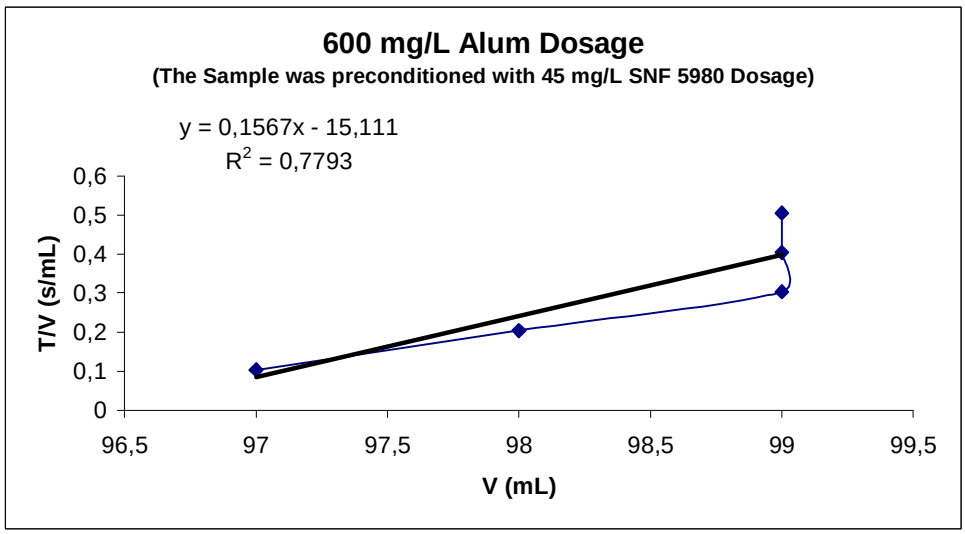


Figure 6.45 T/V values versus filtrate volume (V) for 600 mg/L alum dosage applied to the sludge sample preconditioned with 45 mg/L SNF 5980 cationic polyelectrolyte dosage.

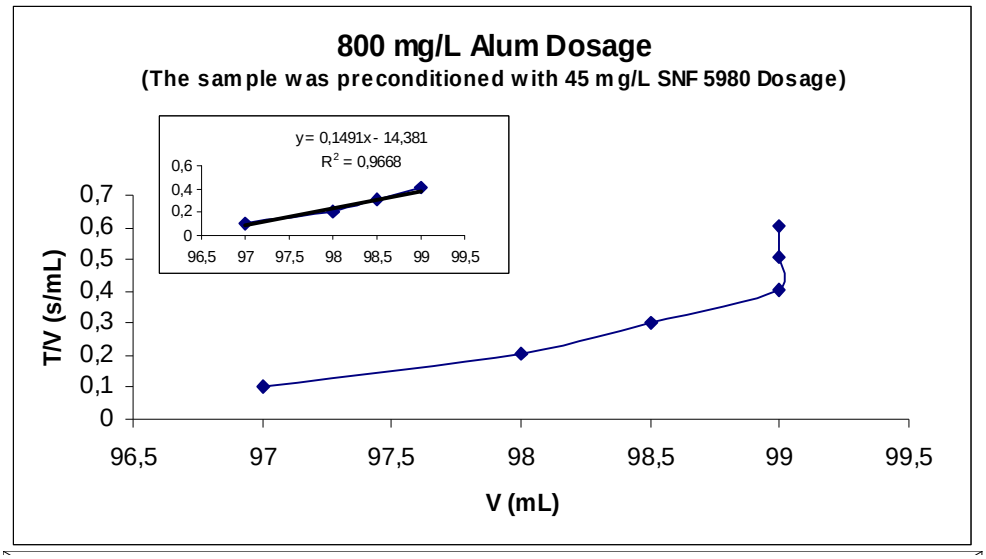


Figure 6.46 T/V values versus filtrate volume (V) for 800 mg/L alum dosage applied to the sludge sample preconditioned with 45 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

Table 6.6 Buchner Funnel Test Results of conditioned sludge samples with different dosages of SNF 5980 cationic polyelectrolyte

Dosage		**Dry Solids Content of Filtrate**		**Organic Solids Content of Filtrate**		**Dry Solids Content of Cake (%)**	**b (s/cm^6)**	**Filtrate Viscosity (mPa.s)**	**r (m/kg)**
mg/L	**mg/kg DS**	**mg/L**	**%**	**mg/L**	**%**				
HAM	0	0,49	4920	53,252	5325	6,42	-	1,25	-
5	500	0,71	7112	51,55	5155	14,34	0,064	1,25	1,16E+14
10	1000	0,69	6976	56,54	5654	13,98	0,199	1,25	3,69E+14
25	2500	0,69	6928	57,33	5733	16,74	0,199	1,25	3,08E+14
30	3000	0,7	7032	65,32	6532	18,56	0,149	1,25	2,08E+14
35	3500	0,52	5216	66,31	6631	19,85	0,1014	1,25	1,32E+14
40	4000	0,46	4696	76,81	7681	20,3	0,0916	1,25	1,17E+14
45	**4500**	**0,62**	**6233**	**68,27**	**6827**	**19,12**	**0,1551**	**1,25**	**2,10E+14**
50	5000	0,29	2928	44,94	4494	16,95	0,199	1,25	3,04E+14
100	10000	0,45	4592	54,33	5433	18,42	0,1019	1,25	1,43E+14
200	20000	0,51	5120	55,37	5537	17,46	0,0087	1,25	1,29E+13
45cp 200al	4500cp 2000al	0,96	9668	55,84	5584	4,59	0,0393	1,25	2,22E+14
45cp 400al	4500cp 4000al	0,89	8962	52,53	5253	5,12	0,1	1,25	5,06E+14
45cp 600al	4500cp 6000al	0,85	8572	51,56	5156	18,22	0,1567	1,25	2,23E+14
45cp 800al	4500cp 8000al	0,78	7868	51,04	5104	17,43	0,1491	1,25	2,22E+14
50al 10cp	500al 1000cp	0,94	9420	57,13	5713	17,59	0,0579	1,25	8,53E+13
50al 25cp	500al 2500cp	0,96	9688	57,78	5778	17,89	0,1	1,25	1,45E+14
50al 50cp	500al 5000cp	1,07	10740	58,51	5851	17,8	0,0174	1,25	2,53E+13

Where, cp: cationic polyelectrolyte and al: alum.

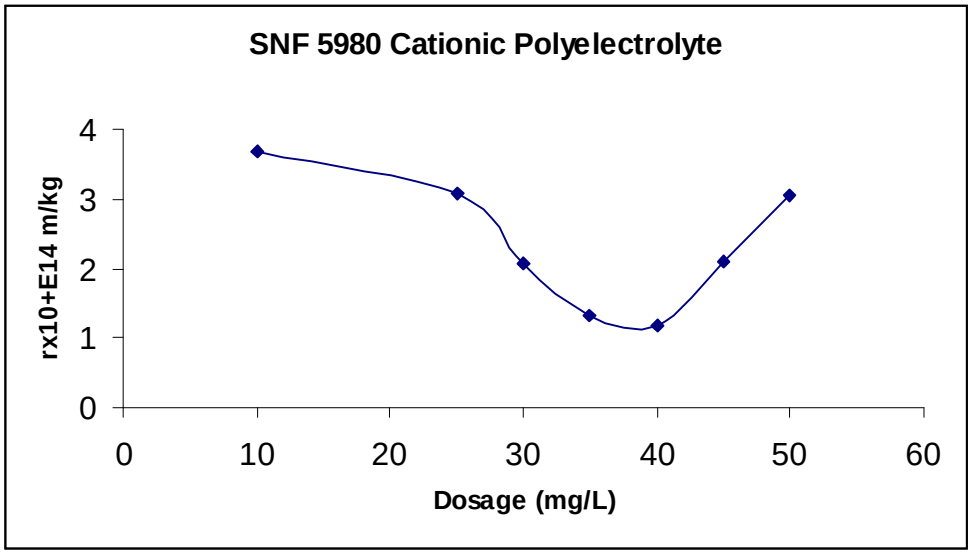


Figure 6.47 Specific Resistance to Filtration (r) values versus SNF 5980 cationic polyelectrolyte dosage

6.2.3 Capillary Suction Time Test Results of SNF 5980 Cationic Polyelectrolyte

After jar test trials, Capillary Suction Time (CST) test was applied to conditioned sludge samples for evaluation of their dewatering capacity. Results of CST measurements of conditioned sludge samples at different dosages of SNF 5980 cationic polyelectrolyte are shown in Table 6.7 and the CST values as a function of polyelectrolyte dosage is plotted in Figure 6.48.

When 45 mg/L SNF 5980 was added to the sludge sample, minimum 7,7 s of CST was achieved as shown in Table 6.7 and Figure 6.48. Dry solids content of the sludge cake was found to be 20,3% at this dosage. Considering the CST test results, optimum SNF 5980 dose range was determined between 40 mg/L and 45 mg/L.

Table 6.50 Results of Capillary Suction Time Measurements of Raw and Conditioned Sludge Samples with SNF 5980 Cationic Polyelectrolyte

Dosage		**Capillary Suction Time**
mg/L	**mg/kg DS**	**s**
0	0	12,5
5	500	5,7
10	1000	10,2
25	2500	7,9
30	3000	8,0
35	3500	8,1
40	4000	8,2
45	**4500**	**7,7**
50	5000	8,3
100	10000	9,4
200	20000	10,1
45cp 200al.	4500 cp, 2000al.	8,8
45cp 400al.	4500 cp, 4000al.	9,2
45cp 600al.	4500 cp, 6000al.	9,8
45cp 800al.	4500 cp, 8000al.	10,6
50al. 10cp	500 al, 1000 cp.	10,8
50al. 25cp.	500 al, 2500 cp.	9,5
50al. 50cp.	500 al, 5000 cp.	12,3

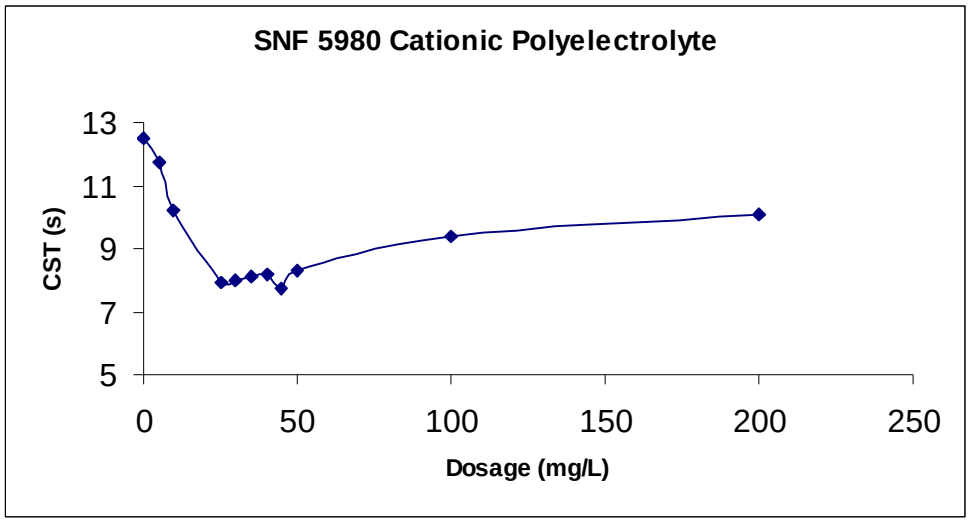


Figure 6.48 Capillary Suction Time (CST) Values versus SNF 5980 Dosage

6.2.4 Results of Centrifugal Settleability Index Measurements for SNF 5980 Cationic Polyelectrolyte Applications

To evaluate sludge dewaterability for centrifugal dewatering processes, centrifugal settleability index (CSI) parameter was analysed. Suspended solid values of sludge and centrate samples and CSI values of sludge samples are given in Table 6.8.

Figure 6.49 shows the CSI values at different dosages of SNF 5980 cationic polyelectrolyte.

Table 6.8 Results of Centrifugal Settleability Index Measurements for SNF 5980 Cationic Polyelectrolyte

Dosage		**Suspended Solids of Sludge (mg/L)**	**Suspended Solids of Centrate (mg/L)**	**Centrifugal Settleability Index (CSI) (%)**
mg/L	**mg/kg DS**			
0	0	4300	170	96,04
5	500	6880	10	99,85
10	1000	2980	30	98,99
25	2500	2880	10	99,65
30	3000	8440	45	99,46
35	3500	8540	50	99,41
40	4000	7100	44	99,38
45	**4500**	**8420**	**54**	**99,35**
50	5000	2140	10	99,53
100	10000	2100	50	97,61
200	20000	5640	75	98,67
45cp 200al.	4500 cp, 2000al.	8940	67	99,25
45cp 400al.	4500 cp, 4000al.	9500	100	98,94
45cp 600al.	4500 cp, 6000al.	7200	100	98,61
45cp 800al.	4500 cp, 8000al.	5660	150	97,34
50al. 10cp	500 al, 1000 cp.	8240	80	99,02
50al. 25cp.	500 al, 2500 cp.	9960	140	98,59
50al. 50cp.	500 al, 5000 cp.	9660	70	99,27

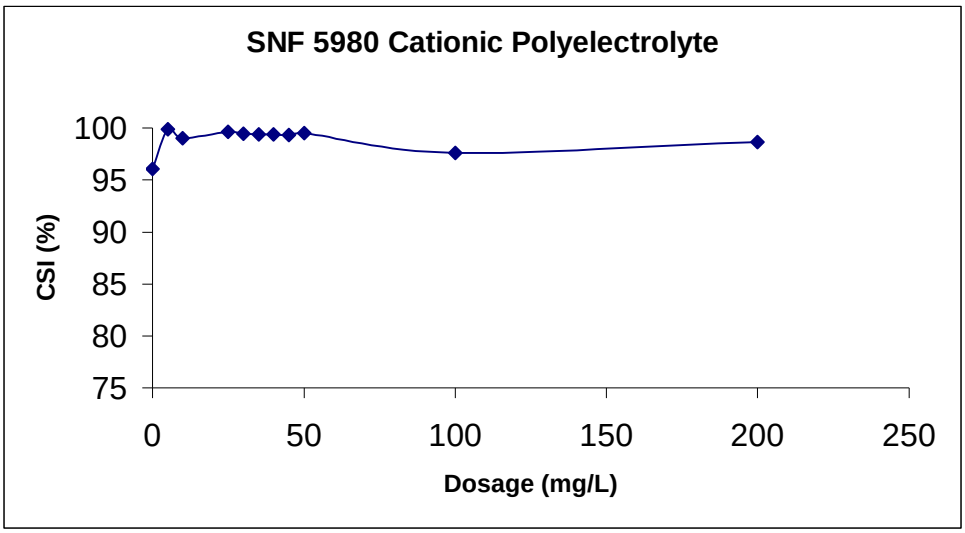


Figure 6.49 CSI values versus SNF 5980 Dosage

6.3 Conditioning Experiments of 5980 SB Cationic Polyelectrolyte Applications to Aerobic Stabilized Sludge Samples

6.3.1 Jar Test Results of 5980 SB Cationic Polyelectrolyte Applications

5980 SB cationic polyelectrolyte ranged from 50 to 450 mg/L was examined in this experiment.

Then different amounts of 5980 SB cationic polyelectrolyte ranged from 150 to 300 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 50 mg/L alum dosage by the same method determined in Chapter 6.1.1.

As opposed to the precondition determined in above, different amounts of alum ranged from 200 to 800 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 350 mg/L 5980 SB cationic polyelectrolyte dosage. Results of the jar test experiments are shown in Table 6.9.

Table 6.9 Jar Test results of 5980 SB cationic polyelectrolyte

Where, cp: 5980 SB cationic polyelectrolyte and al.: Alum

Dosage		**Settled Sludge Volume (mL)**	**Supernatant Turbidity (JTU)**	**Sludge Properties**
mg/L	**mg/L DS**			
50	5000	-	-	Very thin flocs
100	10000	-	-	Very thin flocs
150	15000	-	-	Thin flocs
200	20000	-	-	Thin flocs
250	25000	-	-	Thin flocs
300	30000	550	130	Middle sized flocs
310	31000	550	130	Big flocs
320	32000	550	130	Big flocs
330	33000	550	130	Big flocs
340	34000	550	130	Very big flocs
350	35000	550	130	Very big flocs
400	40000	550	130	Big flocs
450	45000	550	130	Big flocs
350cp, 200al.	35000cp, 2000al.	500	120	Big flocs
350cp, 400al.	35000cp, 4000al.	400	100	Middle sized flocs
350cp, 600al.	35000cp, 6000al.	350	100	Middle sized flocs
350cp, 800al.	35000cp, 8000al.	-	-	Thin flocs
50al, 150cp.	500al, 15000cp	-	-	Thin flocs
50al, 200cp.	500al, 20000cp.	-	-	Thin flocs
50al, 250cp.	500al, 25000cp.	-	-	Thin flocs
50al, 300cp.	500al, 30000cp.	-	-	Thin flocs

6.3.2 Buchner Funnel Test Results of 5980 SB Cationic Polyelectrolyte Applications

Buchner Funnel Test was applied to aerobic stabilized conditioned sludge samples (between 50 to 450 mg/L dosage of 5980 SB cationic polyelectrolyte) to calculate the specific resistance to filtration.

In the experiments, it was observed that aerobic stabilized raw sludge is not filtrable. As opposed to the observation, the filtration data of aerobic stabilized conditioned sludge samples obtained from the Buchner Funnel Test is reported in Appendix C. Obtained T/V ratios versus were plotted and the slope of linear portion of the curve (b) were determined for each trial. Plots –T/V versus V- for each sample are presented between Figure 6.50 – Figure 6.70.

Dry solids content and viscosity values of filtrate samples and dry matter content of sludge cakes taken from the filter and the slope (b) of linear portion of T/V versus V curve and r values are given in Table 6.10. r values versus 5980 SB cationic polyelectrolyte dosage are also depicted in Figure 6.71 for determination of optimum polyelectrolyte dosage.

As shown in Table 6.74, it can not be obtained a relationship between polyelectrolyte dosages and dry solids content of filtrate. Filtrate viscosity values were measured as 1,25 mPa.s for each sample. Minimum r, $6{,}17 \times 10^{13}$ m/kg, was achieved at 350 mg/L 5980 SB dosage and dry solids content of the sludge cake was found to be a high value of 18,53%. At higher dosages than 350 mg/L, increased r values were obtained with the increases in 5980 SB dosage ranged from 300 mg/L to 350 mg/L based on r results.

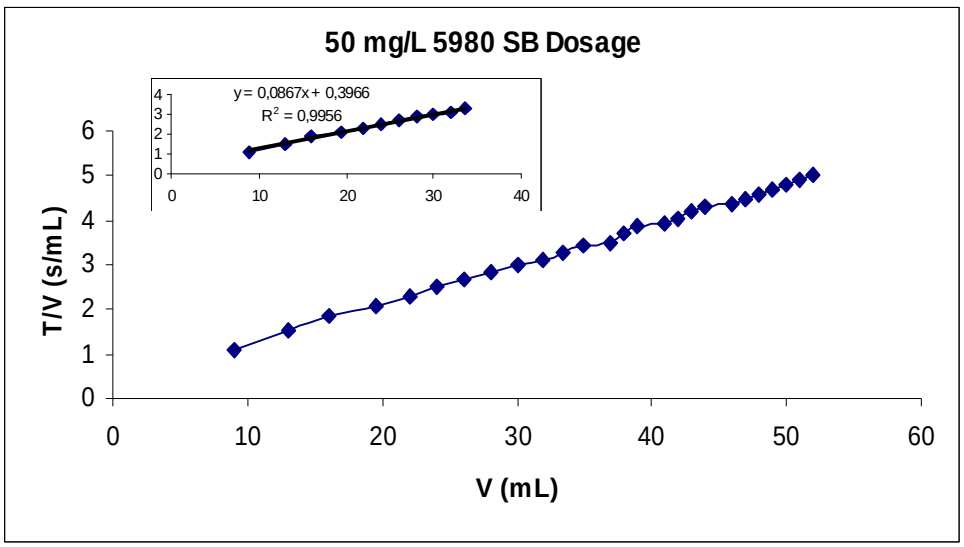


Figure 6.50 T/V values versus filtrate volume (V) for 50 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

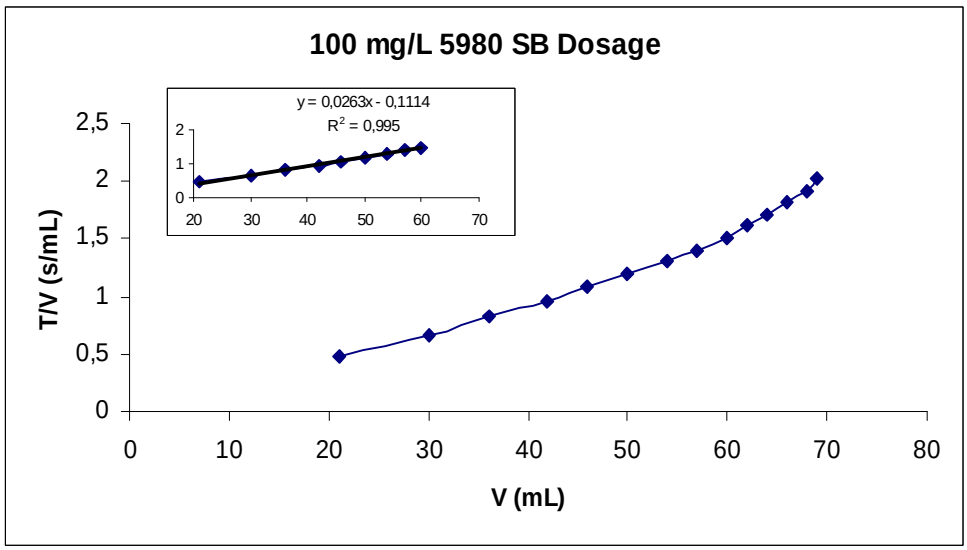


Figure 6.51 T/V values versus filtrate volume (V) for 100 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

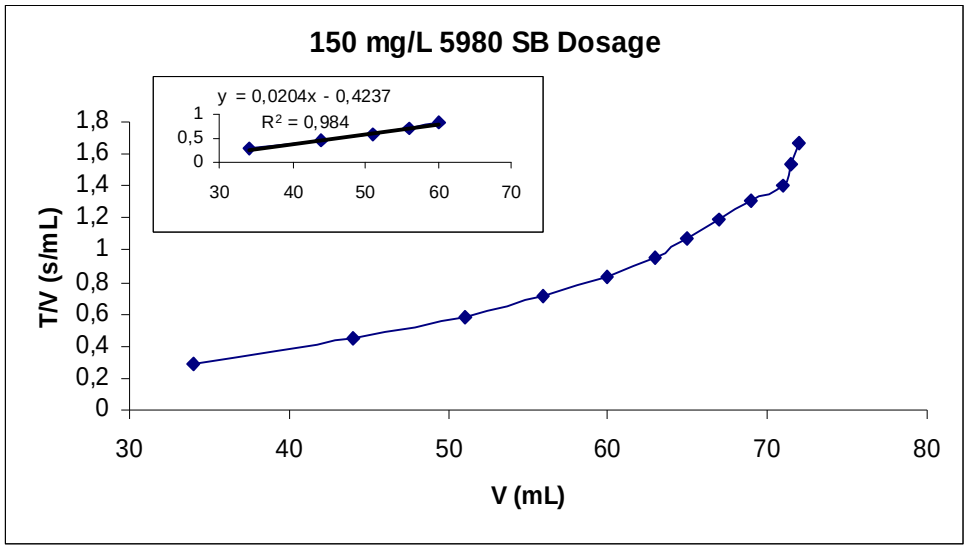


Figure 6.52 T/V values versus filtrate volume (V) for 150 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

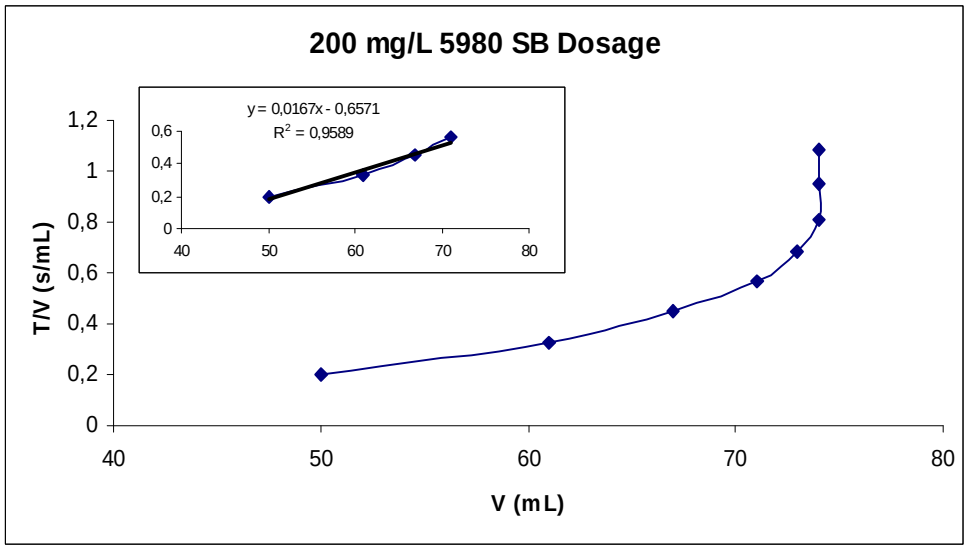


Figure 6.53 T/V values versus filtrate volume (V) for 200 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

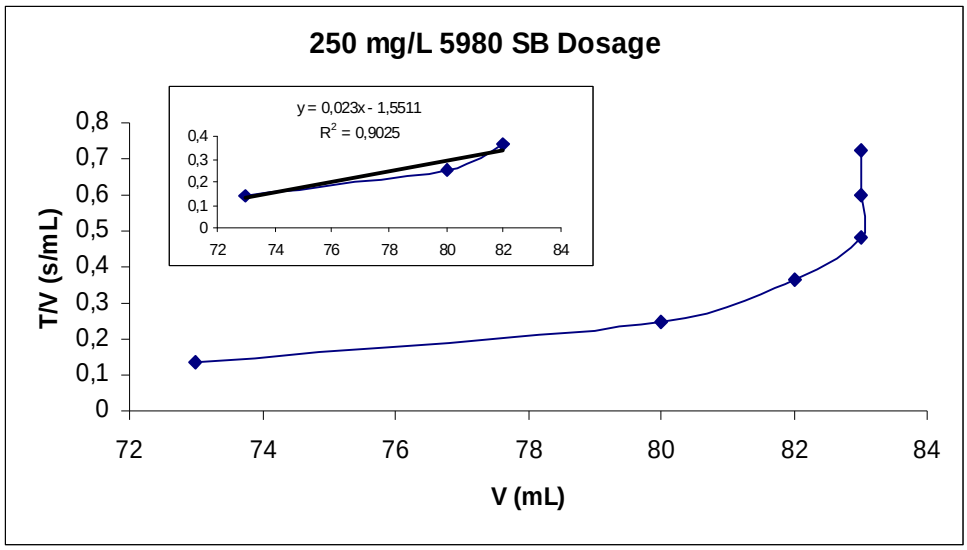


Figure 6.54 T/V values versus filtrate volume (V) for 250 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

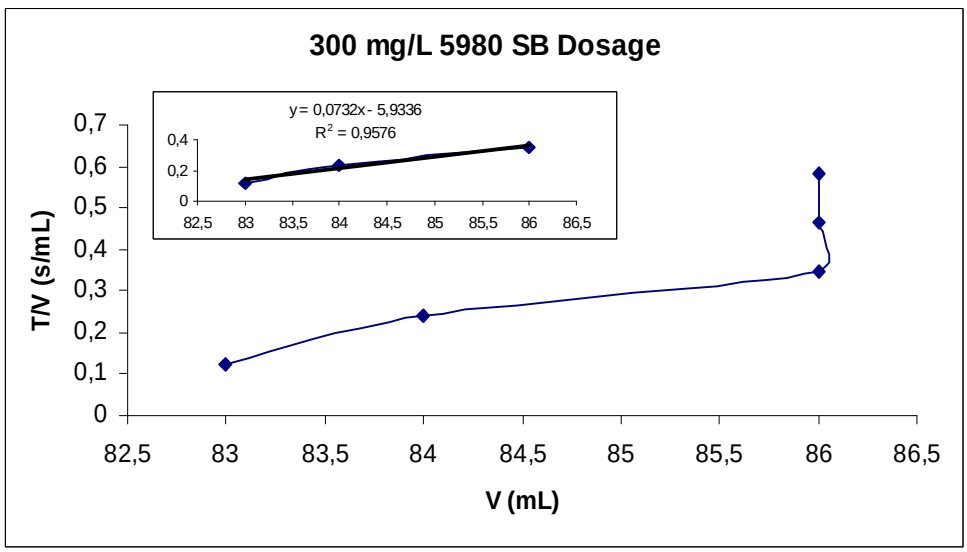


Figure 6.55 T/V values versus filtrate volume (V) for 300 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

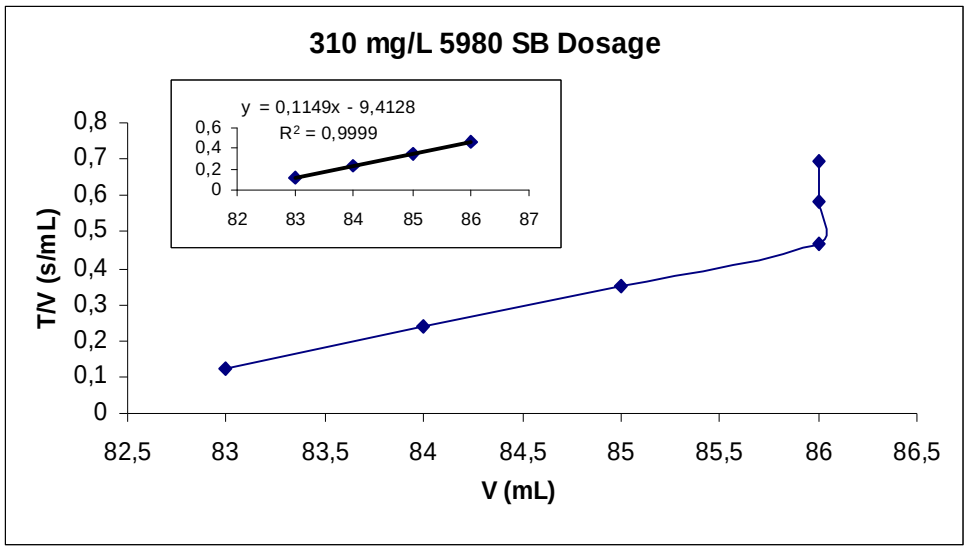


Figure 6.56 T/V values versus filtrate volume (V) for 310 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

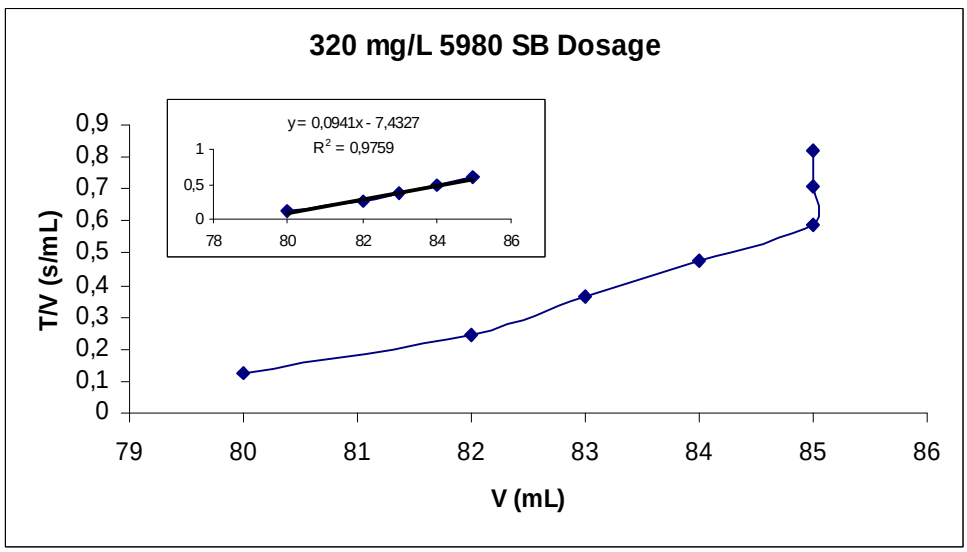


Figure 6.57 T/V values versus filtrate volume (V) for 320 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

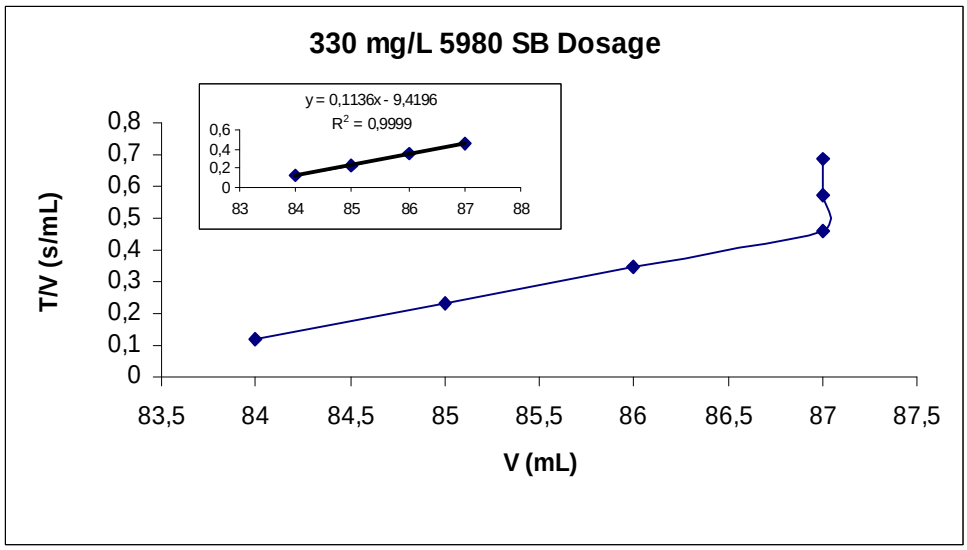


Figure 6.58 T/V values versus filtrate volume (V) for 330 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

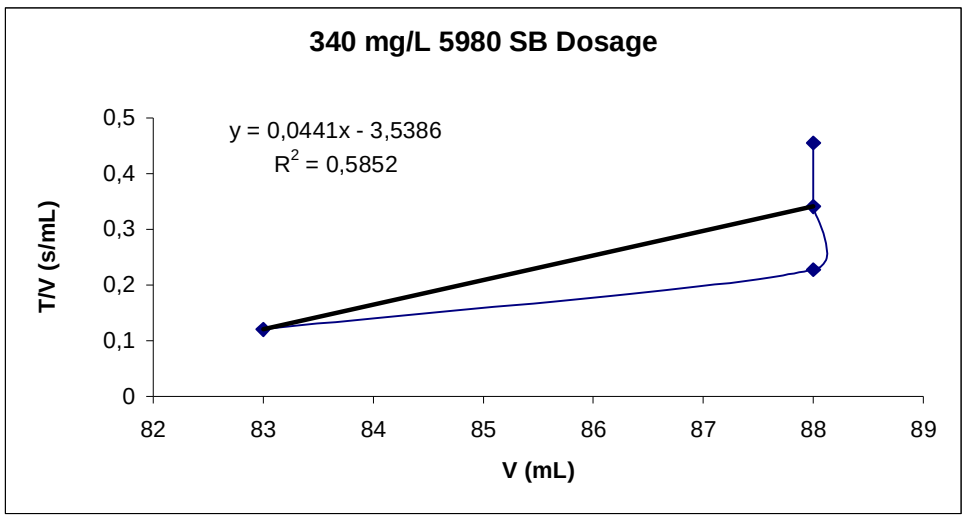


Figure 6.59 T/V values versus filtrate volume (V) for 340 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

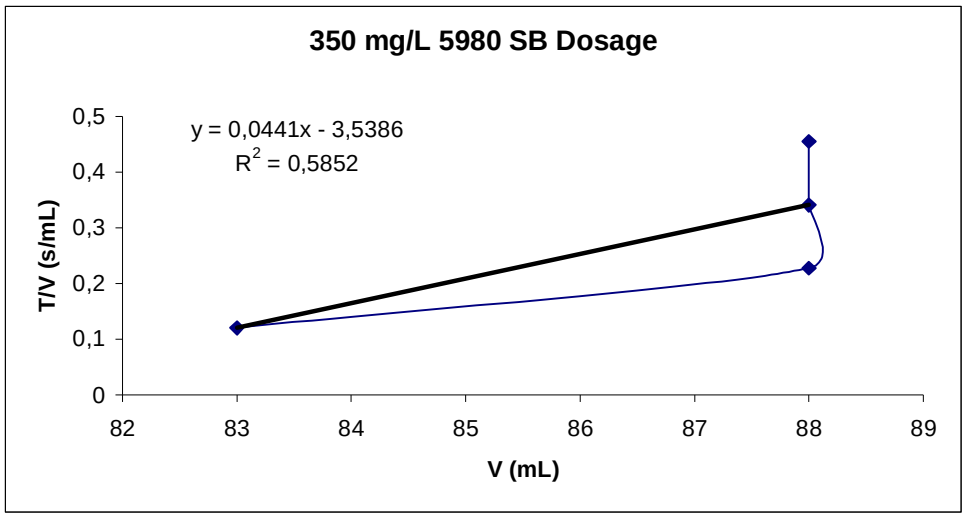


Figure 6.60 T/V values versus filtrate volume (V) for 350 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

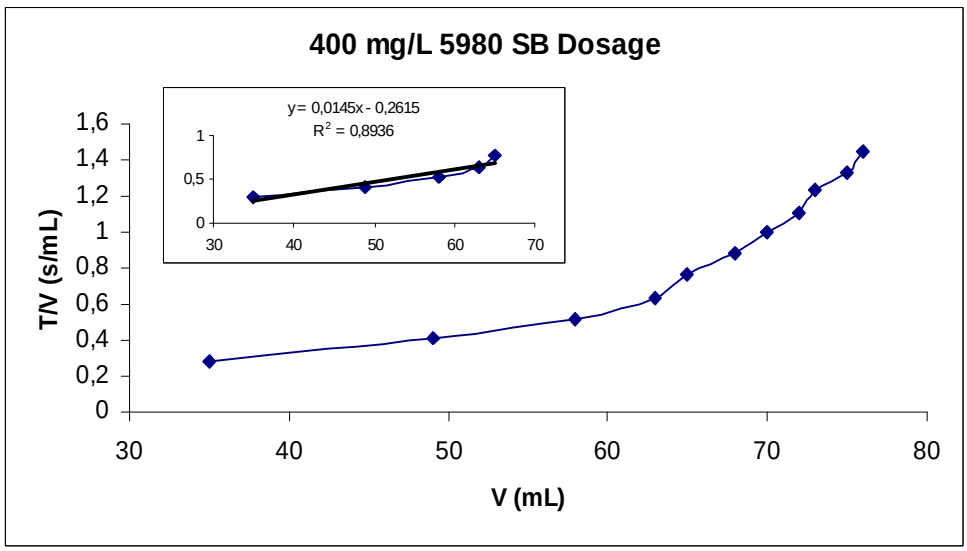


Figure 6.61 T/V values versus filtrate volume (V) for 400 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

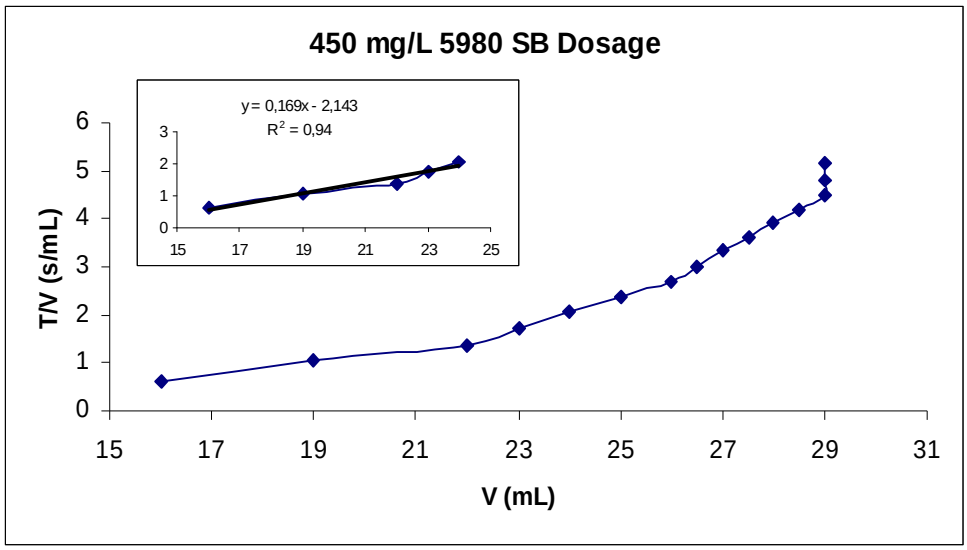


Figure 6.62 T/V values versus filtrate volume (V) for 450 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

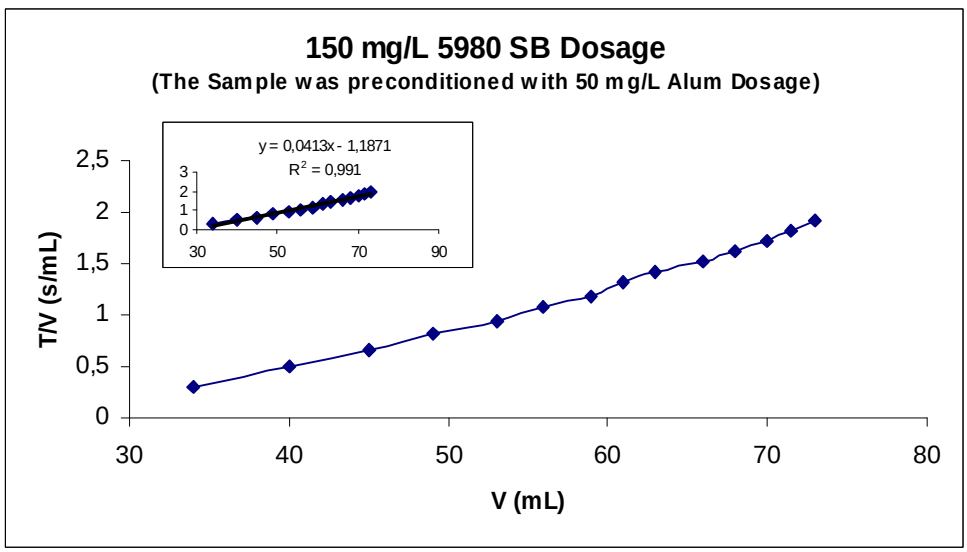


Figure 6.63 T/V values versus filtrate volume (V) for 150 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

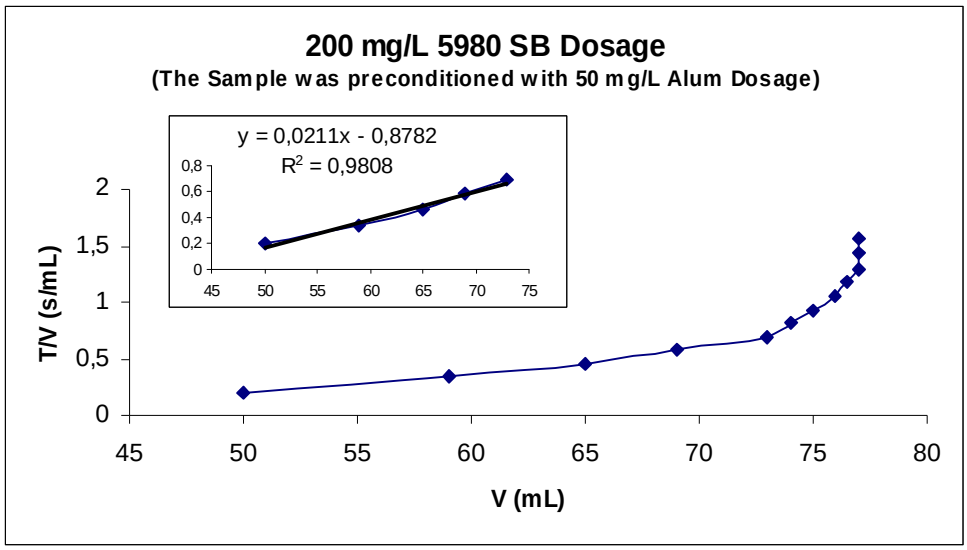


Figure 6.64 T/V values versus filtrate volume (V) for 200 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

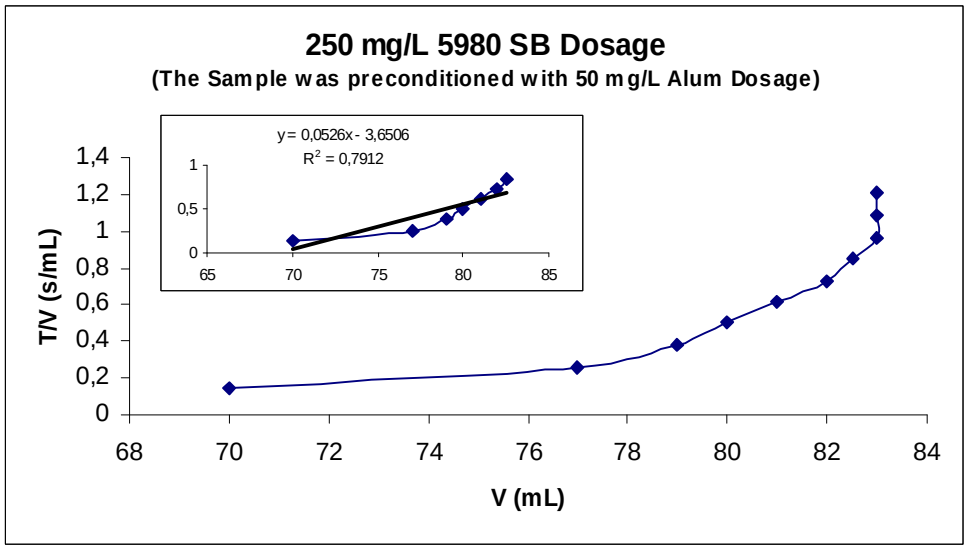


Figure 6.65 T/V values versus filtrate volume (V) for 250 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

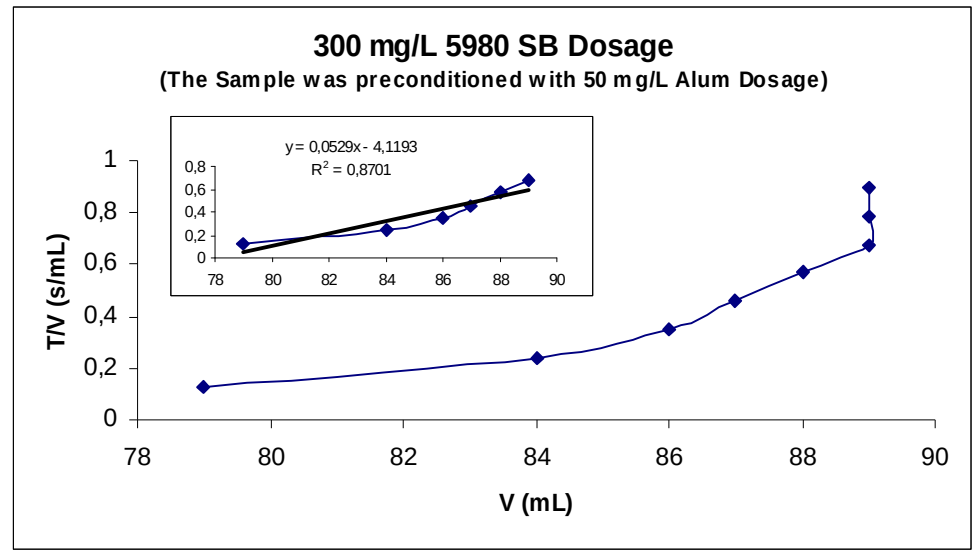


Figure 6.66 T/V values versus filtrate volume (V) for 300 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

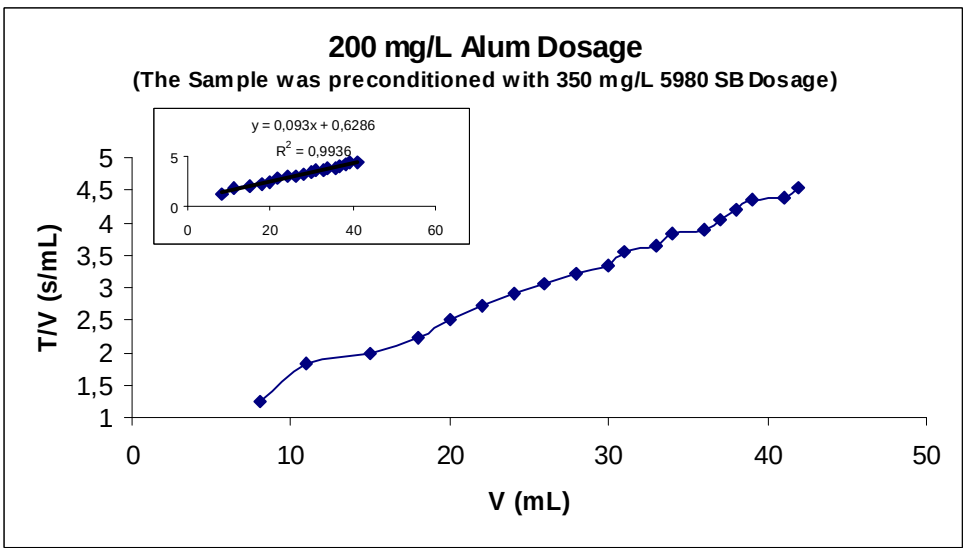


Figure 6.67 T/V values versus filtrate volume (V) for 200 mg/L alum dosage applied to the sludge sample preconditioned with 350 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

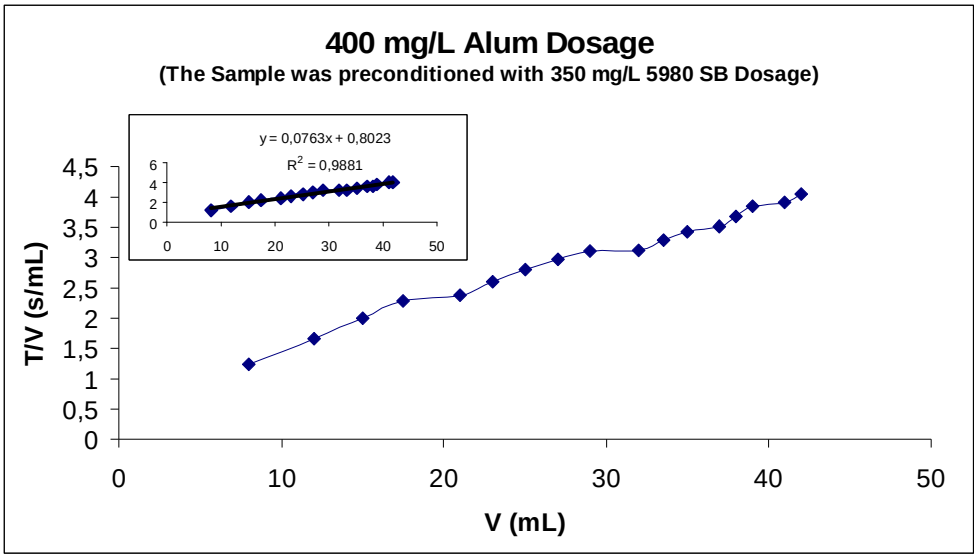


Figure 6.68 T/V values versus filtrate volume (V) for 400 mg/L alum dosage applied to the sludge sample preconditioned with 350 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

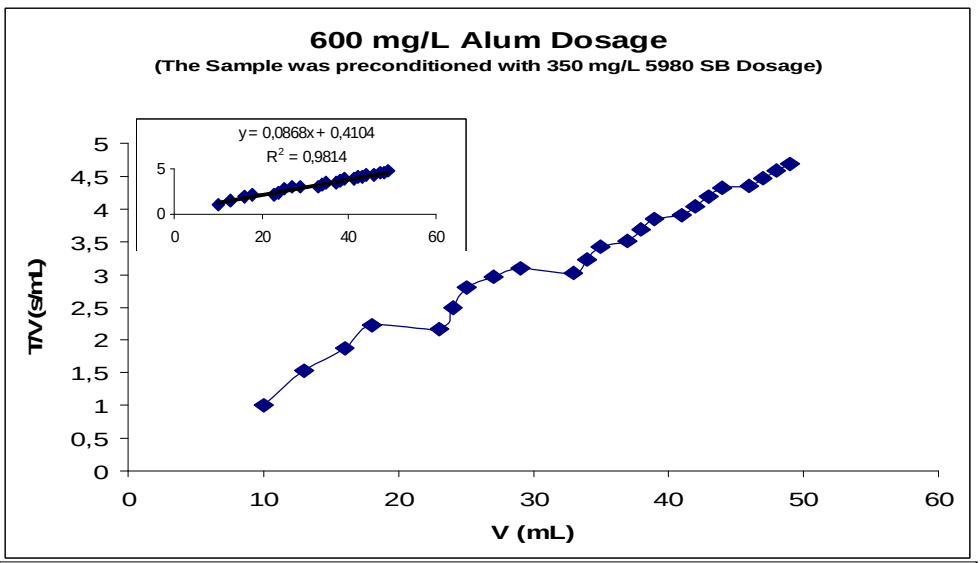


Figure 6.69 T/V values versus filtrate volume (V) for 600 mg/L alum dosage applied to the sludge sample preconditioned with 350 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

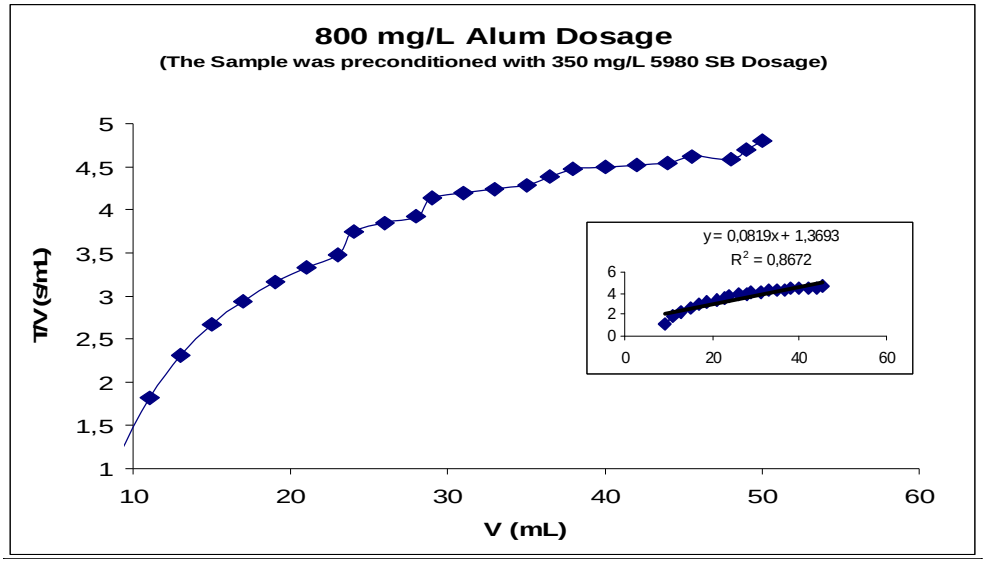


Figure 6.70 T/V values versus filtrate volume (V) for 800 mg/L alum dosage applied to the sludge sample preconditioned with 350 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression.

Table 6.10 Buchner Funnel Test results of conditioned sludge samples with different dosages of 5980 SB cationic polyelectrolyte

Dosage		**Dry Solids Content of Filtrate**		**Organic Solids Content of Filtrate**		**Dry Solids Content of Cake (%)**	**b (s/cm^6)**	**Filtrate Viscosity (mPa.s)**	**r (m/kg)**
mg/L	**mg/kg DS**	**mg/L**	**%**	**mg/L**	**%**				
0	0	1,58	15388	58,92	5892	-	-	1,25	-
50	5000	4,57	45728	63,77	6377	14,19	0,0867	1,25	1,58E+14
100	10000	3,4	34067	63,29	6329	10,23	0,0263	1,25	6,66E+13
150	15000	3,26	32610	62,86	6286	8,14	0,0204	1,25	6,50E+13
200	20000	1,93	19312	61,33	6133	6,58	0,0167	1,25	6,58E+13
250	25000	4,58	45823	64,12	6412	8,14	0,023	1,25	7,32E+13
300	30000	2,5	25108	64,12	6412	17,49	0,0732	1,25	1,08E+14
310	31000	2,45	24512	64,09	6409	17,42	0,1149	1,25	1,71E+14
320	32000	2,4	24089	64,05	6409	17,43	0,0941	1,25	1,40E+14
330	33000	2,35	23567	64,02	6402	17,55	0,1136	1,25	1,68E+14
340	34000	2,32	23229	64	6400	17,93	0,0441	1,25	6,38E+13
350	**35000**	**2,29**	**22936**	**63,98**	**6398**	**18,53**	**0,0441**	**1,25**	**6,17E+13**
400	40000	1,56	15656	61,85	6185	5,42	0,0145	1,25	6,93E+13
450	45000	2,33	23312	64,03	6403	7,41	0,169	1,25	5,91E+14
350K 200A	35000K 2000A	2,3	23012	65,34	6534	10,41	0,093	1,25	2,32E+14
350K 400A	35000K 4000A	2,35	23546	63,21	6321	10,4	0,077	1,25	1,92E+14
350K 600A	35000K 6000A	2,37	23791	64,53	6453	11,11	0,0868	1,25	2,03E+14
350K 800A	35000K 8000A	2,42	24265	65,78	6578	12,13	0,0819	1,25	1,75E+14
50A 150K	500A 15000K	3,56	35678	63,12	6312	10,41	0,0413	1,25	1,03E+14
50A 200K	500A 20000K	3,85	38567	64,59	6459	7,36	0,0211	1,25	7,43E+13
50A 300K	500A 30000K	3,95	39512	64,13	6413	10,12	0,0529	1,25	1,35E+14

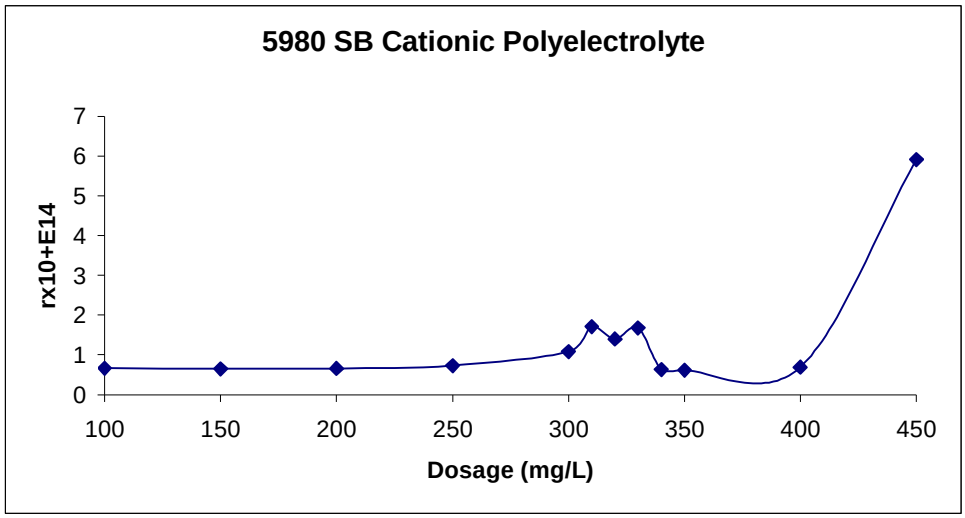


Figure 6.71 Specific Resistance to Filtration (r) values versus 5980 SB cationic polyelectrolyte dosage

6.3.3 Capillary Suction Time Test Results of SNF 5980 Cationic Polyelectrolyte

After jar test trials, Capillary Suction Time (CST) test was applied to conditioned sludge samples for evaluation of their dewatering capacity. Results of CST measurements of conditioned sludge samples at different dosages of 5980 SB cationic polyelectrolyte are shown in Table 6.11 and the CST values as a function of polyelectrolyte dosage is plotted in Figure 6.72.

When 350 mg/L 5980 SB was added to the sludge sample, minimum 7,7 s of CST was achieved as shown in Table 6.11 and Figure 6.72. Dry solids content of the sludge cake was found to be 18,53% at this dosage. Considering the CST test results, optimum 5980 SB dose range was determined between 300 mg/L and 350 mg/L.

Table 6.11 Results of Capillary Suction Time Measurements of raw and conditioned sludge samples with 5980 SB cationic polyelectrolyte

Dosage		**Capillary Suction Time**
mg/L	**mg/kg DS**	**s**
0	0	76,0
50	5000	127,1
100	10000	58,8
150	15000	29,4
200	20000	10,6
250	25000	8,8
300	30000	8,2
310	31000	8,0
320	32000	8,1
330	33000	7,8
340	34000	7,7
350	**35000**	**7,7**
400	40000	10,9
450	45000	18,8
350cp 200al	35000cp 2000al	171,3
350cp 400al	35000cp 4000al	169,3
350cp 600al	35000cp 6000al	161,0
350cp 800al	35000cp 8000al	159,7
50al 150cp	500al 15000cp	30,3
50al 200cp	500al 20000cp	12,5
50al 300cp	500al 30000cp	10,9

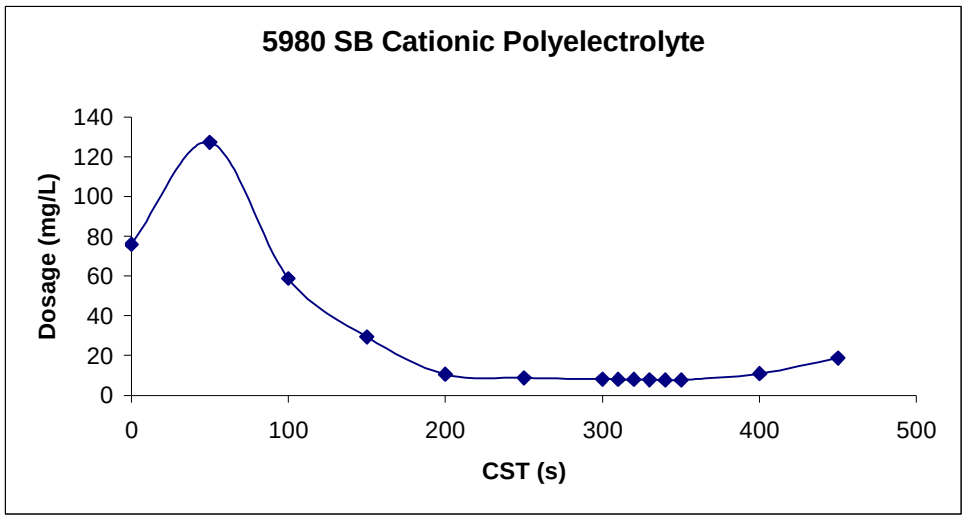


Figure 6.72 Capillary Suction Time (CST) values versus 5980 SB dosage

6.3.4 Results of Centrifugal Settleability Index Measurements for 5980 SB Cationic Polyelectrolyte Applications

To evaluate sludge dewaterability for centrifugal dewatering processes, centrifugal settleability index (CSI) parameter was analyzed. Suspended solid values of sludge and centrate samples and CSI values of sludge samples are given in Table 6.12.

Table 6.12 Results of Centrifugal Settleability Index (CSI) measurements for 5980 SB cationic polyelectrolyte

Dosage		**Suspended Solids of Sludge (mg/L)**	**Suspended Solids of Centrate (mg/L)**	**Centrifugal Settleability Index (CSI) (%)**
mg/L	**mg/kg DS**			
0	0	15000	100	99,33
50	5000	2000	300	85
100	10000	1000	150	85
150	15000	1000	240	76
200	20000	2000	140	93
250	25000	2000	210	89,5
300	30000	10000	220	97,8
310	31000	11000	250	97,72
320	32000	10000	250	97,5
330	33000	11000	280	97,45
340	34000	11000	280	97,45
350	**35000**	**12000**	**1800**	**85**
400	40000	10000	100	99
450	45000	13000	150	98,84
350cp 200al	35000cp 2000al	22000	500	97,72
350cp 400al	35000cp 4000al	21500	480	97,76
350cp 600al	35000cp 6000al	23000	350	98,47
350cp 800al	35000cp 8000al	21000	550	97,38
50al 150cp	500al 15000cp	1900	100	94,73
50al 200cp	500al 20000cp	2500	50	98
50al 300cp	500al 30000cp	18000	1000	94,44

Figure 6.73 shows the CSI values at different dosages of 5980 SB cationic polyelectrolyte.

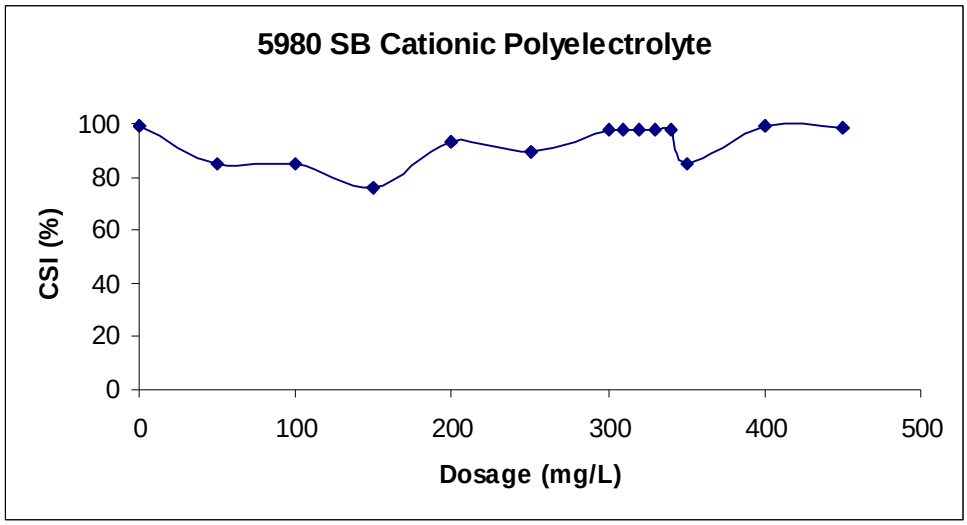


Figure 6.73 CSI values versus 5980 SB dosage

6.4 Conditioning Results of KWD 3500 Cationic Polyelectrolyte Applications to Anaerobic Stabilized Sludge Samples

6.4.1 Jar Test Results of KWD 3500 Cationic Polyelectrolyte Applications

In the jar test trials using KWD 3500 cationic polyelectrolyte, different amounts of the polyelectrolyte ranged from 150 to 450 mg/L were dosed to the anaerobic stabilized sludge samples applying the jar test procedure defined in Chapter 5.2.2.1. The experimental results evaluating settled sludge volume, floc structure of aerobic stabilized sludges and supernatant turbidity are given in Table 6.13.

Then different amounts of KWD 3500 cationic polyelectrolyte ranged from 150 to 300 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 50 mg/L alum (aluminum hydroxyde 18 hydrate) dosage. Precondition was made by mixing samples with 50 mg/L alum at 200 rev/min for 1 minute and after then different amounts of KWD 3500 cationic polyelectrolyte were added to the sample preconditioned and mixed at 25 rev/min for 30 minutes.

Different amounts of alum ranged from 200 to 800 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Precondition was made by the same method defined above.

According to the results summerized in Table 6.13, it was observed that there is no relationship between supernatant quality and KWD 3500 dosage. Furthermore, results indicate that settled sludge volume obtained from jar test applications is not a critical parameter for sludge conditioning.

Table 6.13 Jar Test results of KWD 3500 cationic polyelectrolyte applied to anaerobic stabilized sludge samples

Dosage		**Settled sludge volume**	**Supernatant turbidity**	**Sludge properties**
mg/L	**mg/kg DS**	mL	JTU	-
5	500	300	3100	-
10	1000	325	3100	Very thin flocs
25	2500	200	3000	Very thin flocs
50	5000	300	2000	Very thin flocs
100	10000	165	2000	Very thin flocs
150	15000	210	1900	Very thin flocs
200	20000	320	1900	Very thin flocs
210	21000	-	-	-
220	22000	-	-	-
230	23000	-	-	-
240	24000	-	-	-
250	25000	250	1700	Middle
300	30000	250	1700	Middle
350	35000	210	1400	Big flocs
400	40000	200	1350	Very big flocs
450	45000	130	1700	Very big flocs
50al 150cp	50al 15000cp	-	-	-
50al 200cp	50al 20000cp	-	-	-
50al 250cp	50al 25000cp	-	-	-
50al 300cp	50al 30000cp	-	-	-
200al 250cp	2000al 25000cp	-	-	-
400al 250cp	4000al 25000cp	-	-	-
600al 250cp	6000al 25000cp	-	-	-
800al 250cp	8000al 25000cp	-	-	-

Where, cp: KWD 3500 cationic polyelectrolyte and al.: Alum

6.4.2 Buchner Funnel Test Results of KWD 3500 Cationic Polyelectrolyte

Buchner Funnel Test was applied to raw and conditioned aerobic stabilized sludge samples. Buchner Funnel Test procedure given in Chapter 3.1.3 was used to calculate the specific resistance to filtration value of the sludge samples.

Filtrate volume (V) versus time (T) were recorded and ratios of t/v were calculated. Obtained filtration data of raw and conditioned anaerobic stabilized sludge samples with KWD 3500 cationic polyelectrolyte are given in Appendix D. Obtained T/V ratios versus V were plotted and the slope of linear portion of the curve (b) were determined for each trial. The plots –T/V versus V- for each sample are presented between Figure 6.74 – Figure 6.92.

Dry solids content and viscosity of filtrate, and dry solids content of sludge cake removed from the filter were determined for conditioned samples with KWD 3500 cationic polyelectrolyte. The results of the Buchner Funnel tests for all trials are summarized in Table 6.14.

In order to determine optimum dose range of KWD 3500 cationic polyelectrolyte, the relationship between doses and specific resistance to filtration (r) values were used. Therefore the graph which KWD 3500 dosage versus r values depicted is given in Figure 6.93.

As shown in Table 6.14, it can not be obtained any relationship between polyelectrolyte dosages and dry solids content of filtrate. Filtrate viscosity values were measured as 1,25 mPa.s for each sample. Minimum r, $1{,}26 \times 10^{13}$ m/kg, was achieved at 250 mg/L KWD 3500 dosage and dry solids content of the cake was found to be a high value of 13,4%. At higher dosages than 250 mg/L, increased r values obtained with the increases in KWD 3500 doses. Optimum KWD 3500 dosage ranged from 200 to 250 mg/L based on r value results.

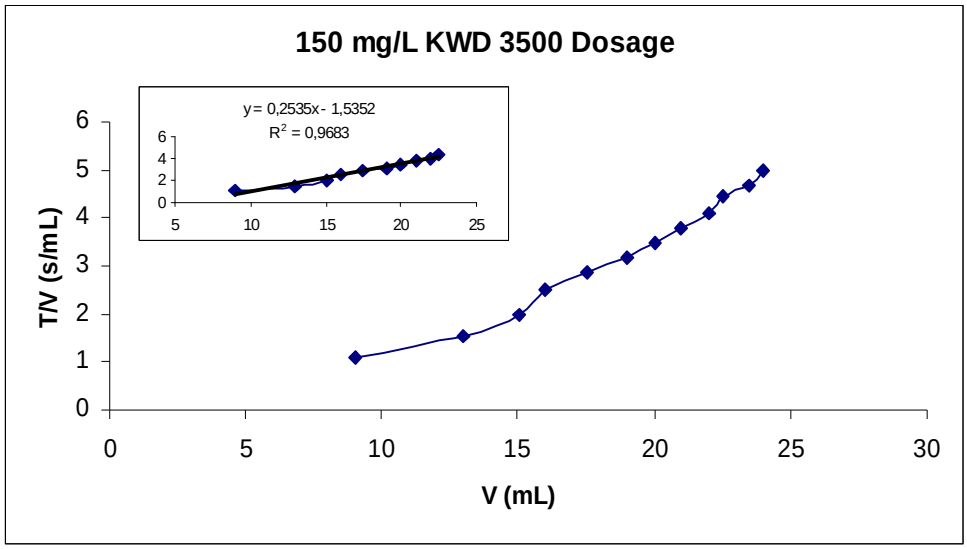


Figure 6.74 T/V values versus filtrate volume (V) for 150 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

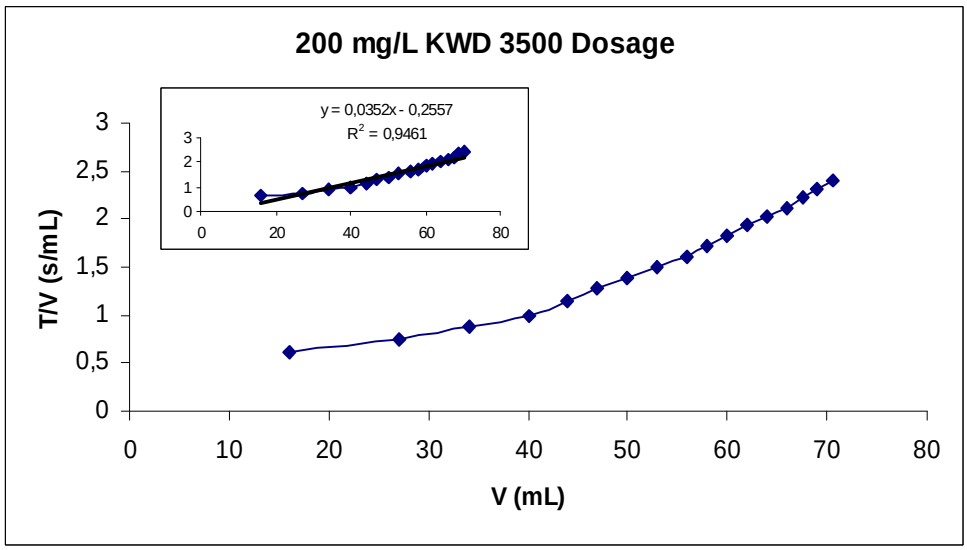


Figure 6.75 T/V values versus filtrate volume (V) for 200 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

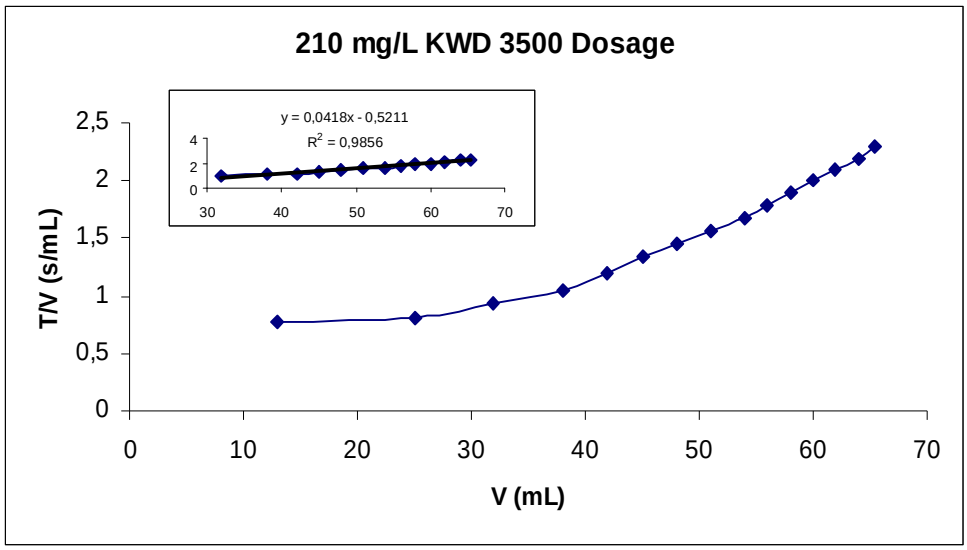


Figure 6.76 T/V values versus filtrate volume (V) for 210 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

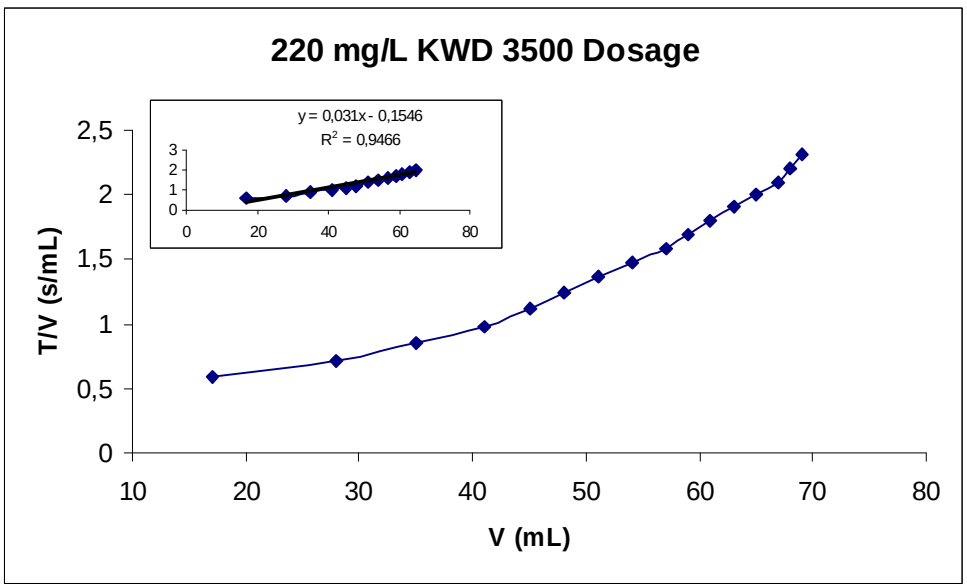


Figure 6.77 T/V values versus filtrate volume (V) for 220 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

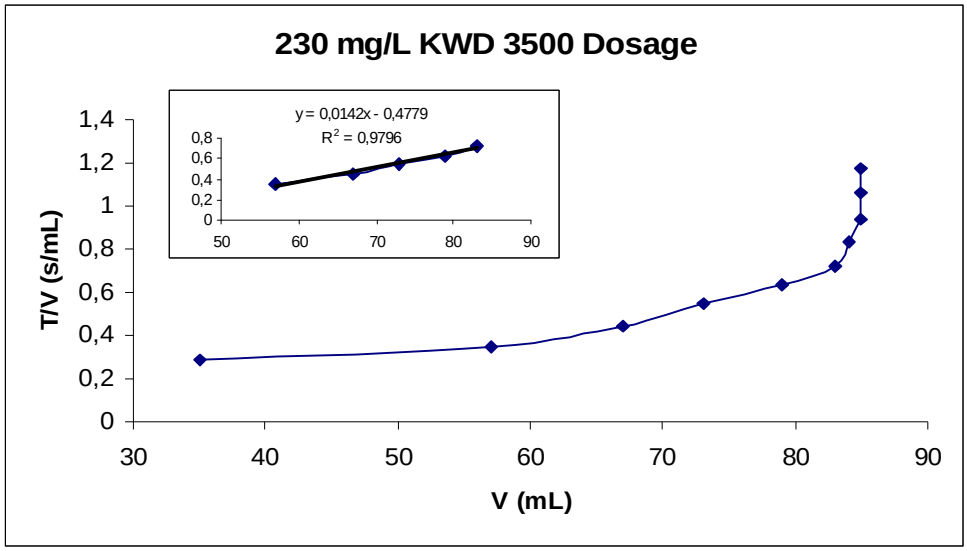


Figure 6.78 T/V values versus filtrate volume (V) for 230 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

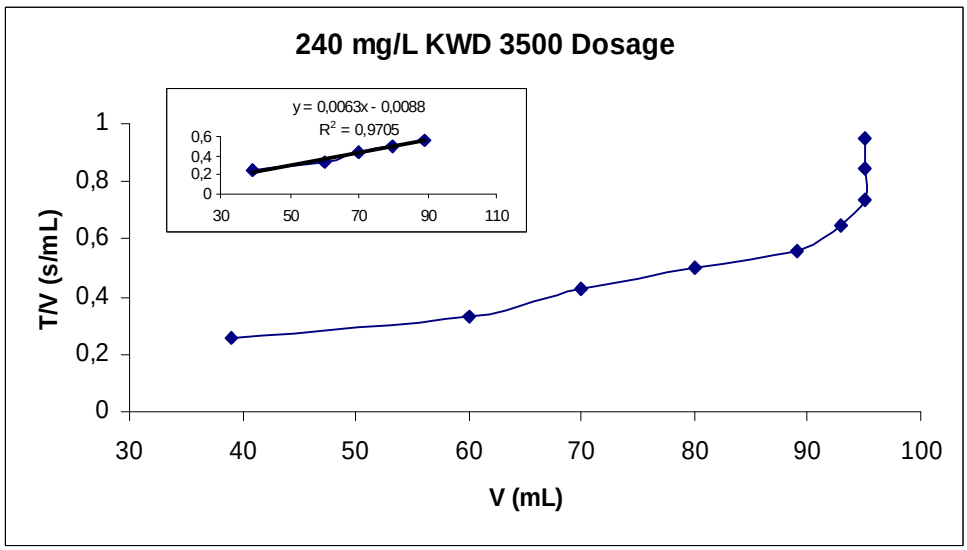


Figure 6.79 T/V values versus filtrate volume (V) for 240 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

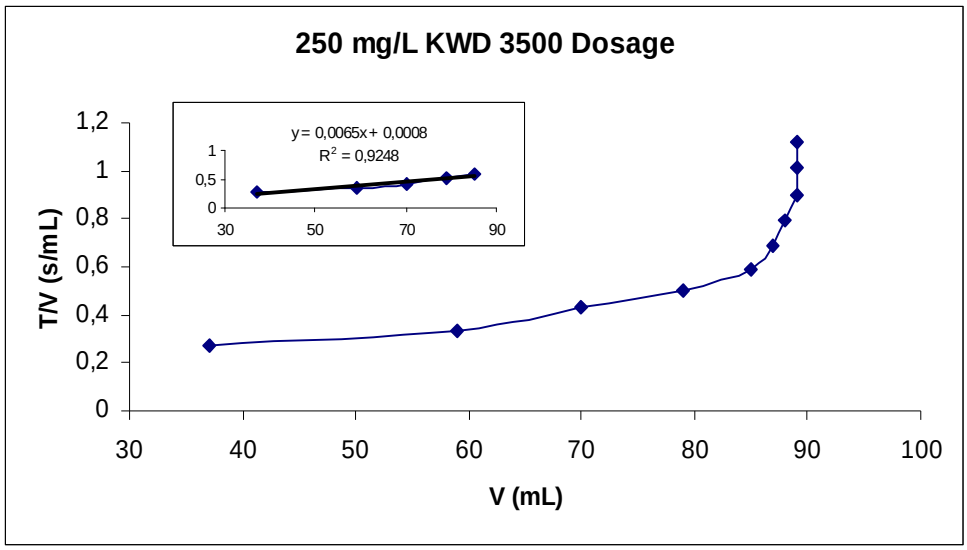


Figure 6.80 T/V values versus filtrate volume (V) for 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

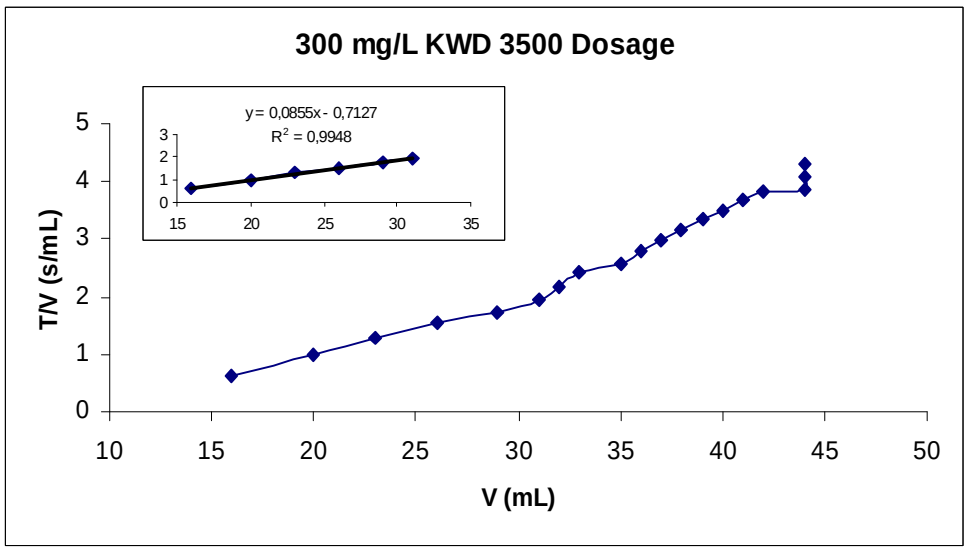


Figure 6.81 T/V values versus filtrate volume (V) for 300 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

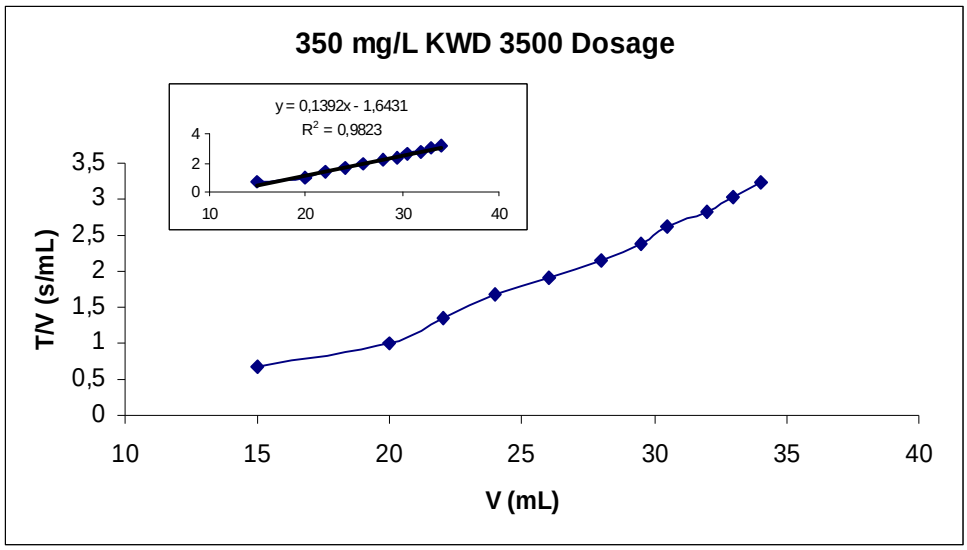


Figure 6.82 T/V values versus filtrate volume (V) for 350 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

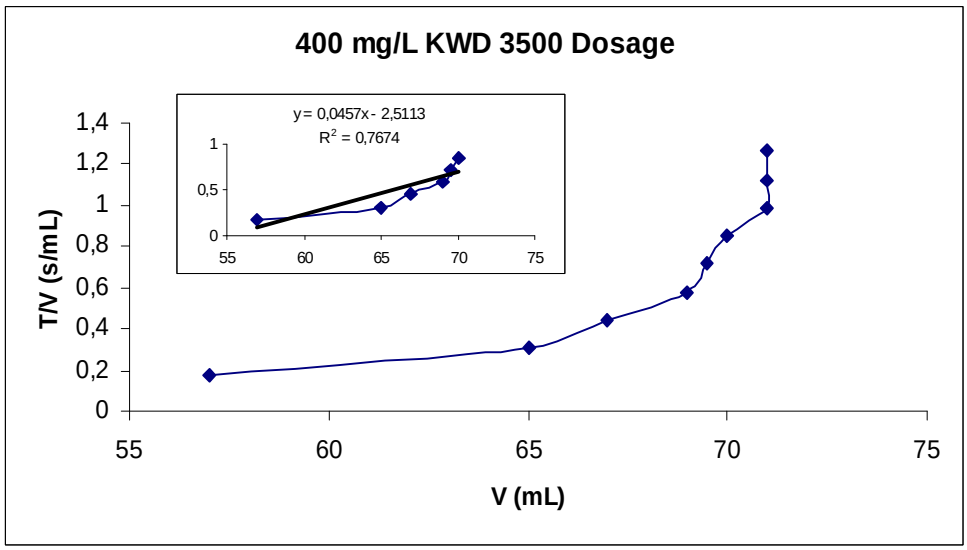


Figure 6.83 T/V values versus filtrate volume (V) for 400 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

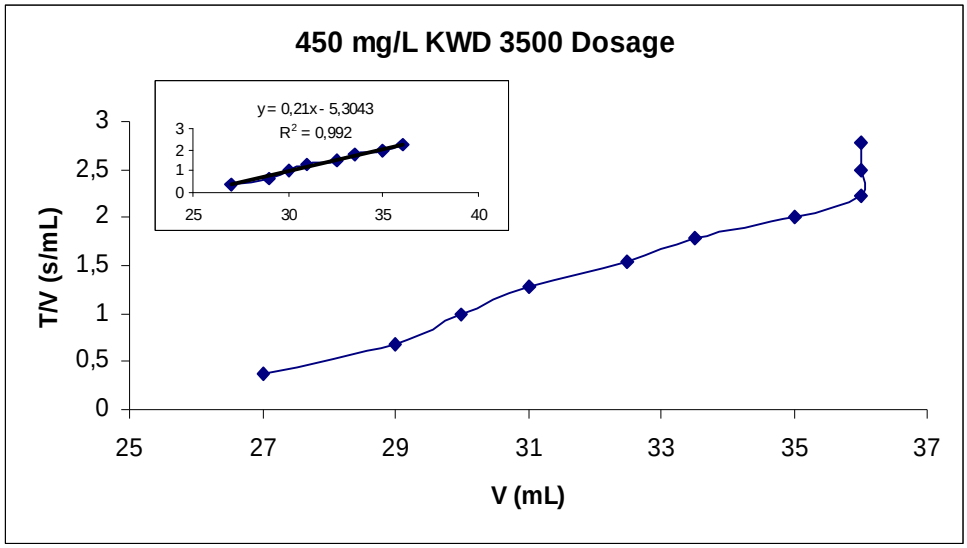


Figure 6.84 T/V values versus filtrate volume (V) for 450 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

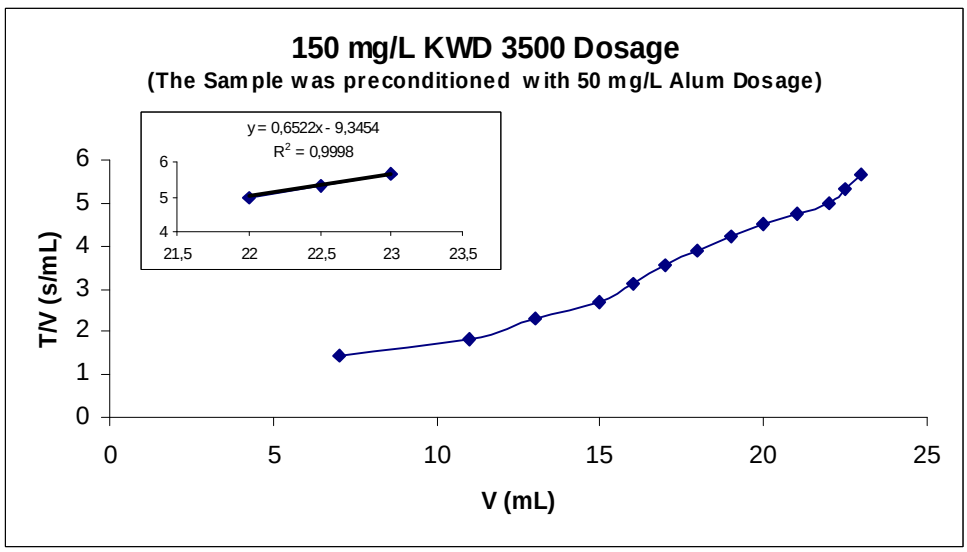


Figure 6.85 T/V values versus filtrate volume (V) for 150 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

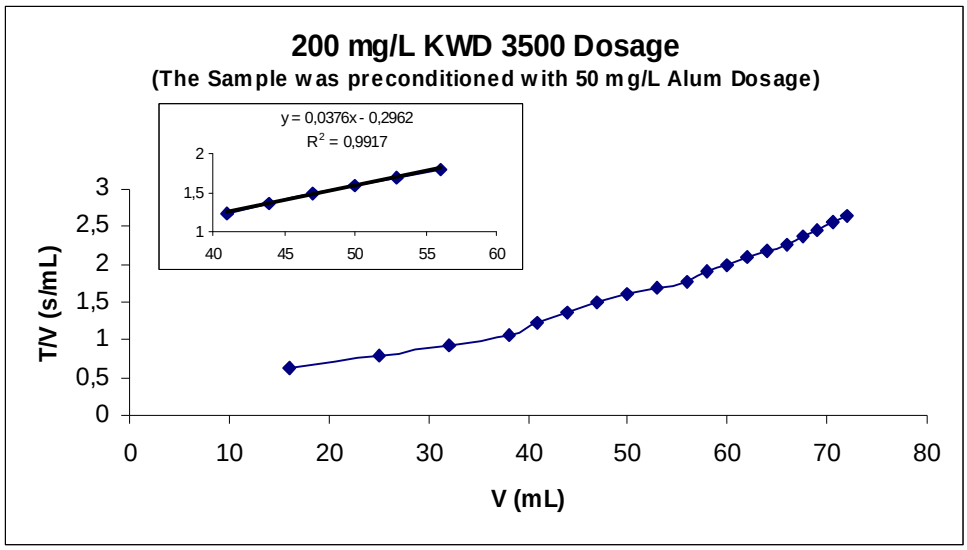


Figure 6.86 T/V values versus filtrate volume (V) for 200 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

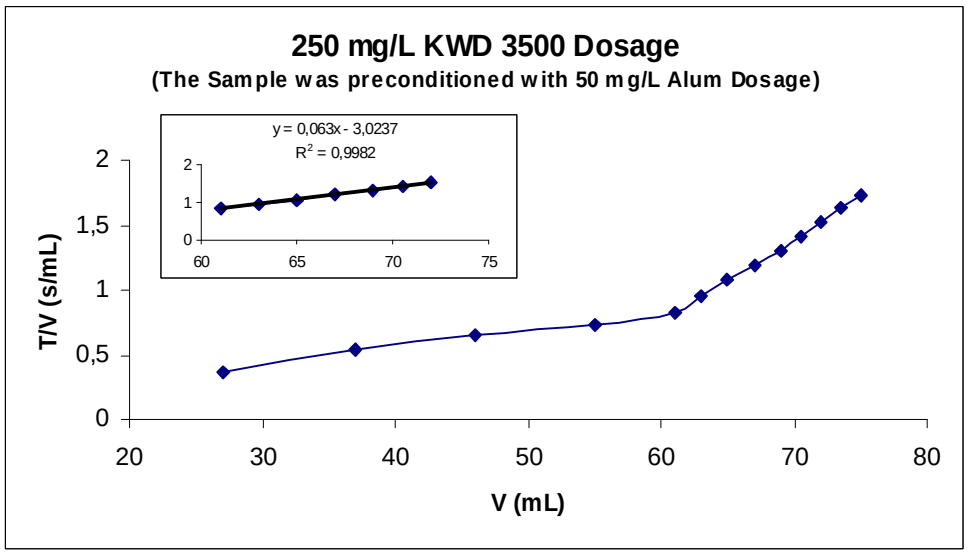


Figure 6.87 T/V values versus filtrate volume (V) for 250 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

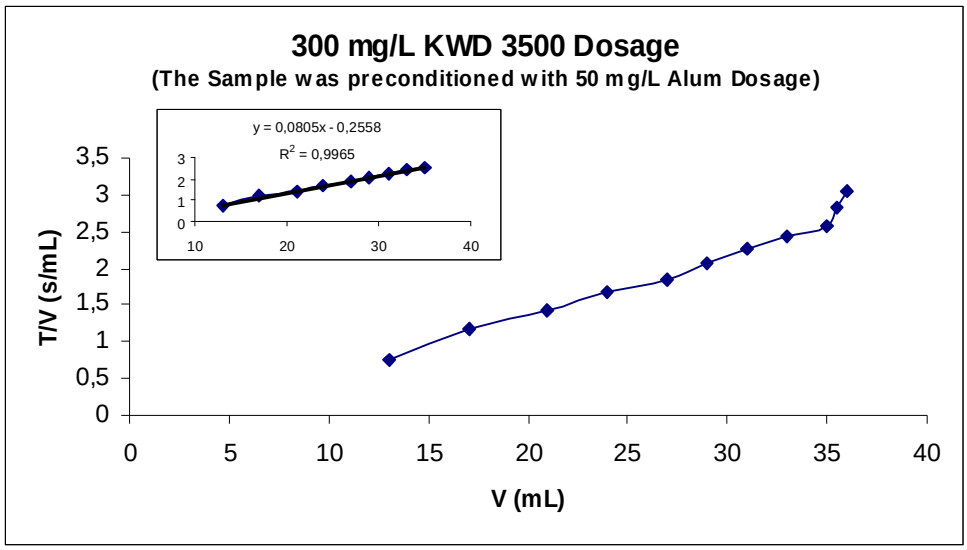


Figure 6.88 T/V values versus filtrate volume (V) for 300 mg/L KWD 3500 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

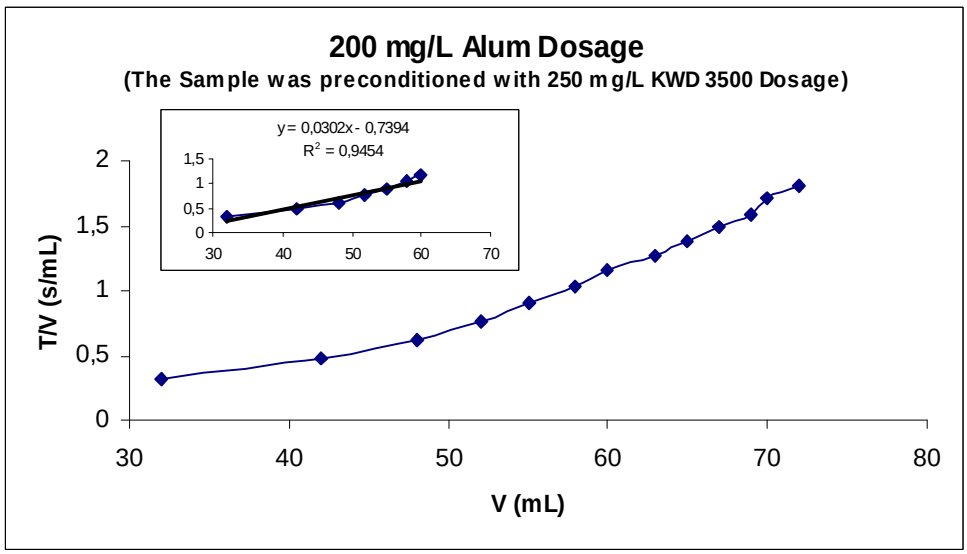


Figure 6.89 T/V values versus filtrate volume (V) for 200 mg/L alum dosage applied to the sludge sample preconditioned with 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

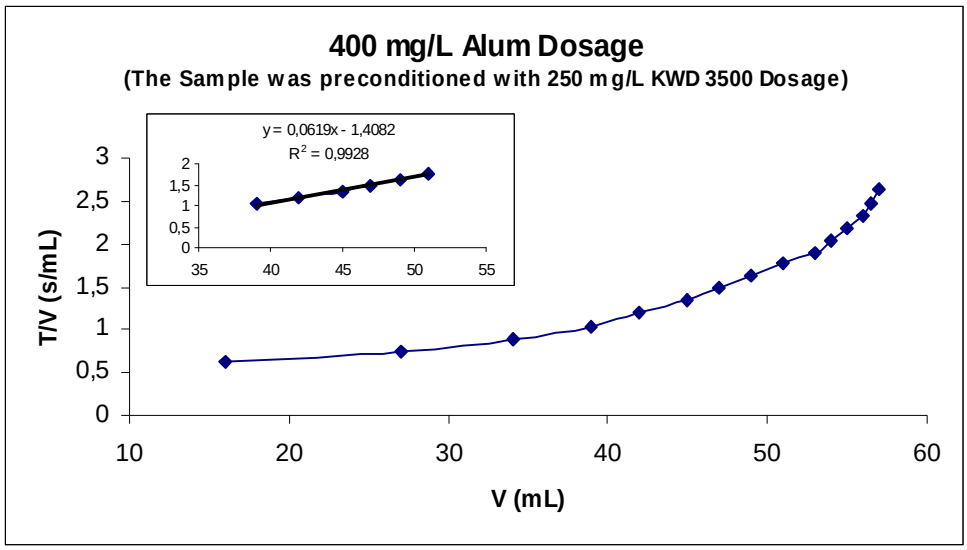


Figure 6.90 T/V values versus filtrate volume (V) for 400 mg/L alum dosage applied to the sludge sample preconditioned with 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

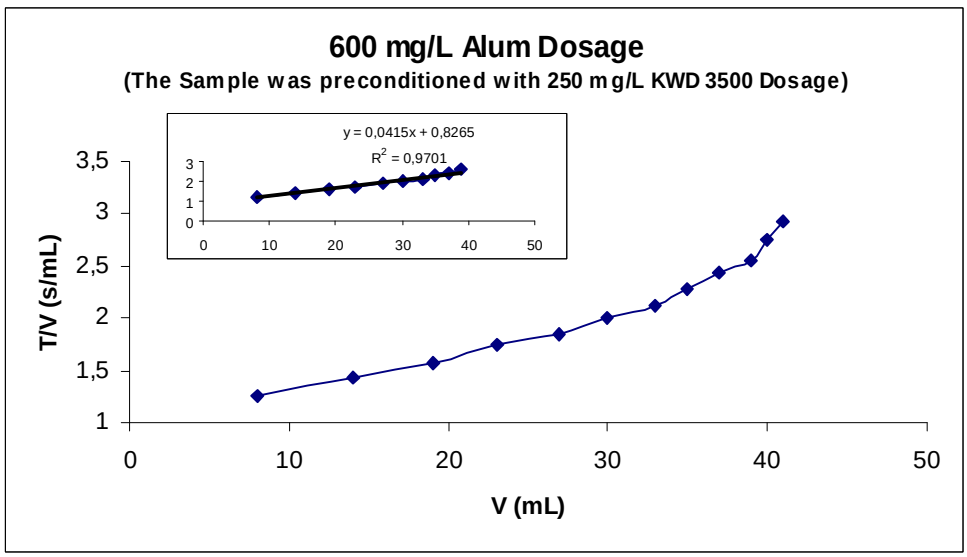


Figure 6.91 T/V values versus filtrate volume (V) for 600 mg/L alum dosage applied to the sludge sample preconditioned with 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

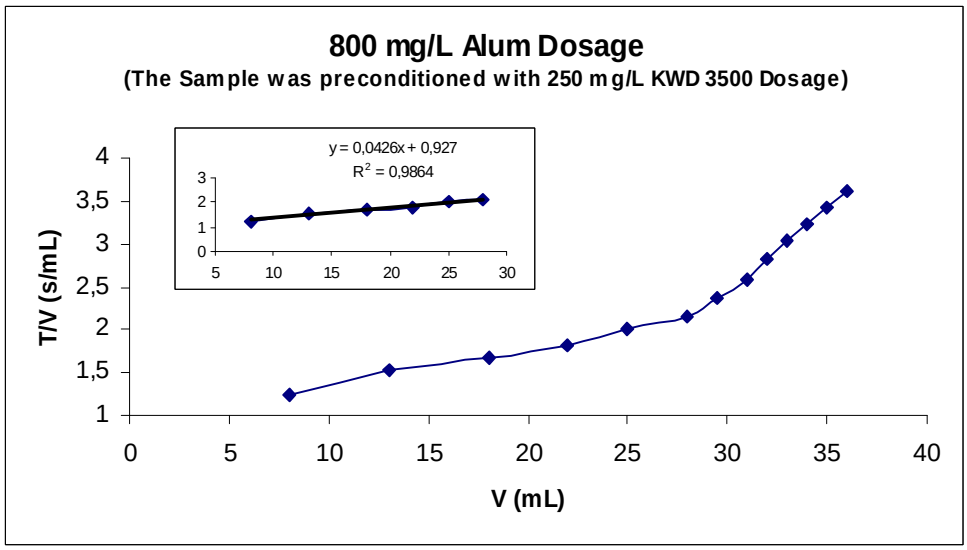


Figure 6.92 T/V values versus filtrate volume (V) for 800 mg/L alum dosage applied to the sludge sample preconditioned with 250 mg/L KWD 3500 cationic polyelectrolyte dosage. Inset: The data applied linear regression

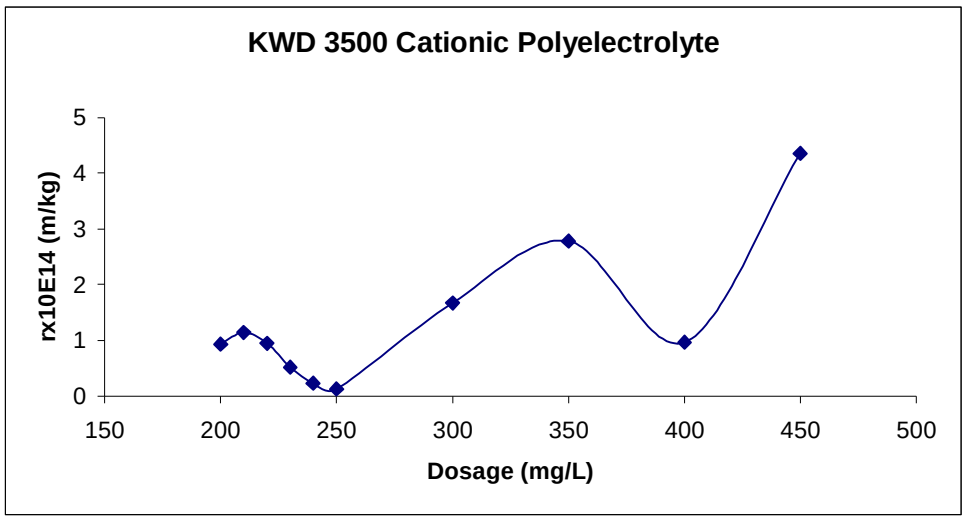


Figure 6.93 Specific Resistance to Filtration (r) values versus KWD 3500 dosage

Table 6.14 Buchner Funnel Test results of raw and conditioned sludge samples with different dosages of KWD 3500 cationic polyelectrolyte.

Dosage		**Dry Solids Content of Filtrate**		**Organic Solids Content of Filtrate**		**Dry Solids Content of Cake (%)**	**b (s/cm^6)**	**Filtrate Viscosity (mPa.s)**	**r (m/kg)**
mg/L	**mg/kg DS**	**mg/L**	**%**	**mg/L**	**%**				
HAM	0	3,24	32432	41,02	4102	-	-	1,25	-
150	15000	1,31	13110	36,97	3697	-	0,2535	1,25	-
200	20000	2,09	20918	38,21	3821	9,8	0,0352	1,25	9,31E+13
210	21000	1,87	18765	37,1	3710	9,52	0,0418	1,25	1,14E+14
220	22000	1,62	16292	36,81	3681	8,51	0,031	1,25	9,44E+13
230	23000	1,61	16198	35,65	3565	7,13	0,0142	1,25	5,16E+13
240	24000	1,55	15522	36,73	3673	7,2	0,0063	1,25	2,27E+13
250	**25000**	**1,41**	**14112**	**43,09**	**4309**	**13,4**	**0,0065**	**1,25**	**1,26E+13**
300	30000	1,82	18256	38,77	3877	13,3	0,0855	1,25	1,67E+14
350	35000	0,9	9003	31,73	3172	12,99	0,1392	1,25	2,78E+14
400	40000	0,87	8745	31,8	3180	12,31	0,0457	1,25	9,62E+13
450	45000	0,81	8128	32,96	3296	12,51	0,21	1,25	4,35E+14
50A 150K	500A 15000K	1,89	18976	38,09	3809	-	0,6522	1,25	-
50A 200K	500A 20000K	1,72	17298	38,56	3856	11,33	0,0376	1,25	8,60E+13
50A 250K	500A 25000K	1,64	16440	41,23	4123	11,73	0,063	1,25	1,39E+14
50A 300K	500A 30000KP	1,78	17876	39,44	3944	11,55	0,0805	1,25	1,81E+14
200A 250K	2000A 25000K	2,25	22568	37,45	3745	9,12	0,0302	1,25	8,58E+13
400A 250K	4000A 25000K	2,45	24598	36,27	3627	-	0,0619	1,25	-
600A 250K	6000A 25000K	2,43	24390	36,12	3612	-	0,0415	1,25	-
800A 250K	8000A 25000K	2,47	24700	35,58	3558	-	0,0426	1,25	-

6.4.3 Capillary Suction Time Test Results of KWD 3500 Cationic Polyelectrolyte

After jar test trials, Capillary Suction Time (CST) test was applied to conditioned sludge samples for evaluation of their dewatering capacity. Results of CST measurements of conditioned sludge samples at different dosages of KWD 3500 cationic polyelectrolyte are shown in Table 6.98 and the CST values as a function of polyelectrolyte dosage is plotted in Figure 6.94.

Table 6.15 Results of Capillary Suction Time (CST) measurements of conditioned sludge samples with KWD 3500 cationic polyelectrolyte

Dosage		**Capillary Suction Time**
mg/L	**mg/kg DS**	**s**
150	15000	171,2
200	20000	25,8
210	21000	47,7
220	22000	25,7
230	23000	16,4
240	24000	14,1
250	**25000**	**12,3**
300	30000	80,5
350	35000	81,2
400	40000	82,5
450	45000	82,7
50al 150cp	500al 15000cp	95,4
50al 200cp	500al 20000cp	42,7
50al 250cp	500al 25000cp	26,8
50al 300cp	500al 30000cp	94,1
200al 250cp	2000al 25000cp	48,5
400al 250cp	4000al 25000cp	49,6
600al 250cp	6000al 25000cp	51,4
800al 250cp	8000al 25000cp	59,8

When 250 mg/L KWD 3500 was added to the sludge sample, minimum 12,3 s of CST was achieved as shown in Table 6.15 and Figure 6.94. Dry solids content of the sludge cake was found to be 13,4% at this dosage. Considering the CST test results, optimum KWD 3500 dose range was determined between 200 mg/L and 250 mg/L.

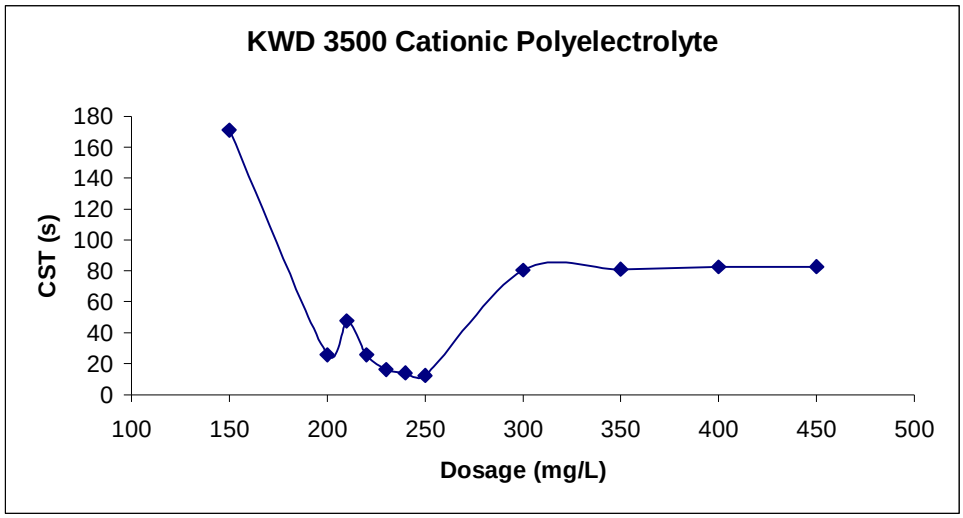


Figure 6.94 Capillary Suction Time (CST) values versus KWD 3500 dosage

6.4.4 Results of Centrifugal Settleability Index Measurements for KWD 3500 Cationic Polyelectrolyte Applications

To evaluate sludge dewaterability for centrifugal dewatering processes, centrifugal settleability index (CSI) parameter was analysed. Suspended solid values of anaerobic stabilized sludge and centrate samples and CSI values of anaerobic stabilized sludge are given in Table 6.16.

Table 6.16 Results of CSI measurements of conditioned anaerobic stabilized sludge samples with KWD 3500 cationic polyelectrolyte

Dosage		Suspended Solids of Sludge (mg/L)	Suspended Solids of Centrate (mg/L)	Centrifugal Settleability Index (CSI) (%)
mg/L	mg/kg DS			
150	15000	11000	250	97,72
200	20000	27300	600	97,80
210	21000	20300	500	97,53
220	22000	20200	200	99,00
230	23000	17400	300	98,27
240	24000	15000	300	98,00
250	25000	24400	600	97,54
300	30000	24000	1000	99,58
350	35000	4300	400	90,69
400	40000	4400	400	90,90
450	45000	2300	100	95,65
50al 150cp	500al 15000cp	22700	280	98,76
50al 200cp	500al 20000cp	22500	350	98,44
50al 250cp	500al 25000cp	23000	400	98,26
50al 300cp	500al 30000cp	22700	350	98,45
200al 250cp	2000al 25000cp	28500	500	98,24
400al 250cp	4000al 25000cp	30500	450	98,52
600al 250cp	6000al 25000cp	29500	500	98,30
800al 250cp	8000al 25000cp	29700	500	98,31

Where al: alum and cp: cationic polyelectrolyte.

Figure 6.95 shows the CSI values at different dosages of KWD 3500 cationic polyelectrolyte.

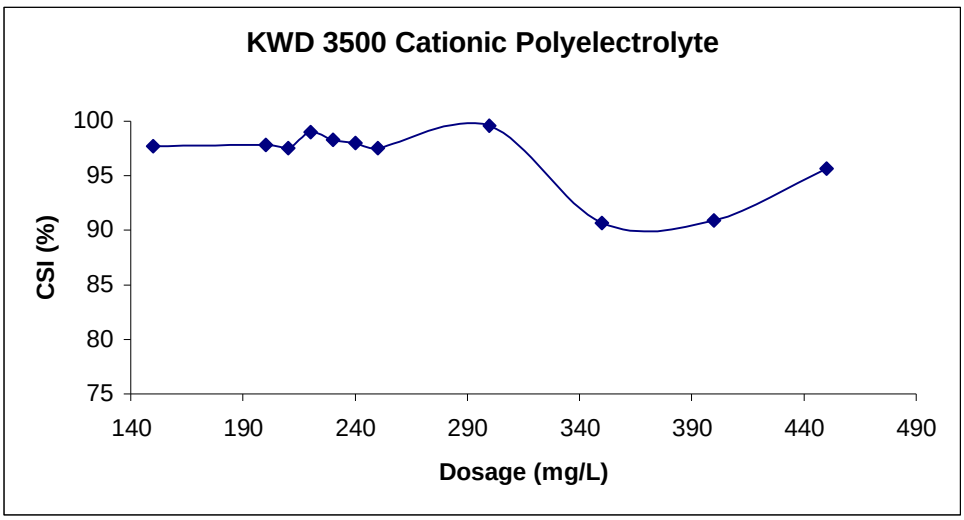


Figure 6.95 CSI Values versus KWD 3500 Dosage

6.5 Conditioning Experiments of SNF 5980 Cationic Polyelectrolyte Applications to Anaerobic Stabilized Sludge Samples

6.5.1 Jar Test Results of SNF 5980 Cationic Polyelectrolyte Applications

In this experiment 150 to 450 mg/L dose of SNF 5980 cationic polyelectrolyte was examined to condition of anaerobic stabilized sludge.

Then different amounts of SNF 5980 cationic polyelectrolyte ranged from 150 to 300 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 50 mg/L alum (aluminum hydroxyde 18 hydrate) dosage by the same method determined in Chapter 6.1.1.

As opposed to the precondition determined in above, different amounts of alum ranged from 200 to 800 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 200 mg/L SNF 5980 cationic polyelectrolyte dosage. Results of the jar test experiments are shown in Table 6.17.

Table 6.17 Jar Test results of SNF 5980 cationic polyelectrolyte

Dosage		Settled sludge volume	Supernatant turbidity	Sludge properties
mg/L	**mg/kg DS**	**mL**	**JTU**	
150	15000	50	1800	Very thin flocs
200	20000	50	1700	Very thin flocs
210	21000	120	1500	Midlle
220	22000	120	1650	Middle
230	23000	120	1750	Middle
240	24000	175	1200	Midlle
250	25000	50	1600	Very thin flocs
260	26000	200	1600	Middle
270	27000	200	1600	Middle
280	28000	200	1700	Middle
290	29000	175	1600	midlle
300	30000	50	1600	Very thin flocs
350	35000	95	1620	Middle
400	40000	95	1600	Middle
450	45000	60	1700	Middle
50al 150cp	50A 15000KP	200	2000	Very thin flocs
50al 200cp	50A 20000KP	200	1700	Midlle
50al 250cp	50A 25000KP	200	1700	Big flocs
50al 300cp	50A 30000KP	200	1600	Very big flocs
200al 200cp	2000al 20000cp	50	1500	Thin flocs
400al 200cp	4000al 20000cp	50	1400	Thin flocs
600al 200cp	6000al 20000cp	50	1400	Thin flocs
800al 200cp	8000al 20000cp	50	1400	Thin flocs

Where, cp: SNF 5980 cationic polyelectrolyte and al.: Alum.

6.5.2 Buchner Funnel Test Results of SBF 5980 Cationic Polyelectrolyte Applications

Buchner Funnel Test was applied to anaerobic stabilized conditioned sludge samples (between 150 to 450 mg/L dosage of SNF 5980 cationic polyelectrolyte) to calculate the specific resistance to filtration.

In the experiments it is observed that aerobic stabilized raw sludge is not filtrable. As opposed to the observation, the filtration data of aerobic stabilized conditioned sludge samples obtained from the Buchner Funnel Test is reported in Appendix E. The plots –T/V versus V- for each sample are presented between Figure 6.98 – Figure 6.118.

Dry solids content and viscosity values of filtrate samples and dry matter content of sludge cakes taken from the filter and the slope (b) of linear portion of T/V versus V curve and r values are given in Table 6.18. r values versus SNF 5980 cationic polyelectrolyte dosage are also depicted in Figure 6.119 for determination of optimum polyelectrolyte dosage.

As shown in Table 6.18, it can not be obtained a relationship between polyelectrolyte dosages and dry solids content of filtrate. Filtrate viscosity values were measured as 1,25 mPa.s for each sample. Minimum r, $6{,}29 \times 10^{12}$ mg/kg, was achieved at 200 mg/L SNF 5980 dosage and dry solids content of the sludge cake was found to be a high value of 16,08%. At higher dosages than 200 mg/L, increased r values were obtained with the increases in SNF 5980 dosage ranged from 200mg/L to 300mg/L based on r results.

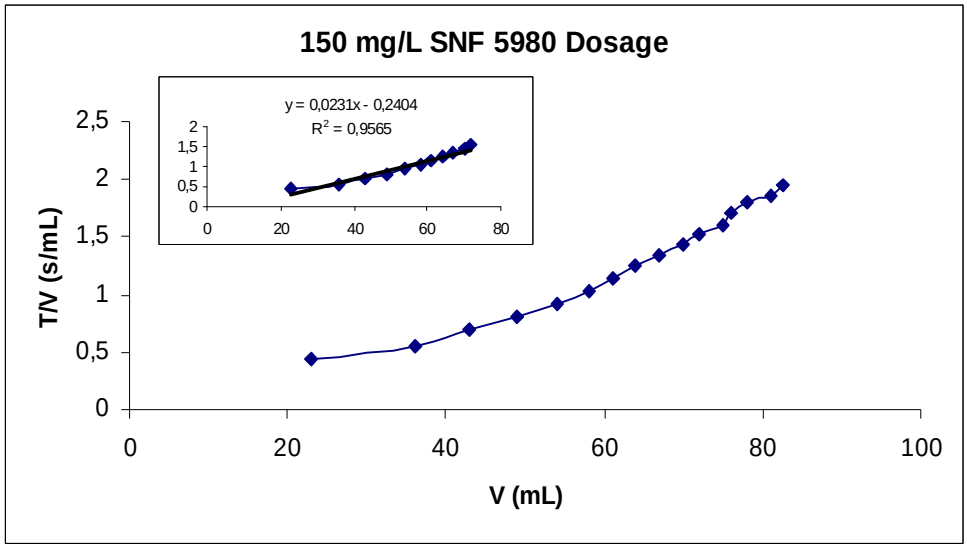


Figure 6.96 T/V values versus filtrate volume (V) for 150 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

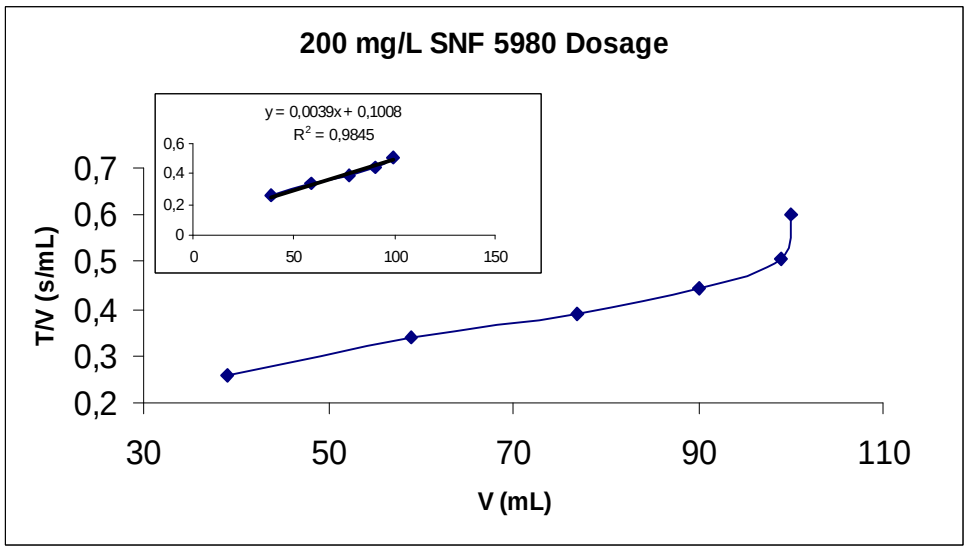


Figure 6.97 T/V values versus filtrate volume (V) for 200 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

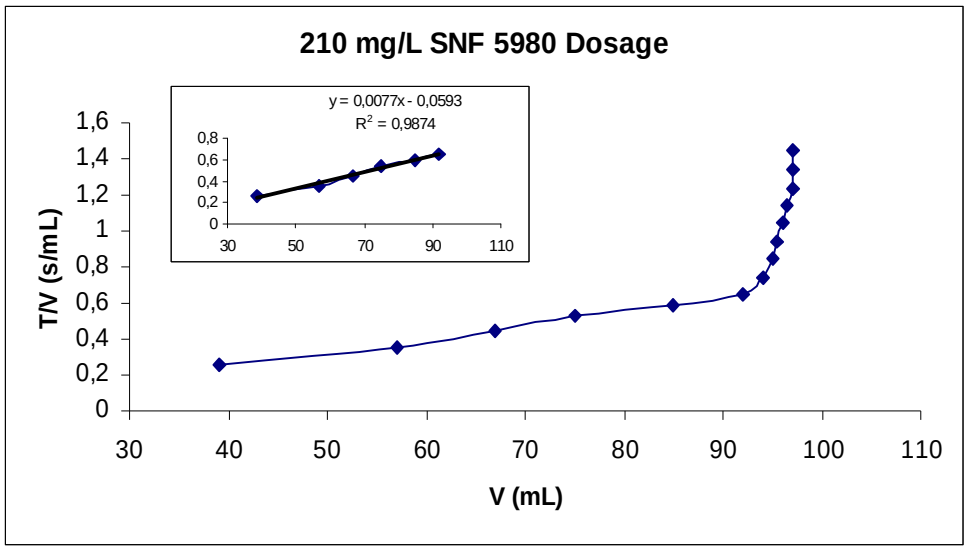


Figure 6.98 T/V values versus filtrate volume (V) for 210 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

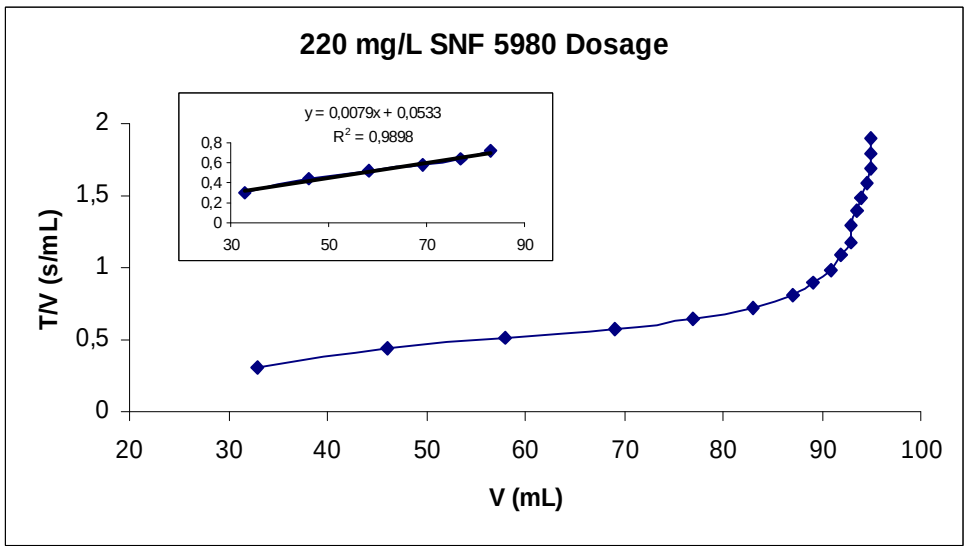


Figure 6.99 T/V values versus filtrate volume (V) for 220 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

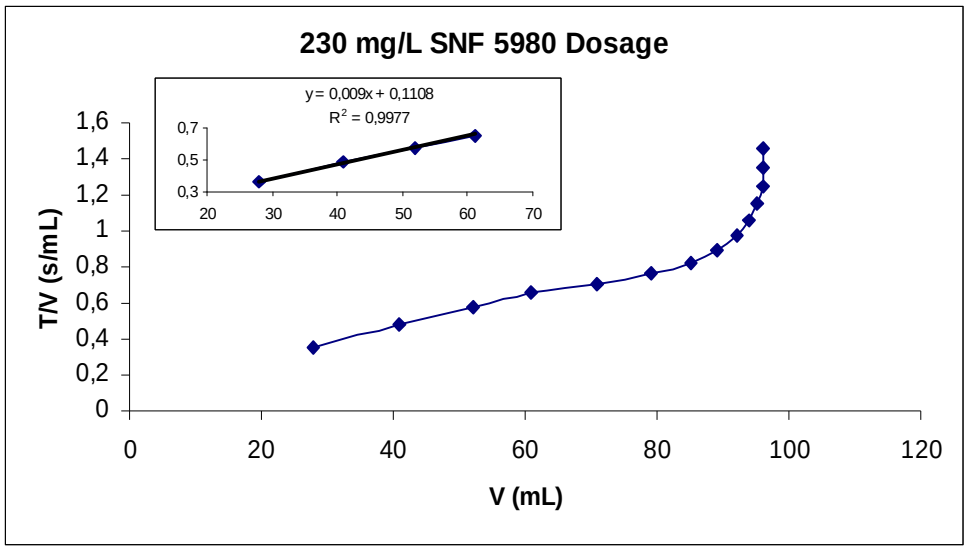


Figure 6.100 T/V values versus filtrate volume (V) for 230 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

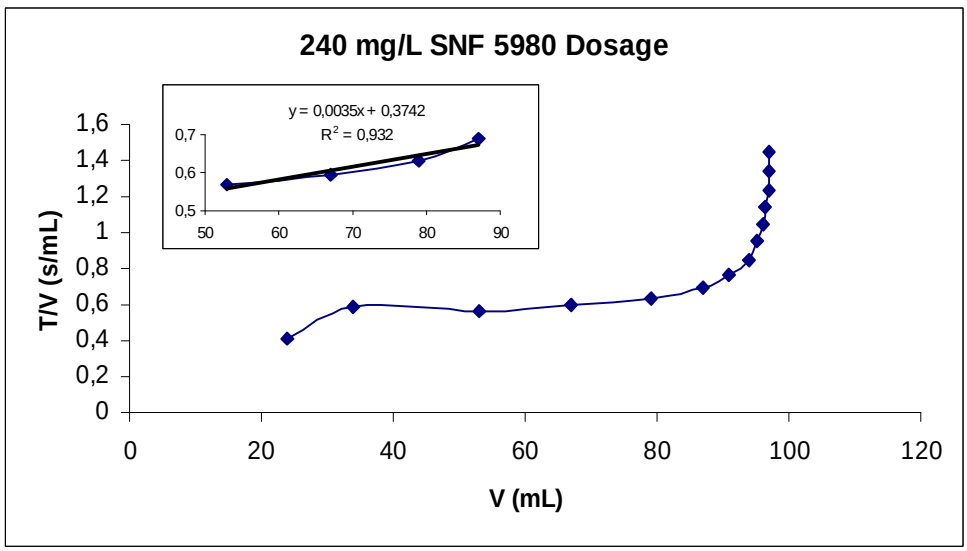


Figure 6.101 T/V values versus filtrate volume (V) for 240 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

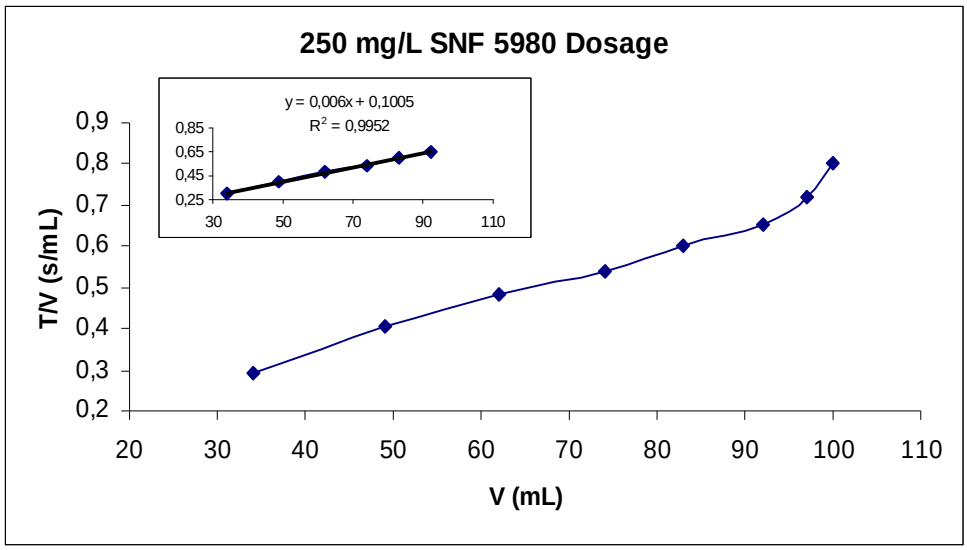


Figure 6.102 T/V values versus filtrate volume (V) for 250 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

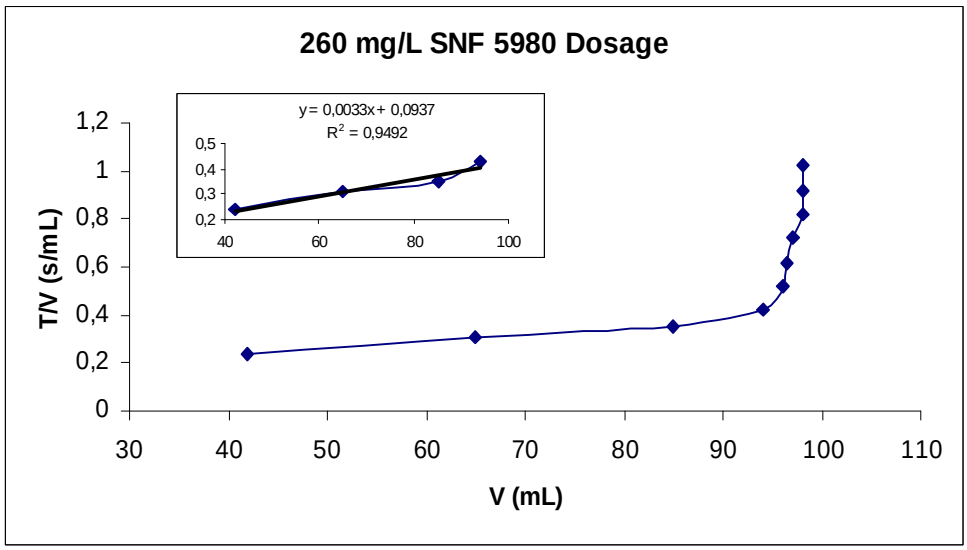


Figure 6.103 T/V values versus filtrate volume (V) for 260 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

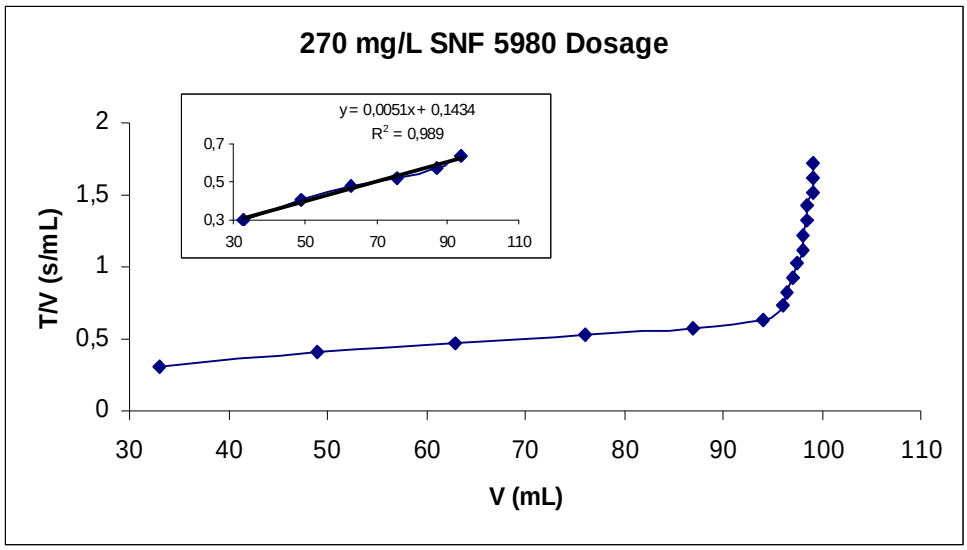


Figure 6.104 T/V values versus filtrate volume (V) for 270 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

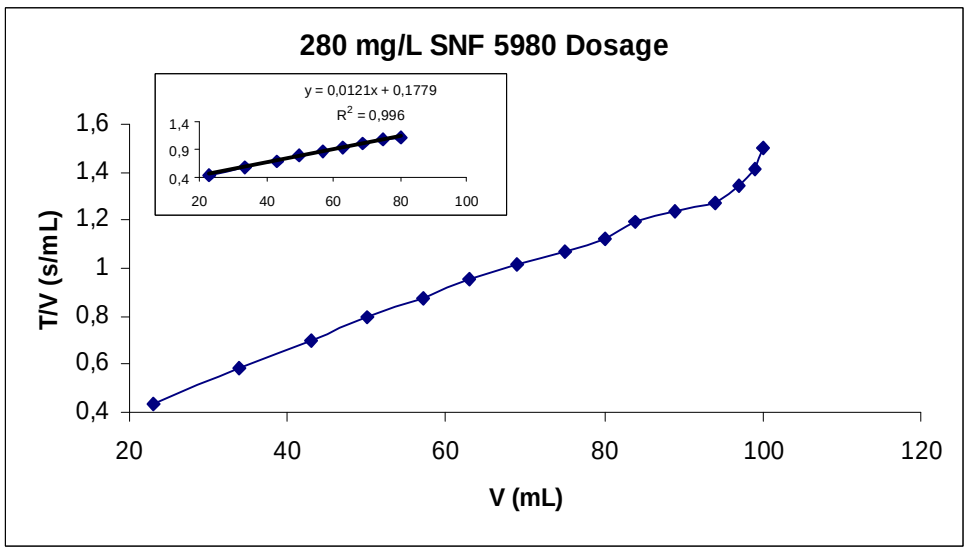


Figure 6.105 T/V values versus filtrate volume (V) for 280 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

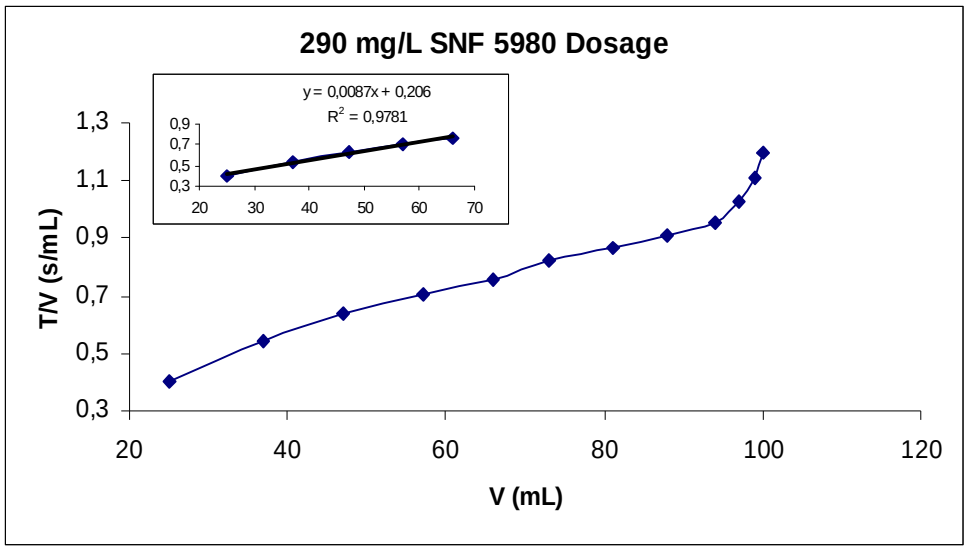


Figure 6.106 T/V values versus filtrate volume (V) for 290 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

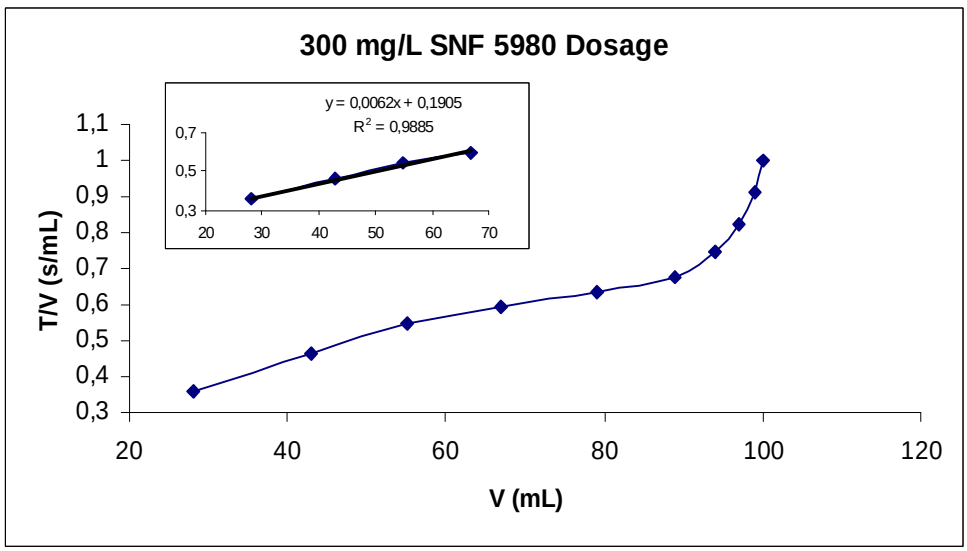


Figure 6.107 T/V values versus filtrate volume (V) for 300 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

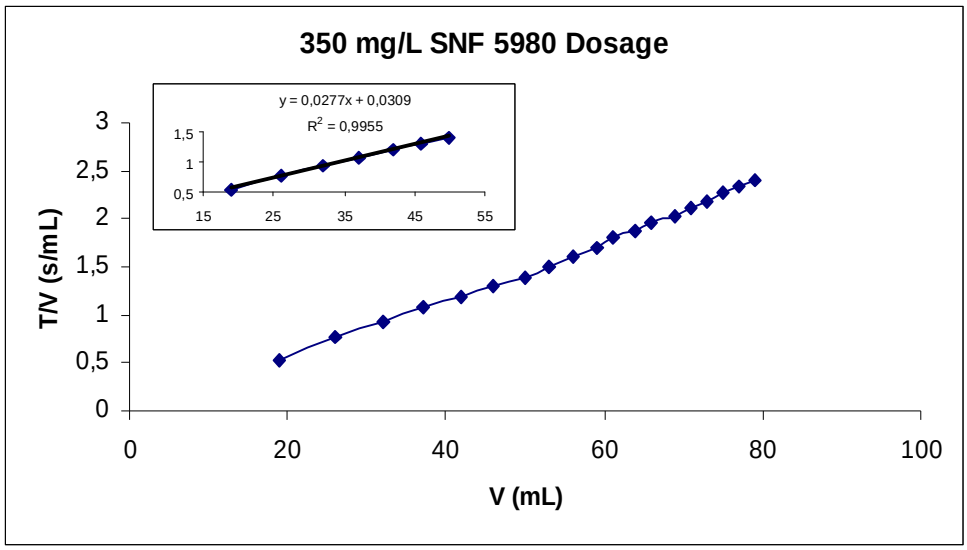


Figure 6.108 T/V values versus filtrate volume (V) for 350 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

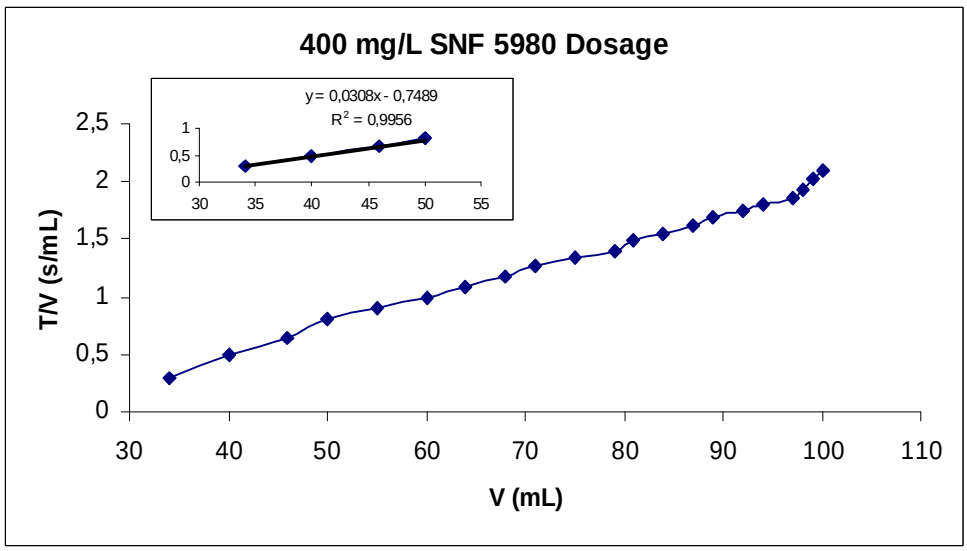


Figure 6.109 T/V values versus filtrate volume (V) for 400 mg/L SNF 5980 dosage.
Inset: The data applied linear regression.

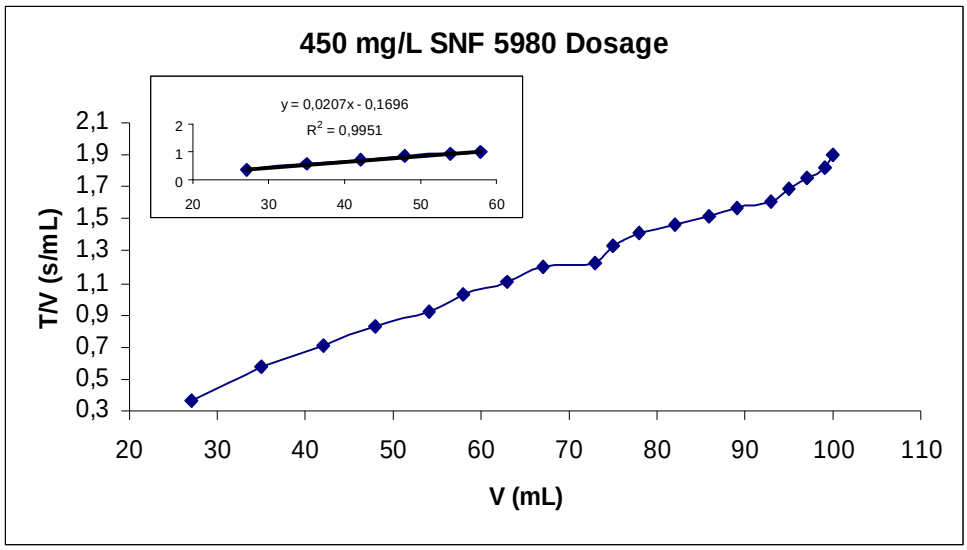


Figure 6.110 T/V values versus filtrate volume (V) for 450 mg/L SNF 5980 dosage. Inset: The data applied linear regression.

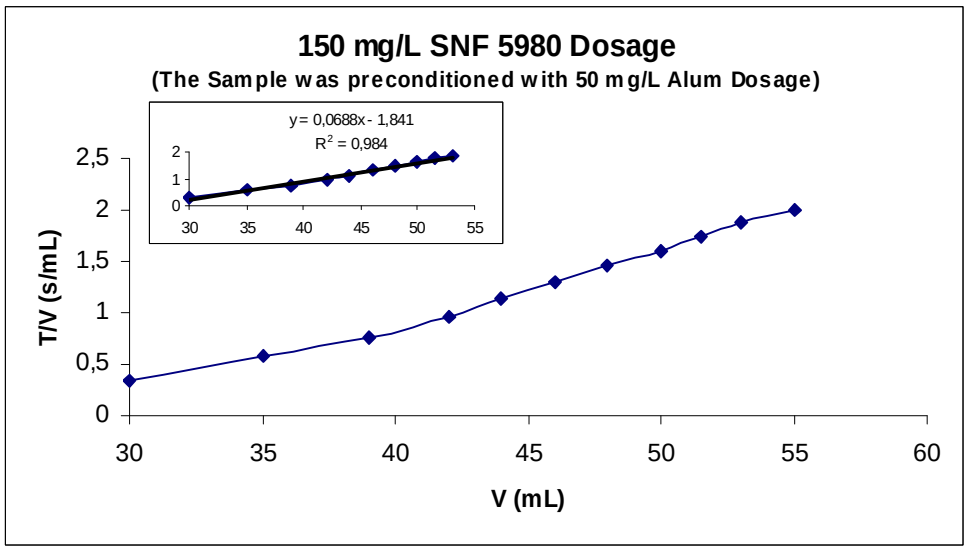


Figure 6.111 T/V values versus filtrate volume (V) for 150 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

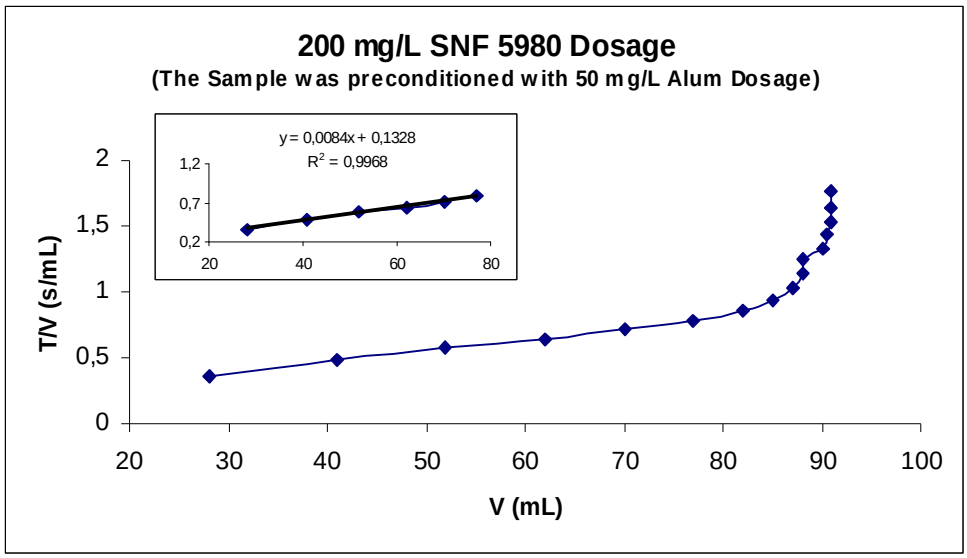


Figure 6.112 T/V values versus filtrate volume (V) for 200 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

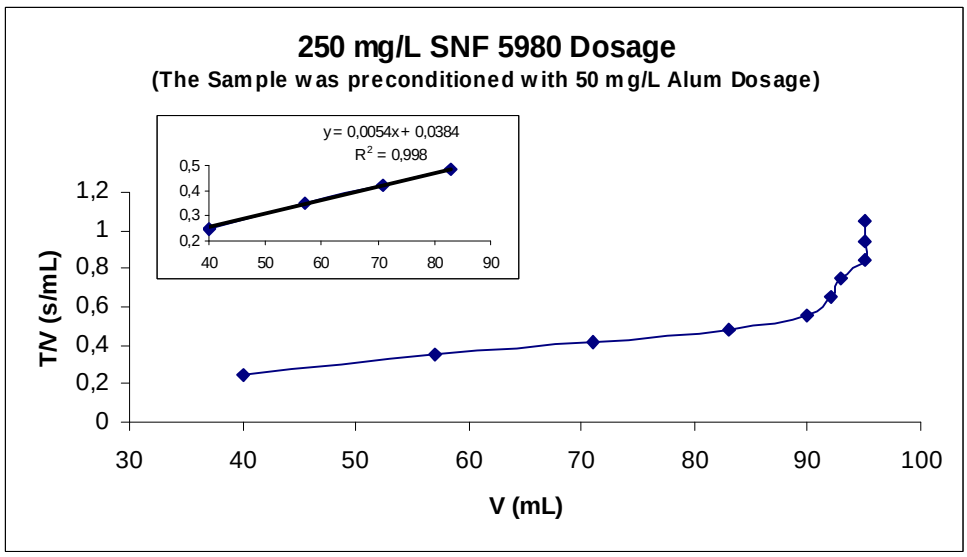


Figure 6.113 T/V values versus filtrate volume (V) for 250 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

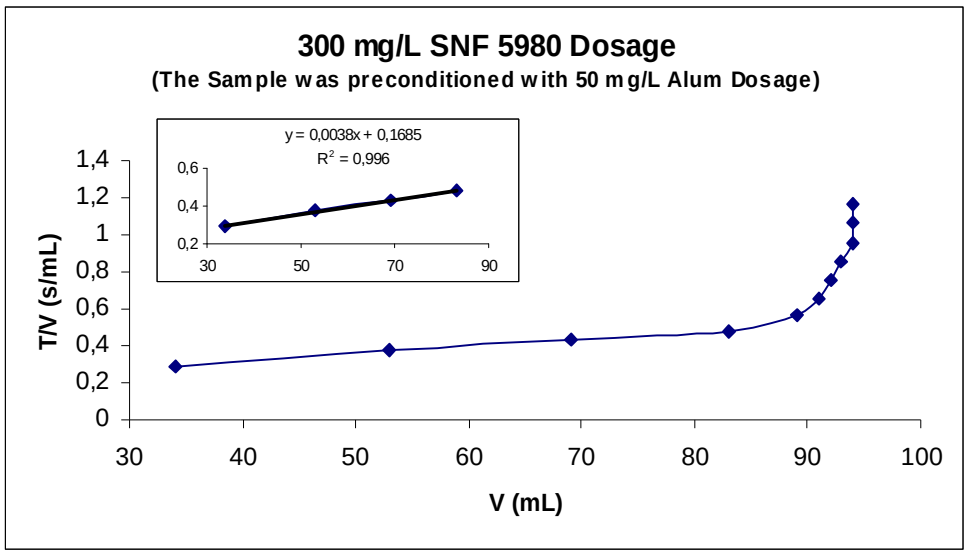


Figure 6.114 T/V values versus filtrate volume (V) for 300 mg/L SNF 5980 cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

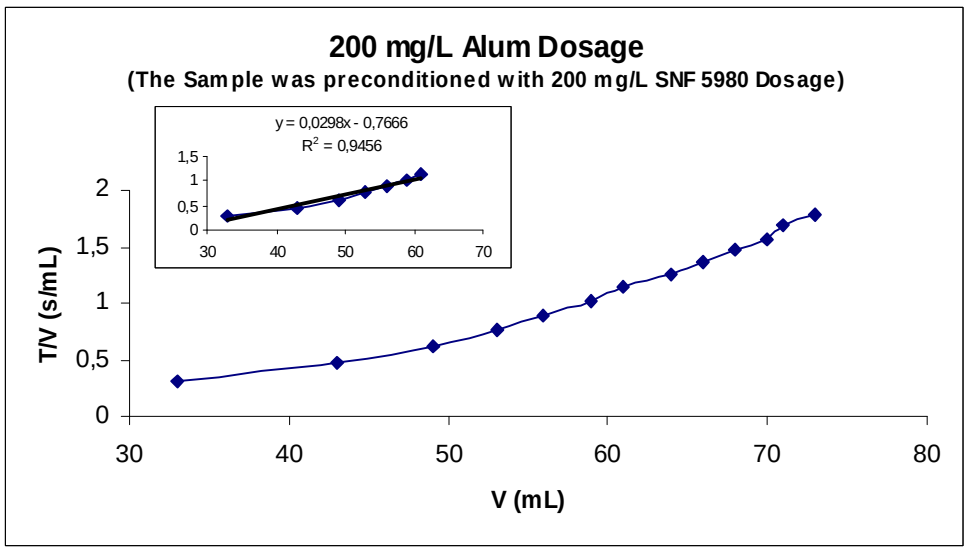


Figure 6.115 T/V values versus filtrate volume (V) for 200 mg/L alum dosage applied to the sludge sample preconditioned with 200 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

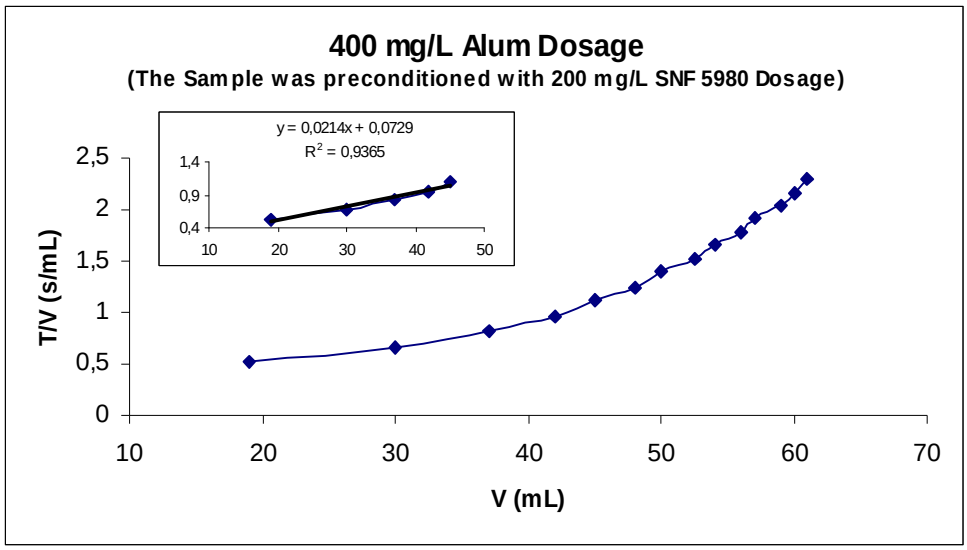


Figure 6.116 T/V values versus filtrate volume (V) for 400 mg/L alum dosage applied to the sludge sample preconditioned with 200 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

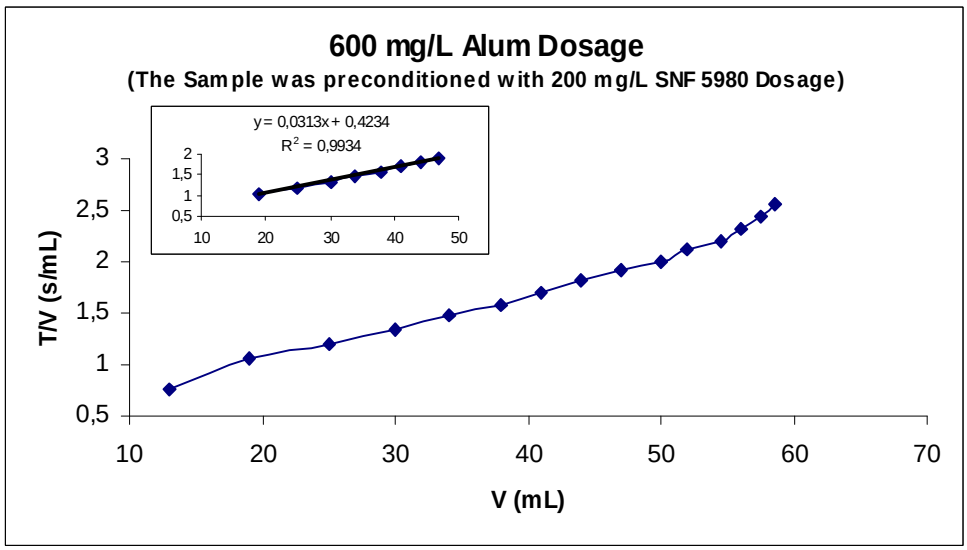


Figure 6.117 T/V values versus filtrate volume (V) for 600 mg/L alum dosage applied to the sludge sample preconditioned with 200 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

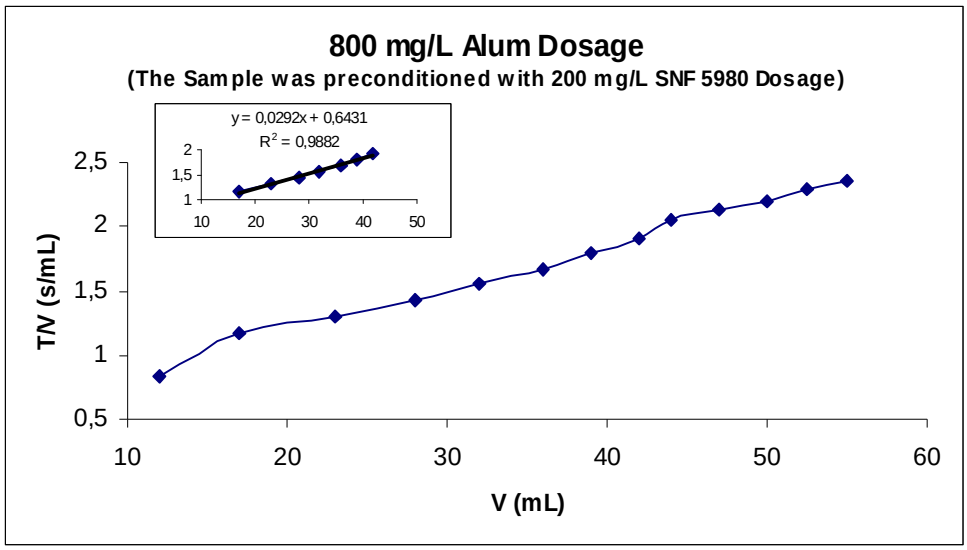


Figure 6.118 T/V values versus filtrate volume (V) for 800 mg/L alum dosage applied to the sludge sample preconditioned with 200 mg/L SNF 5980 cationic polyelectrolyte dosage. Inset: The data applied linear regression

Table 6.18 Buchner Funnel Test results of conditioned sludge samples with different dosages of SNF 5980 cationic polyelectrolyte

Dosage		**Dry Solids Content of Filtrate**		**Organic Solids Content of Filtrate**		**Dry Solids Content of Cake (%)**	**b (s/cm^6)**	**Filtrate Viscosity (mPa.s)**	**r (m/kg)**
mg/L	**mg/kg DS**	**mg/L**	**%**	**mg/L**	**%**				
150	15000	1,31	13110	36,97	3697	11,61	0,0231	1,25	5,16E+13
200	**20000**	**1,11**	**11178**	**34,73**	**3474**	**16,08**	**0,0039**	**1,25**	**6,29E+12**
210	21000	1,38	13842	37,1	3710	12,53	0,0077	1,25	1,59E+13
220	22000	1,64	16492	39,8	3980	12,8	0,0079	1,25	1,60E+13
230	23000	1,53	15342	38,84	3884	11,34	0,009	1,25	2,06E+13
240	24000	1,45	14568	39,09	3909	12,15	0,0035	1,25	7,47E+12
250	25000	0,93	9304	33,41	3340	11,08	0,006	1,25	1,40E+13
260	26000	1,51	15120	39,07	3907	12,65	0,0033	1,25	6,76E+12
270	27000	1,6	16056	40,36	4037	16,08	0,0051	1,25	8,22E+12
280	28000	1,15	11598	34,31	3431	11,17	0,0121	1,25	2,81E+13
290	29000	1,46	14639	38,47	3847	1,82	0,0087	1,25	1,24E+14
300	30000	0,94	9484	32,44	3244	8,38	0,0062	1,25	1,92E+13
350	35000	1,04	10440	46,91	4665	7,39	0,0277	1,25	9,72E+13
400	40000	0,95	9584	34,68	3468	4,02	0,0308	1,25	1,99E+14
450	45000	0,85	8548	39,43	3943	6,46	0,0207	1,25	8,31E+13
50al 150cp	500al 15000cp	2,05	20516	37,47	3747	-	0,0688	1,25	-
50al 200cp	500al 20000cp	1,8	18062	37,84	3782	11,19	0,0084	1,25	1,95E+13
50al 250cp	500al 25000cp	1,51	15180	36,61	3661	11,7	0,0054	1,25	1,20E+13
50al 300cp	500al 30000cp	1,39	13956	36,5	3651	11,37	0,0038	1,25	8,66E+12
200al 200cp	2000al 20000cp	1,59	15936	41,04	4104	11,65	0,0298	1,25	6,63E+13
200al 400cp	2000al 40000cp	1,52	15296	40,83	4082	11,43	0,0214	1,25	4,85E+13
600al 200cp	6000al 20000cp	1,65	16515	39,63	3963	18,22	0,0313	1,25	4,45E+13
800al 200cp	8000al 20000cp	1,51	15132	40,76	4076	-	0,0292	1,25	-

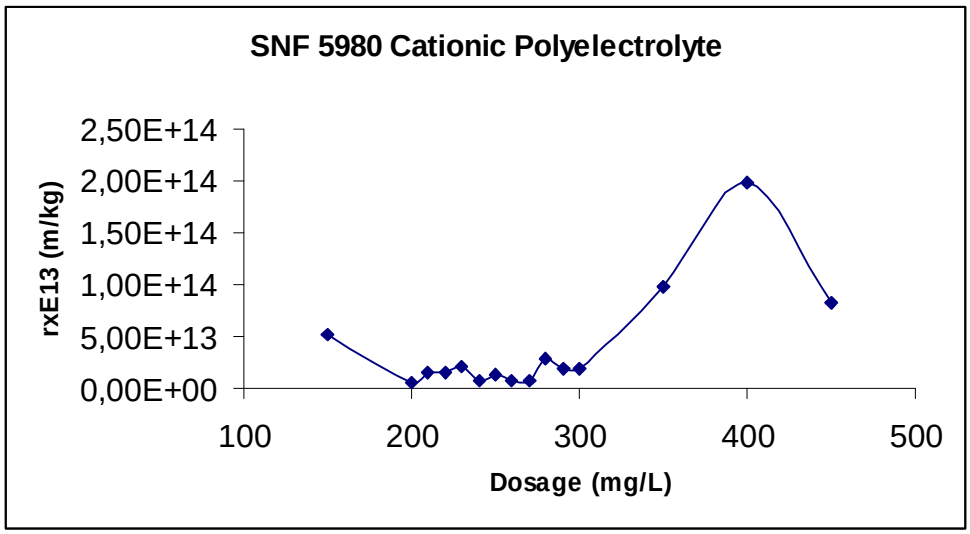


Figure 6.119 Specific Resistance to Filtration (r) values versus SNF 5980 cationic polyelectrolyte dosage

6.5.3 Capillary Suction Time Test Results of SNF 5980 Cationic Polyelectrolyte

After jar test trials, Capillary Suction Time (CST) test was applied to conditioned anaerobic stabilized sludge samples for evaluation of their dewatering capacity. Results of CST measurements of conditioned anaerobic stabilized sludge samples at different dosages of SNF 5980 cationic polyelectrolyte are shown in Table 6.19 and the CST values as a function of polyelectrolyte dosage is plotted in Figure 6.120.

When 200 mg/L SNF 5980 was added to the sludge sample, minimum 17,2 s of CST was achieved as shown in Table 6.19 and Figure 6.117. Dry solids content of the sludge cake was found to be 16,08% at this dosage. Considering the CST test results, optimum SNF 5980 dose range was determined between 200 mg/L and 300 mg/L.

Table 6.19 Results of Capillary Suction Time (CST) measurements of raw and conditioned sludge samples with SNF 5980 cationic polyelectrolyte

Dosage		**Capillary Suction Time**
mg/L	**mg/kg DS**	**s**
150	15000	20,3
200	**20000**	**17,2**
210	21000	18,3
220	22000	19,7
230	23000	18,2
240	24000	17,5
250	25000	21,5
260	26000	17,8
270	27000	18,2
280	28000	19,5
290	29000	23,9
300	30000	22,6
350	35000	30,05
400	40000	38,1
450	45000	35,4
50A 150KP	500A 15000K	20,8
50A 200KP	500A 20000K	20,9
50A 250KP	500A 25000K	21,0
50A 300KP	500A 30000K	21,8
200A 200KP	2000A 20000K	21,8
200A 400KP	2000A 40000K	21,2
600A 200KP	6000A 20000K	19,8
800A 200KP	8000A 20000K	21,0

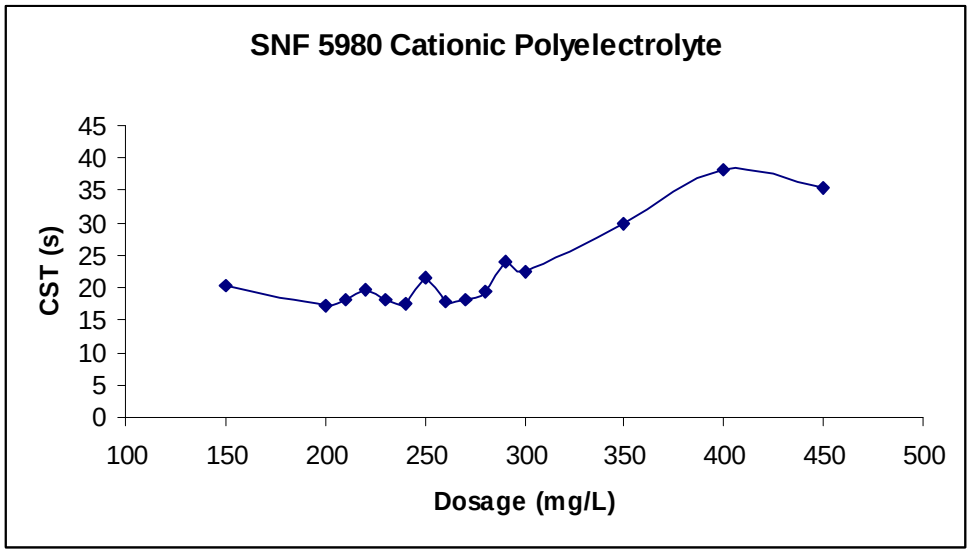


Figure 6.120 Capillary Suction Time (CST) values versus SNF 5980 dosage

6.5.4 Results of Centrifugal Settleability Index Measurements for SNF 5980 Cationic Polyelectrolyte Applications

To evaluate sludge dewaterability for centrifugal dewatering processes, centrifugal settleability index (CSI) parameter was analyzed. Suspended solid values of sludge and centrate samples and CSI values of sludge samples are given in Table 6.20.

Table 6.20 Results of Centrifugal Settleability Index (CSI) measurements for SNF 5980 cationic polyelectrolyte

Dosage		**Suspended Solids of Sludge (mg/L)**	**Suspended Solids of Centrate (mg/L)**	**Centrifugal Settleability Index (CSI) (%)**
mg/L	**mg/kg DS**			
150	15000	11000	250	97,72
200	**20000**	**9000**	**270**	**97**
210	21000	20400	260	98,72
220	22000	14600	340	97,67
230	23000	13200	340	97,42
240	24000	13000	360	97,23
250	25000	7000	270	96,14
260	26000	14200	200	98,59
270	27000	13400	200	98,50
280	28000	14900	240	98,38
290	29000	18800	200	98,93
300	30000	8000	210	97,37
350	35000	1000	100	90
400	40000	13000	180	98,61
450	45000	4000	200	95
50A 150KP	500A 15000K	24600	280	98,86
50A 200KP	500A 20000K	22500	280	98,75
50A 250KP	500A 25000K	24600	360	98,53
50A 300KP	500A 30000K	28700	320	98,88
200A 200KP	2000A 20000K	21000	420	98
200A 400KP	2000A 40000K	12400	360	97,09
600A 200KP	6000A 20000K	21200	260	98,77
800A 200KP	8000A 20000K	15200	280	98,15

Figure 6.121 shows the CSI values at different dosages of SNF 5980 cationic polyelectrolyte.

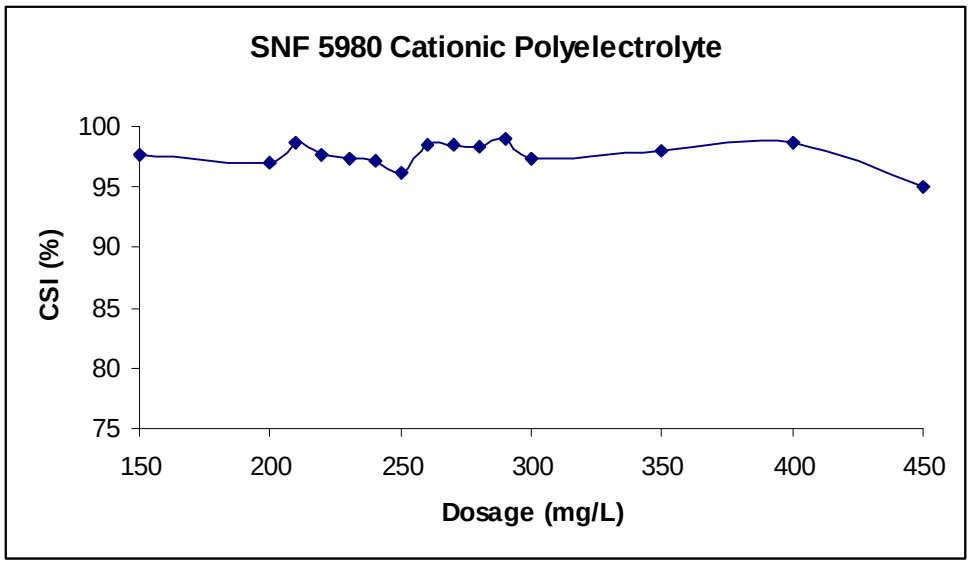


Figure 6.121 CSI values versus SNF 5980 dosage

6.6 Conditioning Experiments of 5980 SB Cationic Polyelectrolyte Applications to Anaerobic Stabilized Sludge Samples

6.6.1 Jar Test Results of 5980 SB Cationic Polyelectrolyte Applications

In this experiment 160 to 450 mg/L dose of SNF 5980 cationic polyelectrolyte was examined to condition aerobic stabilized sludge.

Then different amounts of 5980 SB cationic polyelectrolyte ranged from 150 to 300 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 50 mg/L alum dosage by the same method determined in Chapter 6.1.1.

In contrast to the preconditioning procedure described above, different amounts of alum ranged from 200 to 800 mg/L were dosed to aerobic stabilized sludge samples preconditioned with 160 mg/L 5980 SB cationic polyelectrolyte dosage. Results of the jar test experiments are shown in Table 6.21.

Table 6.21 Jar Test results of 5980 SB cationic polyelectrolyte

Dosage		Settled sludge volume	Supernatant turbidity	Sludge properties
mg/L	**mg/kg DS**	**mL**	**JTU**	
160	16000	150	2000	Thin flocs
180	18000	100	1900	Thin flocs
200	20000	80	1650	Thin flocs
210	21000	150	1620	Middle
220	22000	200	1700	Big flocs
230	23000	200	1720	Big flocs
240	24000	250	1500	Big flocs
250	25000	200	1520	Big flocs
260	26000	200	1600	Big flocs
270	27000	150	1600	Big flocs
280	28000	300	1200	Midlle flocs
290	29000	400	1100	Middle flocs
300	30000	400	1120	Middle
350	35000	400	1800	Big flocs
400	40000	400	1900	Very big flocs
450	45000	400	1800	Very big flocs
50al 150cp	500al 15000cp	300	1700	Midlle
50al 200cp	500al 20000cp	300	1700	Big flocs
50al 250cp	500al 25000cp	300	1600	Very big flocs
50al 300cp	500al 30000cp	300	1500	Thin flocs
200al 270cp	2000al 27000cp	150	1400	Thin flocs
400al 270cp	4000al 27000cp	150	1400	Thin flocs
600al 270cp	6000al 27000cp	150	1400	Thin flocs
800al 270cp	8000al 27000cp	150	1400	Thin flocs

Where, cp: 5980 SB cationic polyelectrolyte and al.: Alum

6.6.2 Buchner Funnel Test Results of 5980 SB Cationic Polyelectrolyte Applications

Buchner Funnel Test was applied to anaerobic stabilized conditioned sludge samples (between 160 to 450 mg/L dosage of 5980 SB cationic polyelectrolyte) to calculate the specific resistance to filtration.

In the experiments it was observed that anaerobic stabilized raw sludge is not filtrable. Contrary to the observation, the filtration data of anaerobic stabilized conditioned sludge samples obtained from the Buchner Funnel Test is reported in Appendix F. The plots –T/V versus V- for each sample are presented between Figure 6.122 – Figure 6.145.

Dry solids content and viscosity values of filtrate samples and dry matter content of sludge cakes taken from the filter and the slope (b) of linear portion of T/V versus V curve and r values are given in Table 6.22. r values versus 5980 SB cationic polyelectrolyte dosage are also depicted in Figure 6.146 for determination of optimum polyelectrolyte dosage.

As shown in Table 6.22, it can not be obtained a relationship between polyelectrolyte dosages and dry solids content of filtrate. Filtrate viscosity values were measured as 1,25 mPa.s for each sample. Minimum r, 2.82×10^{13}mg/kg, was achieved at 270 mg/L 5980 SB dosage and dry solids content of the sludge cake was found to be a high value of 18,22%. At higher dosages than 270 mg/L, increased r values were obtained with the increases in 5980 SB dosage ranged from 200 mg/L to 200 mg/L based on r results.

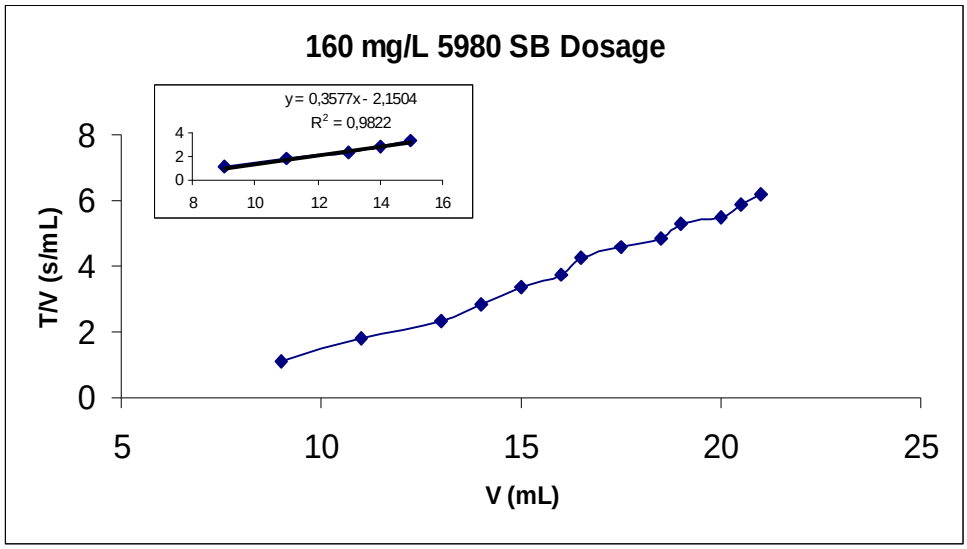


Figure 6.122 T/V values versus filtrate volume (V) for 160 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

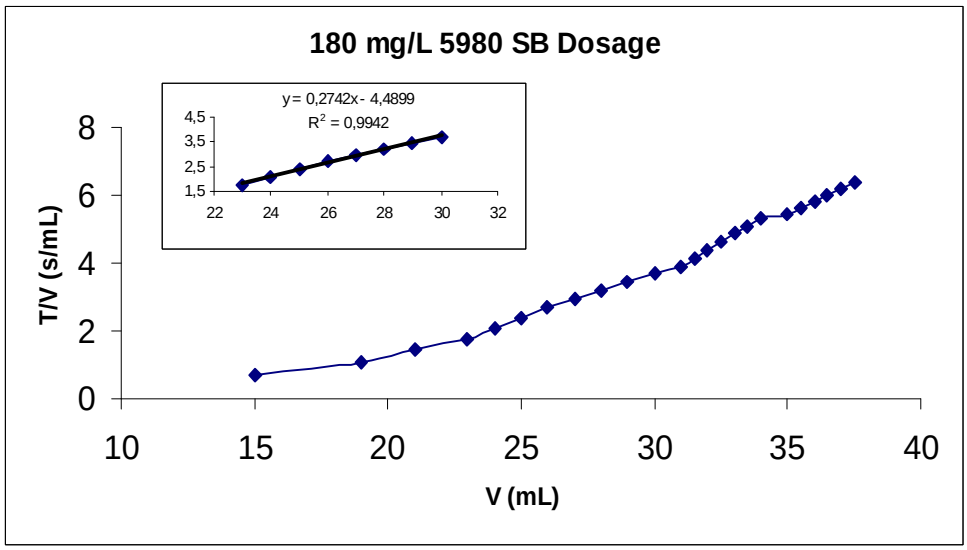


Figure 6.123 T/V values versus filtrate volume (V) for 180 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

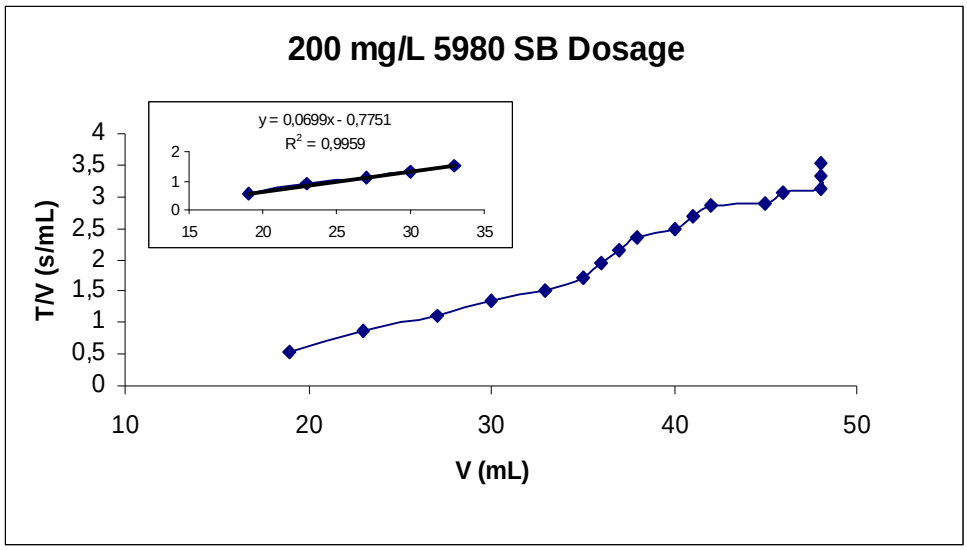


Figure 6.124 T/V values versus filtrate volume (V) for 200 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

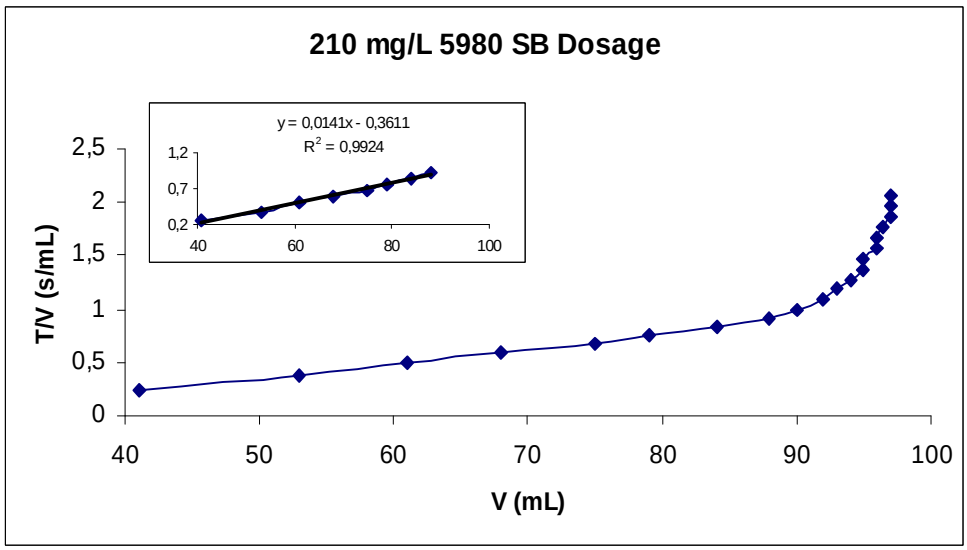


Figure 6.125 T/V values versus filtrate volume (V) for 210 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

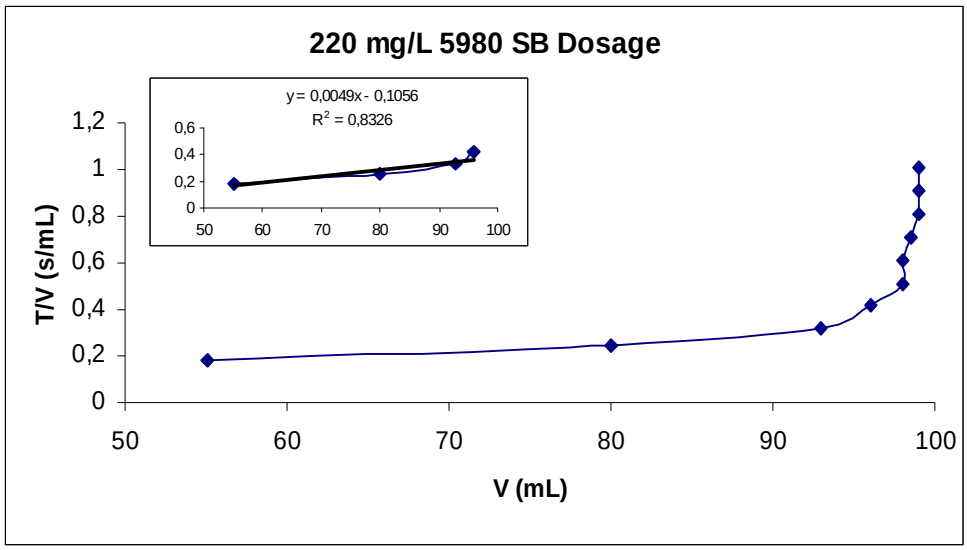


Figure 6.126 T/V values versus filtrate volume (V) for 220 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

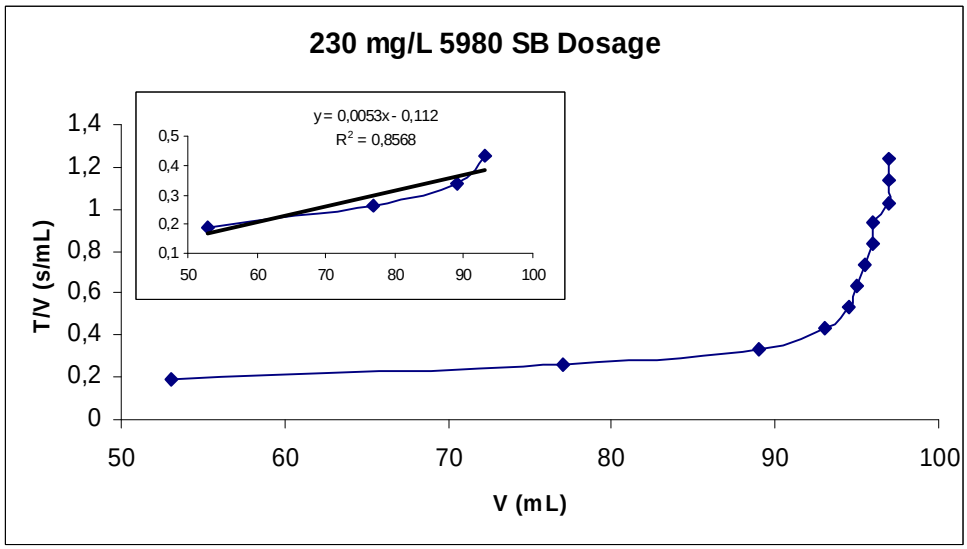


Figure 6.127 T/V values versus filtrate volume (V) for 230 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

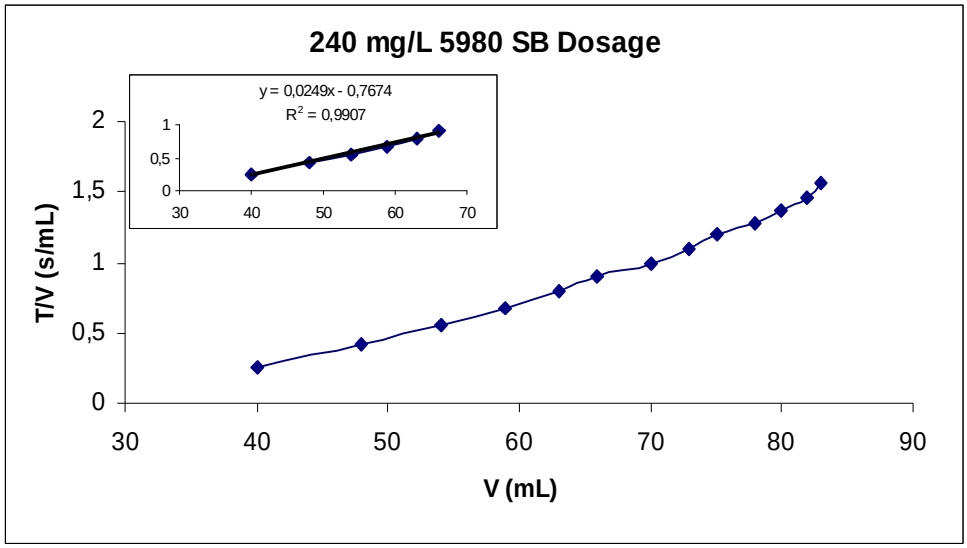


Figure 6.128 T/V values versus filtrate volume (V) for 240 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

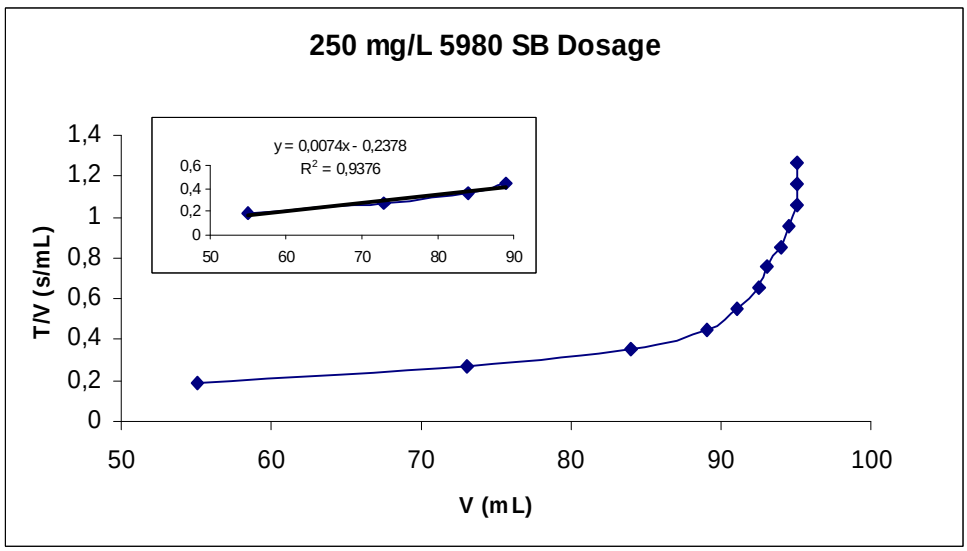


Figure 6.129 T/V values versus filtrate volume (V) for 250 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

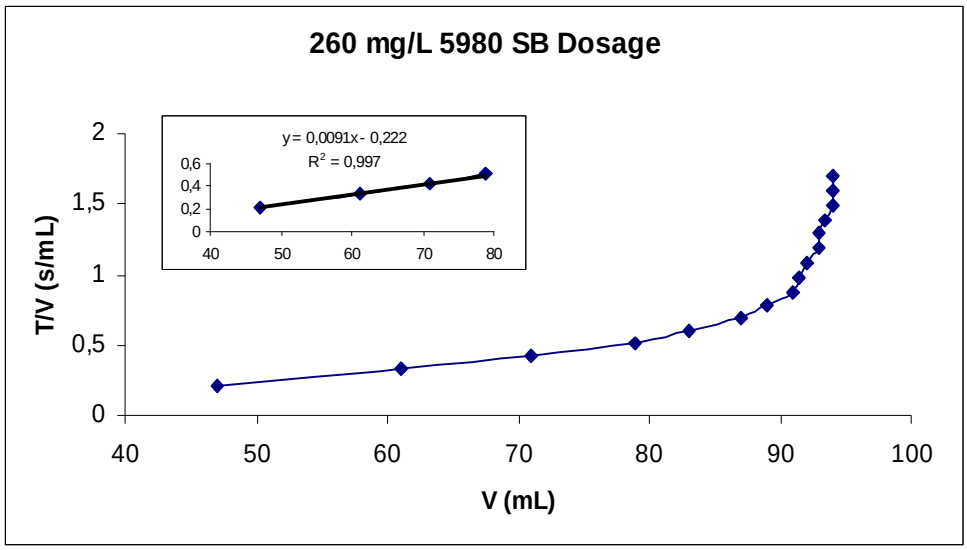


Figure 6.130 T/V values versus filtrate volume (V) for 260 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

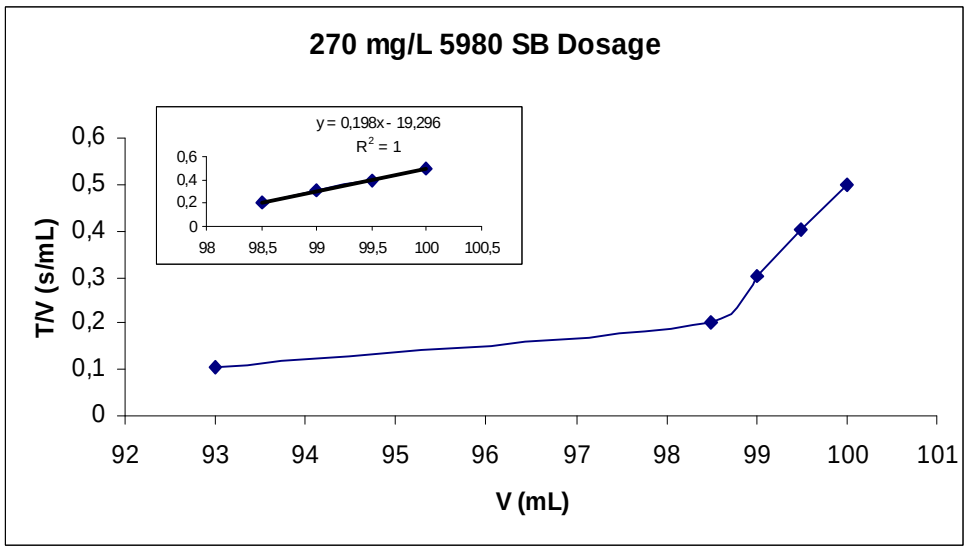


Figure 6.131 T/V values versus filtrate volume (V) for 270 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

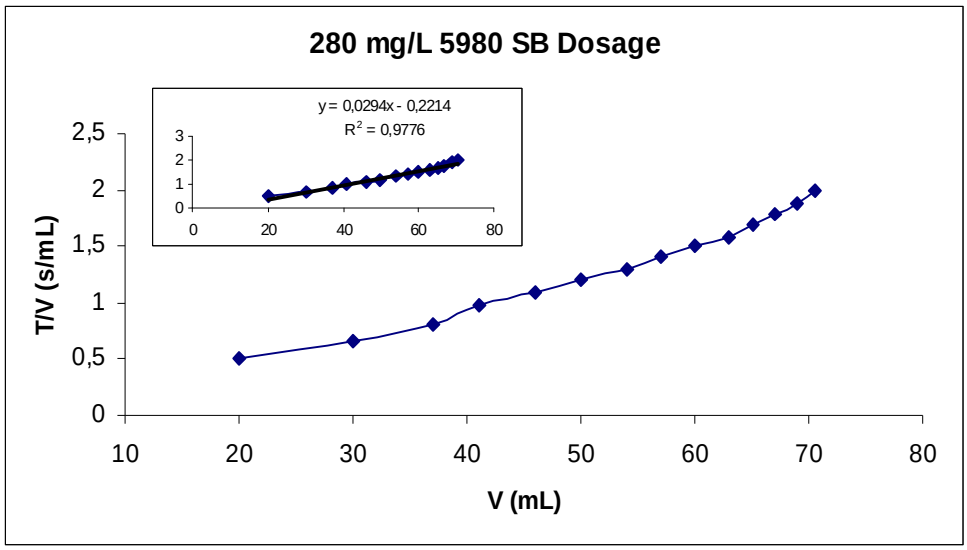


Figure 6.132 T/V values versus filtrate volume (V) for 280 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

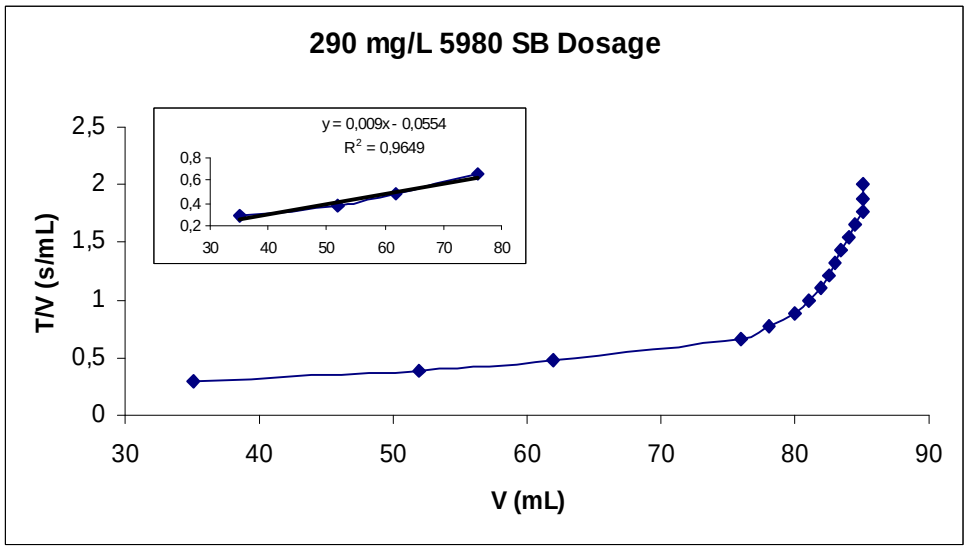


Figure 6.133 T/V values versus filtrate volume (V) for 290 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

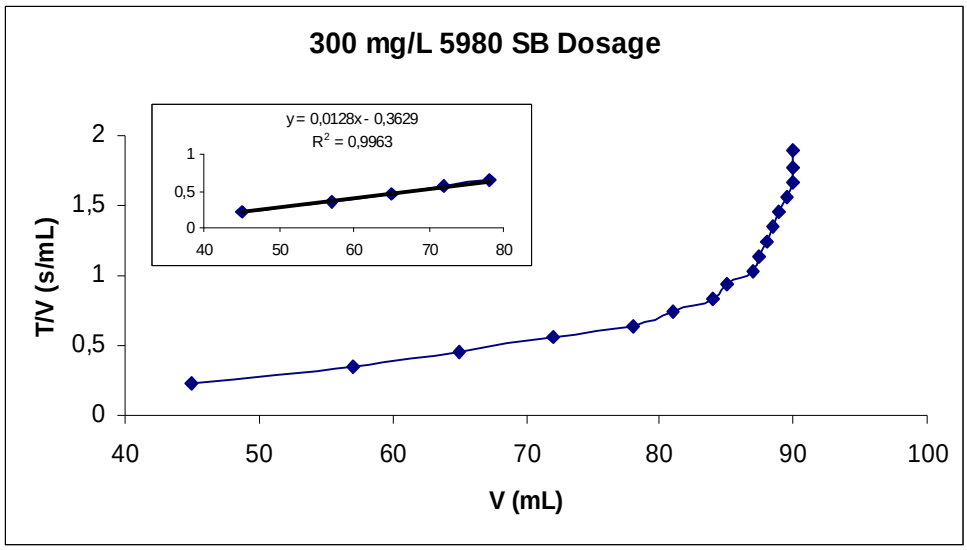


Figure 6.134 T/V values versus filtrate volume (V) for 300 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

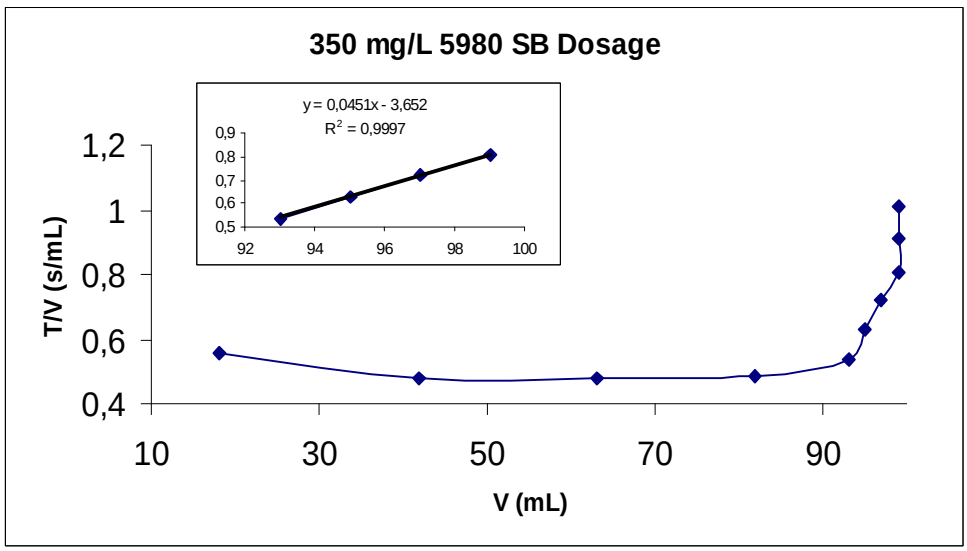


Figure 6.135 T/V values versus filtrate volume (V) for 350 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

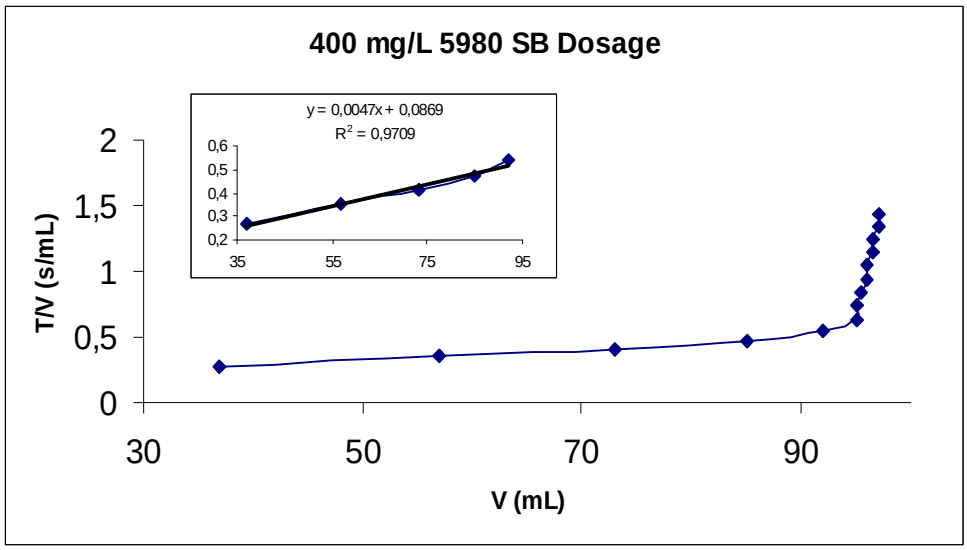


Figure 6.136 T/V values versus filtrate volume (V) for 400 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

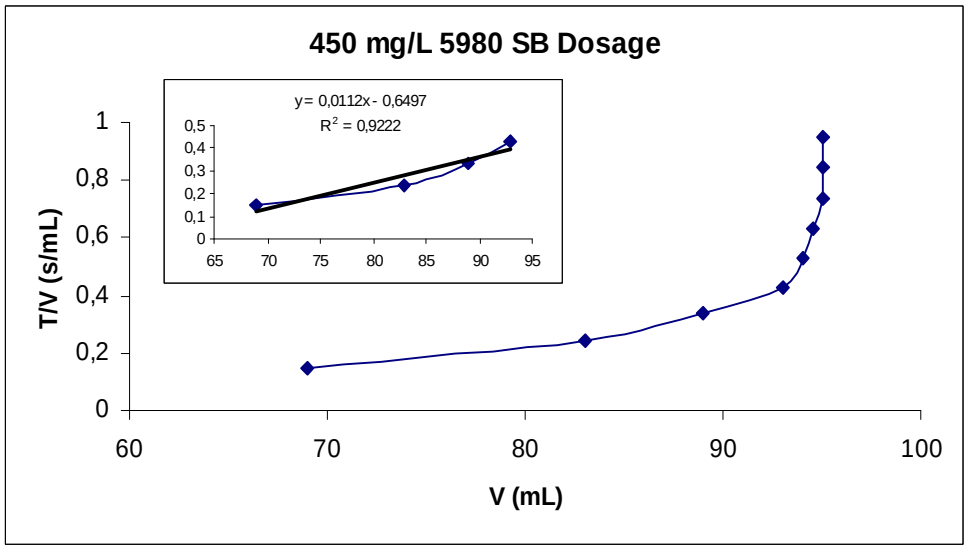


Figure 6.137 T/V values versus filtrate volume (V) for 450 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

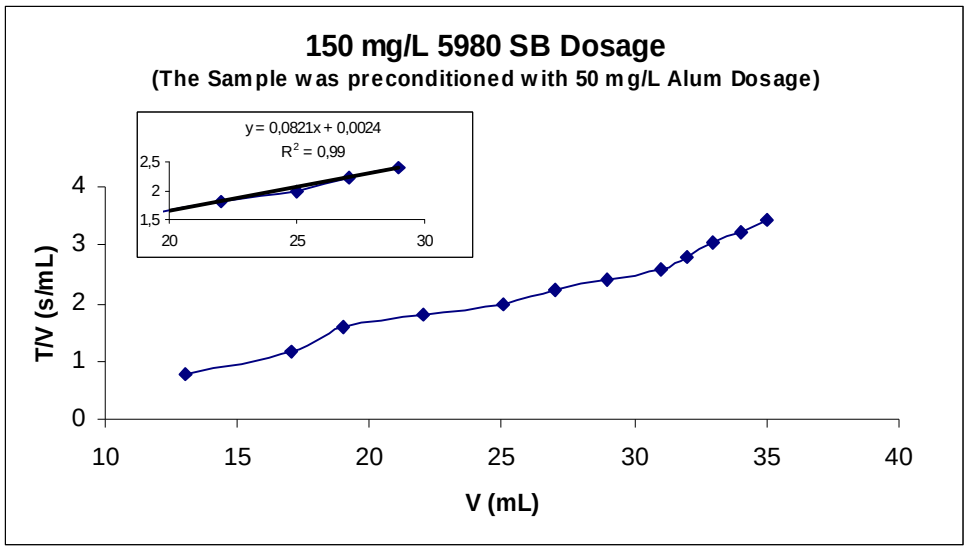


Figure 6.138 T/V values versus filtrate volume (V) for 150 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

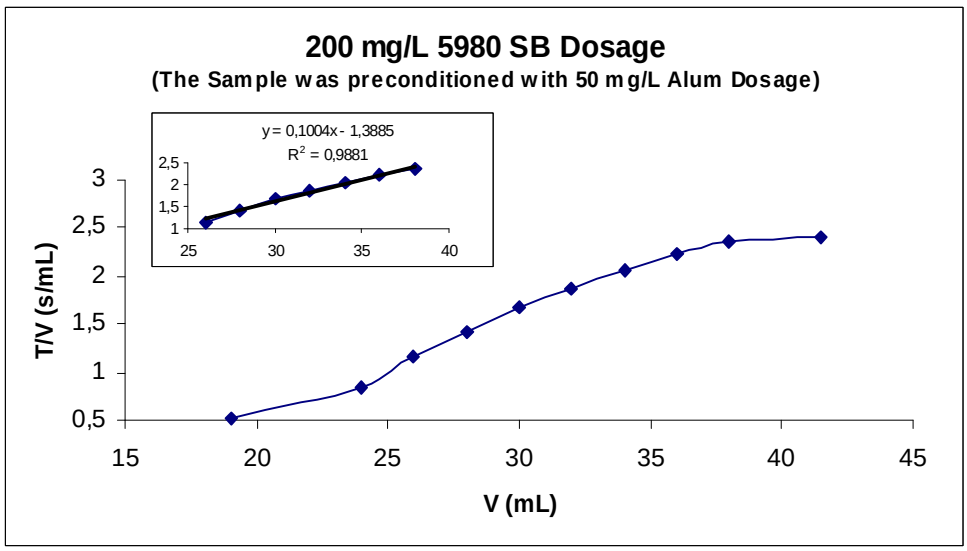


Figure 6.139 T/V values versus filtrate volume (V) for 200 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

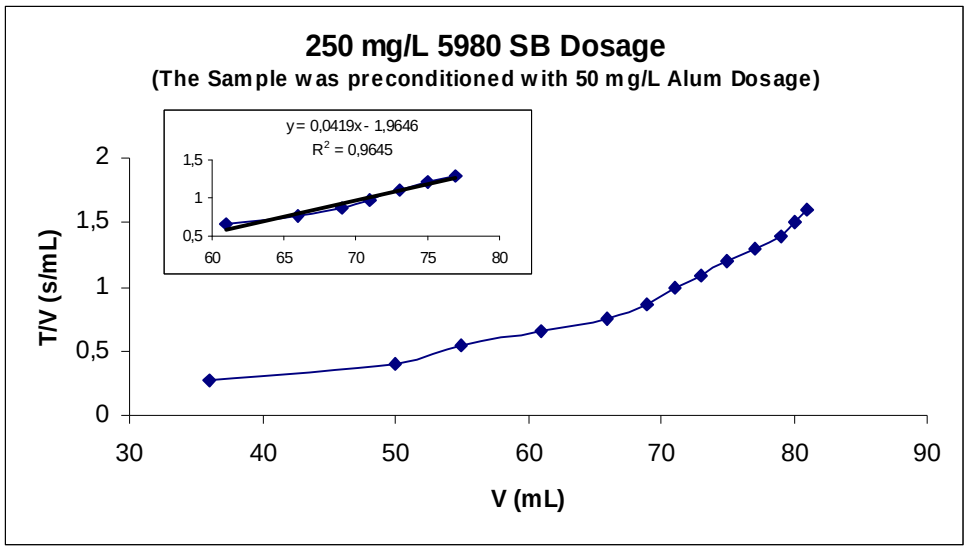


Figure 6.140 T/V values versus filtrate volume (V) for 250 mg/L 5980 SB cationic polyelectrolyte dosage applied to the sludge sample preconditioned with 50 mg/L alum dosage. Inset: The data applied linear regression

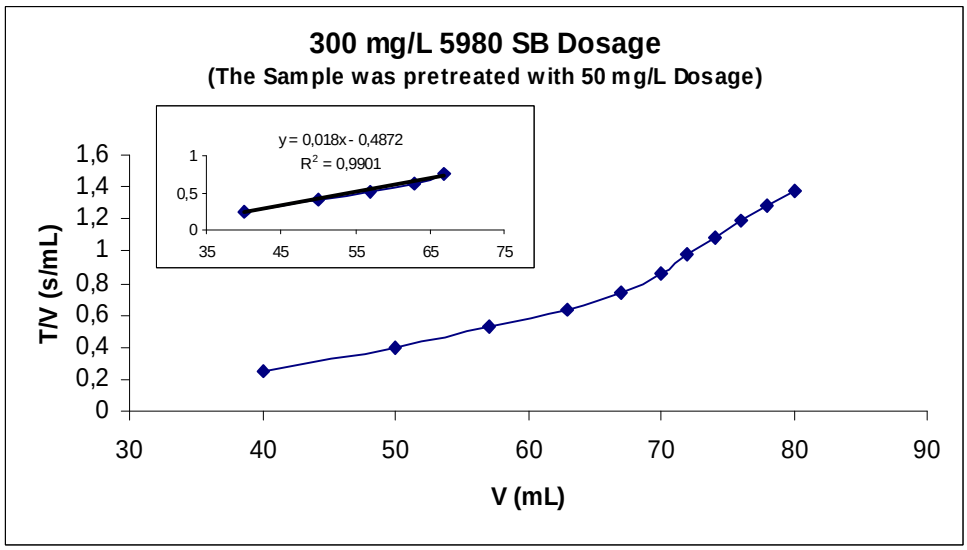


Figure 6.141 T/V values versus Filtrate Volume (V) for 300 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage. Inset: The Data Applied Linear Regression

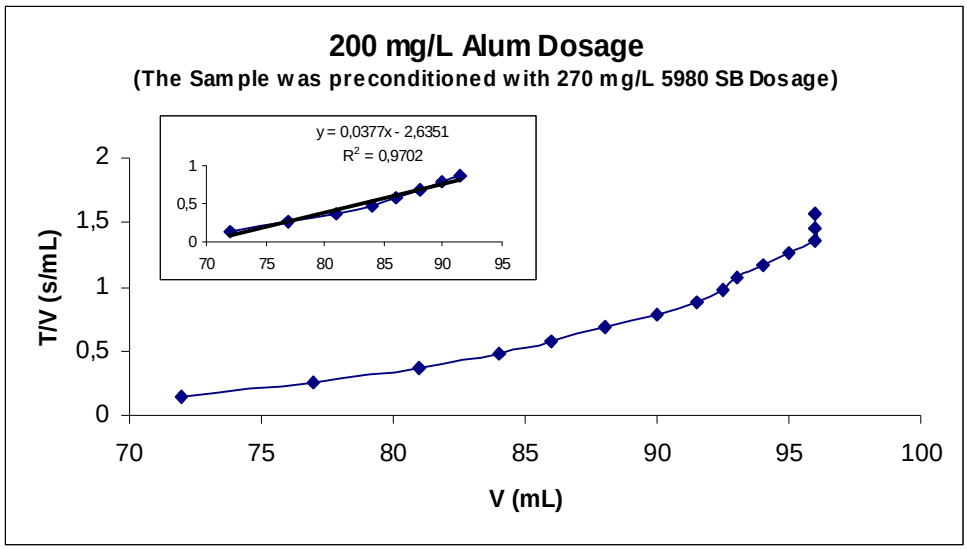


Figure 6.142 T/V values versus filtrate volume (V) for 200 mg/L alum dosage applied to the sludge sample preconditioned with 270 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression.

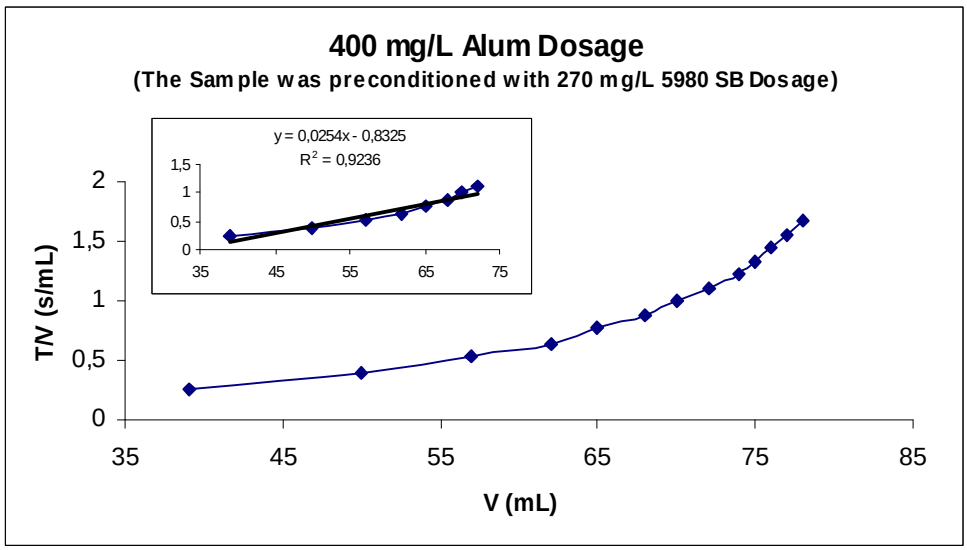


Figure 6.143 T/V values versus Filtrate Volume (V) for 400 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 270 mg/L 5980 SB Cationic Polyelectrolyte Dosage. Inset: The Data Applied Linear Regression

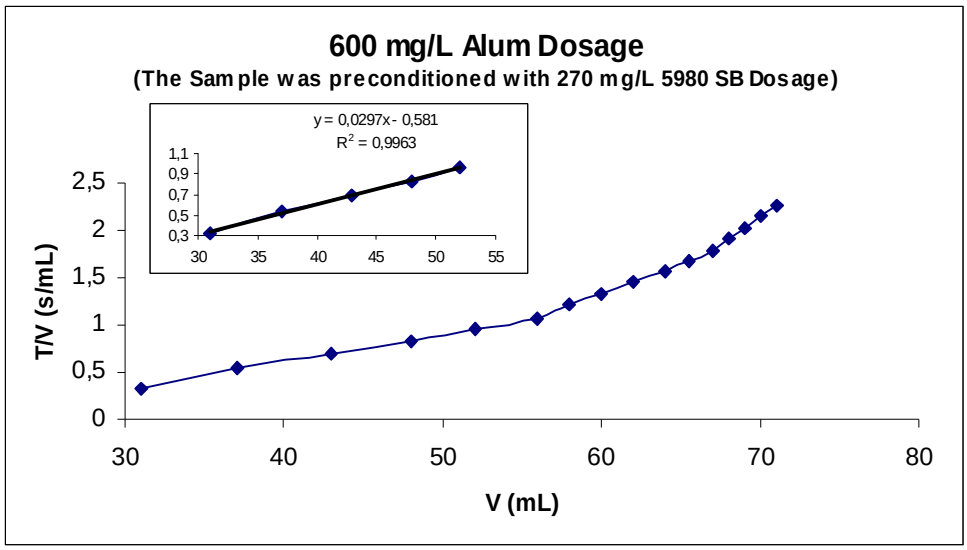


Figure 6.144 T/V values versus filtrate volume (V) for 600 mg/L alum dosage applied to the sludge sample preconditioned with 270 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

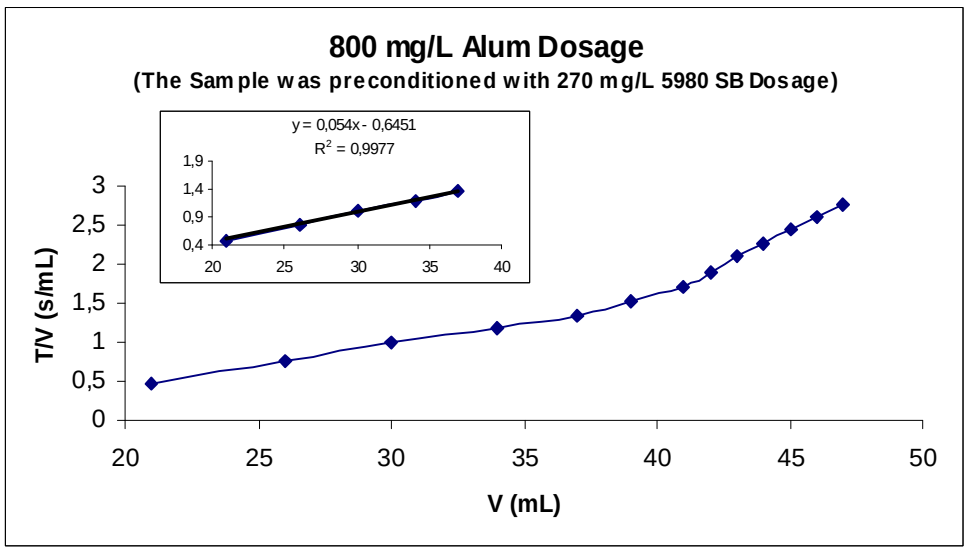


Figure 6.145 T/V values versus filtrate volume (V) for 800 mg/L alum dosage applied to the sludge sample preconditioned with 270 mg/L 5980 SB cationic polyelectrolyte dosage. Inset: The data applied linear regression

Table 6.22 Buchner Funnel Test results of conditioned sludge samples with different dosages of 5980 SB cationic polyelectrolyte

Dosage		**Dry Solids Content of Filtrate**		**Organic Solids Content of Filtrate**		**Dry Solids Content of Cake (%)**	**b (s/cm^6)**	**Filtrate Viscosity (mPa.s)**	**r (m/kg)**
mg/L	**mg/kg DS**	**mg/L**	**%**	**mg/L**	**%**				
160	16000	Oca.60	16240	37.51	6092	4,72	0,3577	1,25	1,96E+15
180	18000	Oca.21	12324	36.44	4492	3,94	0,2742	1,25	1,80E+15
200	20000	Oca.78	16300	36.58	5964	9,84	0,0699	1,25	1,84E+14
210	21000	1,48	14844	38,06	3806	8,61	0,0141	1,25	4,24E+13
220	22000	1,1	11000	41,86	4180	1,57	0,0049	1,25	8,09E+13
230	23000	1,05	10510	40	4000	5,11	0,0053	1,25	2,99E+13
240	24000	1,69	16928	39,79	3979	5,56	0,0249	1,25	1,16E+14
250	25000	1,27	12732	36,74	3674	6,42	0,0074	1,25	2,99E+13
260	26000	1,26	12660	56,21	5621	7,56	0,0091	1,25	3,12E+13
270	**27000**	**1,4**	**14000**	**36,03**	**3603**	**18,22**	**0,0198**	**1,25**	**2,82E+13**
280	28000	1,82	18296	41,75	4175	10,98	0,0294	1,25	6,94E+13
290	29000	1,47	14703	38,2	3820	8,03	0,009	1,25	2,91E+13
300	30000	1,71	17189	41,5	4150	8,58	0,0128	1,25	3,87E+13
350	35000	1,59	15920	39,36	3936	9,08	0,0451	1,25	1,29E+14
400	40000	1,11	11176	32,2	3220	9,14	0,047	1,25	1,33E+14
450	45000	1,41	14125	35,21	3521	10,2	0,0112	1,25	2,85E+13
50al 150cp	500al 15000cp	2,84	28420	40,67	4067	-	0,0821	1,25	-
50al 200cp	500al 20000cp	1,78	17864	39,87	3987	11,22	0,1004	1,25	2,32E+14
50al 250cp	500al 25000cp	1,32	13297	35,42	3542	11,65	0,0419	1,25	9,32E+13
50al 300cp	50al 300cp	1,63	16300	39,65	3965	11,43	0,018	1,25	4,08E+13
200al 270cp	2000al 27000cp	1,89	18900	37,63	3763	10,13	0,0377	1,25	9,65E+13
400al 270cp	4000al 27000cp	2,04	20430	36,89	3689	-	0,0254	1,25	-
600al 270cp	6000al 27000cp	2,19	21980	36,55	2655	-	0,0297	1,25	-
800al 270cp	8000al 27000cp	2,45	24521	36,09	3609	-	0,054	1,25	-

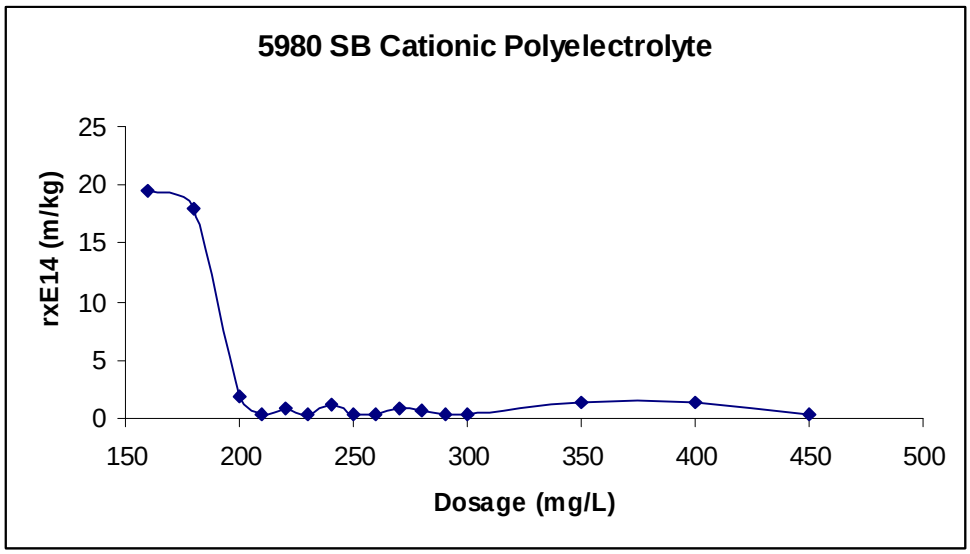


Figure 6.146 Specific Resistance to Filtration (r) values versus 5980 SB cationic polyelectrolyte dosage

6.6.3 Capillary Suction Time Test Results of SNF 5980 Cationic Polyelectrolyte

After jar test trials, Capillary Suction Time (CST) test was applied to conditioned sludge samples for evaluation of their dewatering capacity. Results of CST measurements of conditioned sludge samples at different dosages of 5980 SB cationic polyelectrolyte are shown in Table 6.23 and the CST values as a function of polyelectrolyte dosage is plotted in Figure 6.147.

When 270 mg/L 5980 SB was added to the sludge sample, minimum 12,9 s of CST was achieved as shown in Table 6.23 and Figure 6.147. Dry solids content of the sludge cake was found to be 18,22% at this dosage. Considering the CST test results, optimum 5980 SB dose range was determined between 200 mg/L and 300 mg/L.

Table 6.23 Results of Capillary Suction Time (CST) measurements of raw and conditioned sludge samples with 5980 SB cationic polyelectrolyte

Dosage		**Capillary Suction Time**
mg/L	**mg/kg DS**	**s**
160	16000	89.3
180	18000	67.4
200	20000	40
210	21000	18,4
220	22000	15,3
230	23000	15,1
240	24000	18
250	25000	15,1
260	26000	20,55
270	**27000**	**12,9**
280	28000	24,2
290	29000	16,45
300	30000	18,15
350	35000	26,2
400	40000	16,0
450	45000	13,1
50al 150cp	500al 15000cp	52,5
50al 200cp	500al 20000cp	37,5
50al 250cp	500al 25000cp	14,7
50al 300cp	50al 300cp	17,89
200al 270cp	2000al 27000cp	41,9
400al 270cp	4000al 27000cp	52,3
600al 270cp	6000al 27000cp	67,8
800al 270cp	8000al 27000cp	82,1

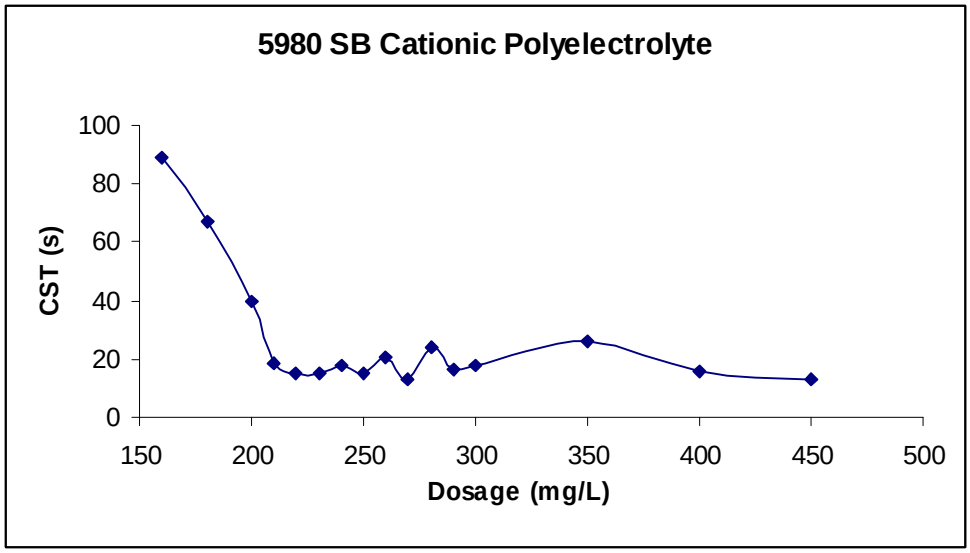


Figure 6.147 Capillary Suction Time (CST) values versus 5980 SB dosage

6.6.4 Results of Centrifugal Settleability Index Measurements for 5980 SB Cationic Polyelectrolyte Applications

To evaluate sludge dewaterability for centrifugal dewatering processes, centrifugal settleability index (CSI) parameter was analiysed. Suspended solid values of sludge and centrate samples and CSI values of sludge samples are given in Table 6.24.

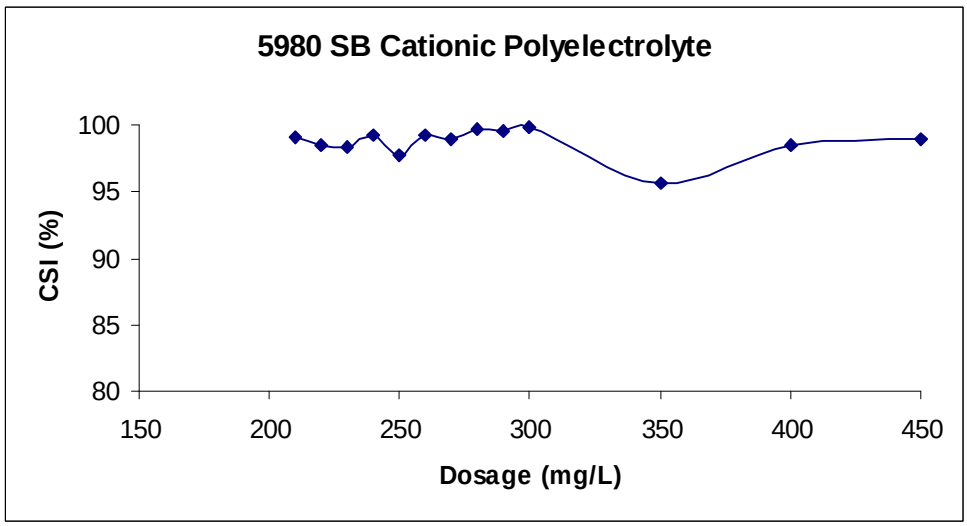


Figure 6.148 CSI values versus 5980 SB dosage

Table 6.24 Results of Centrifugal Settleability Index (CSI) measurements for 5980 SB cationic polyelectrolyte

Dosage		**Suspended Solids of Sludge (mg/L)**	**Suspended Solids of Centrate (mg/L)**	**Centrifugal Settleability Index (CSI) (%)**
mg/L	**mg/kg DS**			
160	16000	68000	330	99,33
180	18000	44000	300	85
200	20000	62000	80	99.51
210	21000	15000	130	99,13
220	22000	13000	200	98,46
230	23000	10000	170	98,3
240	24000	29000	200	99,31
250	25000	8000	180	97,75
260	26000	21000	150	99,28
270	**27000**	**17000**	**170**	**99**
280	28000	37000	100	99,72
290	29000	28000	130	99,53
300	30000	47000	100	99,78
350	35000	30000	130	95,66
400	40000	13000	190	98,53
450	45000	14000	150	98,92
50al 150cp	500al 15000cp	11700	300	97,43
50al 200cp	500al 20000cp	27600	400	98,55
50al 250cp	500al 25000cp	11600	250	97,84
50al 300cp	50al 300cp	24900	300	98,79
200al 270cp	2000al 27000cp	24400	500	97,95
400al 270cp	4000al 27000cp	27000	650	97,59
600al 270cp	6000al 27000cp	22400	440	98,03
800al 270cp	8000al 27000cp	23000	300	98,69

Figure 6.148 shows the CSI values at different dosages of 5980 SB cationic polyelectrolyte.

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The aim of this study was to investigate the dewaterability of aerobic and anaerobic stabilized sludges. For this purpose, aerobic stabilized sludge samples were taken from Manisa Organized Industrial District Wastewater Treatment Plant and anaerobic stabilized sludge samples were taken from Pakmaya Wastewater Treatment Plant/Kemalpaşa and these samples were used for experimental studies. After characterization studies, raw sludge samples were conditioned using different types of polymers and aluminum hydroxide. In conditioning experiments , three types of cationic polyelectrolytes (KWD 3500, 5980 SB and SNF 5980), non-ionic polyelectrolyte (KWD-20 LT) and anionic polyelectrolyte (KWD A-0055) and alum were applied to sludge samples at different dosages (together or separately). To determine the optimum dose range of each type of conditioners applications, specific resistance to filtration (Buchner Funnel Test) and capillary suction time (CST) test were applied to the raw and conditioned sludge samples.

According to the experimental results, the conclusion remarks from this study could be given as follows:

- Chemical conditioning using cationic polyelectrolyte played an important role on the dewaterability of aerobic and/or anaerobic stabilized sludges; however non-ionic and anionic polyelectrolyte have not any effect on dewatering capacity. Filibeli A., & Kaynak, G. E. (2005) stated in their study that cationic polyelectrolytes have an important effect on sludge dewaterability which shows that the experimental result is reaching an agreement with it.
- In the jar test trials, it was easier to condition aerobic stabilized sludge samples compared to anaerobic sludge samples.

- In the jar test trials, the addition of cationic polyelectrolyte increased substantially the floc formation on the contrary non-ionic and anionic polyelectrolyte applications.
- Results indicated that the settled sludge volume and supernatant turbidity obtained from jar test applications did not have any relationship with conditioner type and dosage.
- In jar test trials most of raw sludge samples could not be filtrated and there were any sludge cake formation for these samples. For this reason there is any SRF parameter data in this thesis for these raw sludge samples.
- CST and r values decreased with the increasing of the cationic polyelectrolyte dosage. However, this decrease was not observed at all for non-ionic and anionic polyelectrolyte applications.
- In conditioning experiments alum was dosed separately at first, results indicated from these experiments that alum has a negative effect on dewatering capacity for this type of aerobic or anaerobic stabilized sludge.
- Typical results from conditioning experiments by using cationic polyelectrolyte can be seen in Table 7.1.
- It can be seen from the table that maximum dry solid contents are not sufficient according to dry solid content values given (minimum 35%) in Turkish environmental regulations.

Table 7.1 Typical results from conditioning experiments by using cationic polyelectrolyte

		Optimum Dose (mg/L)	**Minimum r Value**	**Minimum CST (s)**	**Maximum Dry Solid (%)**
Aerobic	KWD 3500	240	1,31E+13	7,8	20,64
	SNF 5980	45	2,10E+14	7,7	19,12
	5980 SB	350	6,17E+13	7,7	18,53
Anaerobic	KWD 3500	250	1,26E+13	12,3	13,4
	SNF 5980	200	6,29E+12	17,2	16,08
	5980 SB	270	2,82E+13	12,9	18,22

- Conditioning experiments showed that KWD-20 LT, non-ionic and KWD A-0055 anionic polyelectrolyte could not flocculate sludge samples and sludge samples conditioned with these polyelectrolytes could not be filtrated. KWD-20 LT, non-ionic and KWD A-0055 anionic polyelectrolyte have any positive coagulant effect on aerobic and/or anaerobic stabilized sludges.
- In conditioning experiments it was observed that co-conditioned sludge samples with cationic polyelectrolyte and alum dewatering capacity is not as effective as separately conditioned sludge samples. Lai,J.Y. & Liu, J.C. stated in their study that co-conditioning of mixed (alum sludge and waste activated sludge mixture) sludge was very effective due to alum sludge's skeleton builder behavior. (Lai,J.Y. & Liu, J.C, 2004).
- In conditioning experiments, it was observed that alum has any effect on aerobic and/or anaerobic stabilized sludge dewatering when used as preconditioning agent. It is more beneficial to use polymers for these types of sludge. "Polymers also have an important conditioning advantage called 'bridging effect'." (Dentel, S.K. & Dursun, D., 2005).
- In conditioning experiments, it was observed that alum has any effect on aerobic and/or anaerobic stabilized sludge preconditioned with cationic polyelectrolyte.
- As anionic, non-ionic polyelectrolyte and alum had any positively significant effect on dewatering capacity of aerobic and anaerobic sludge samples; so data taken from jar test trials and conditioning experiments made by using anionic, non-ionic and alum are not shown in this thesis.

7.2 Recommendations

- Regarding to the optimal dosages, it may be beneficial to carry out a cost analysis in addition to investigation of sludge dewatering properties.
- Since KWD-20 LT, non-ionic and KWD A-0055 anionic polyelectrolyte have any significant effect on aerobic and anaerobic stabilized sludge, they cannot be used as conditioner on this type of sludges.

- Since alum have no significantly positive effect on these type of stabilized sludges when used alone without any polyelectrolyte addition, it’s use as conditioner on these type of sludge is not recommended.

REFERENCES

Akça, L., Erdinçler, A., Kocakulak, E.Y. (2005). Alum çamurlarının ikili şartlandırılması. *I. Ulusal Arıtma Çamurları Sempozyum, AÇS2005,* 211-220.

American Public Health Association (1995). *Standard Methods for the Examination of Waste and Wastewater.* (19th ed.), USA.

Aslan, S. & Şekerdağ, N. (2005). Donma/çözülme ile çamur şartlandırılması. *I. Ulusal Arıtma Çamurları Sempozyum, AÇS2005,* 571-580.

Ayol, A., Dentel, S.K., Filibeli, A. (2004). Use of drainability and filterability simulations for evaluation of oxidative treatment and polymer conditioning of sludge. *Water Science and Technology,* 50, 9-16.

Baskerville, R.C., & Gale, R.S. (1968). A simple automatic instrument for determining the filterability of sewage sludge. *Water Pollution Control,* 67, 233-241.

Cetin, S., Erdincler, A.(2004). The role of carbohydrate and protein parts of extracellular polymeric substances on the dewaterability of biological substances. *Water Science and Technology,* 50, 49-56.

Chang, G.R., Liu, J., & Lee, D.J. (2001). Co-conditioning and dewatering of chemical sludge and waste activated sludge. *Water Research,* 35 (3), 786-794.

Cheung, R.Y.H., Chu, C.W., Poon, C.S. (1998). Characterization of raw sludge, chemically modified sludge and anaerobically digested sludge in Hong Kong. Water Science and Technology 38,2,25-32.

Chikitela, S., & Dentel, S. (1998). Dual chemical conditioning and dewatering of anaerobically digested biosolids: laboratory evaluations. *Water Environmental Research,* 70, 1062-1069.

Christensen, J.R., Sorensen, P.B., Chirstensen, G.L., & Hansen, J.A. (1993). Mechanism for overdosing in sludge conditioning. *Journal of Environmental Engineering,* 119, 159-171.

Dentel, S.K. (2001). Conditioning, thickening, and dewatering: research update/research needs. *Water Science and Technology,* 44 (10).

Dentel, S.K., Resta, J.J., Shetty, P.V., & Bober, T.A. (1998). Selecting coagulant, filtration, and sludge conditioning aids. *Journal of American Water Works,* 80, 72-84.

Dentel, S.K., Dursun, D. (2005). Sludge as gel like material. *I. Ulusal Arıtma Çamurları Sempozyum, AÇS2005,*77-86.

Dohanyos, M., Zabranska, J., Kutil, J., Jenicek, P., (2004). Improvement of anaerobic digestion of sludge. *Water Science and Technology,* 49, 89-96.

Eckenfelder, Jr. W.W., & Santhanam, C.J. (1981). *Sludge Treatment.* New York: Marcel Dekker Inc.

Filibeli, A. & Kaynak, G.E., (2005). Şartlandırma işlemlerinin arıtma tesisi çamurlarının su verme kapasitesi üzerindeki etkileri. *I. Ulusal Arıtma Çamurları Sempozyum, AÇS2005,* 211-220.

Huang, C., Lee, D.J. & Wu, C.C. (2000). Determination of the optimal dose of polyelectrolyte sludge conditioner considering particle sedimentation effects. *Advances in Environmental Research,* 4, 245-249.

Huang, R.Y., Wu, C.C. & Wu, J.J.(2003). Floc strength and dewatering efficiency of alum sludge. *Advances in Environmental Research,* 7, 617-621.

Lai, J.Y., & Liu, J.C. (2004). Co-conditioning and dewatering of alum sludge and waste activated sludge. *Water Science and Technology,* 50, 9-41.

Lee, C.H., & Liu, J.C. (2001). Sludge dewaterability and floc structure in dual polymer conditioning. *Advances in Environmental Research,* 5, 129-136.

Lin, C.F., & Shien, Y. (2001). Sludge dewatering using centrifuge with thermal/polymer conditioning. *Water Science and Technology,* 44 (10), 321-325.

Lue-Hing, C.H., Zenz, D.R., & Kuchenriter, R. (Eds.) (1992). *Municipal Sewage Sludge Management Processing, Utilization, Disposal.*

Novak, J.T., & Haugen, B.E. (1980). Mechanisms and methods for polymer conditioning of activated sludge. *Journal of Water Pollution Control Federation,* 52, 2571-2580.

Novak, J.T., & Park, C. (2004). Chemical conditioning of sludge. *Water Science and Technology,* 49, 73-80.

Pan, J.R., Huang, C., Cherng, M., Li, K.C., & Lin, C.F. (2003). Correlation between dewatering index and dewatering performance of three mechanical dewatering devices. *Advances in Environmental Research,* 7, 599-632.

Papavasilopoulos, E.N., Keenan, H.E., & Bache, D.C. (1998). Technical note: Measurement of polymer residuals in an alum sludge. *Water Research,* 32 (10), 3173-3176.

Tchobanoglous, G. (1995). *Wastewater Engineering, Treatment, Disposal, Reuse* (3rt ed.).

Tunca, T., Arıtma tesislerinde kullanılan kimyasalların özellikleri, kullanım ve saklama koşulları. *Atıksu Arıtma Tesislerinin Tasarım ve İşletim Esasları Kursu (ATTIK-II)*

U.S. Environmental Protection Agency (1974). *Process Design Manual for Sludge Treatment and Disposal*. Cincinnati,Ohio: EPA 6251/1-74-006.

U.S. Environmental Protection Agency (1987). *Design Manual: Dewatering Municipal Wastewater Sludges.* Cincinnati, Ohio: EPA 625/1-87/014.

Vesilind, P.A. (1979). *Treatment and Disposal of Wastewater sludge (Revised addition).* Michigan: Ann Arbor Science Publishers Inc.

Vesilind, P.A. (1988). Capillary suction time as a fundamental measure of the sludge dewaterability. *Journal Water Pollution Control Federation,* 60, 215-220.

Werle, C.P., & Novak, J.T. (1984). Mixing intensity and polymer conditioning. *Journal of Environmental Engineering ASCE,* 110, 919-934.

Wu, C.C., & Wu, J.J. (2001). Effect of charge neutralization on the dewatering performance of alum sludge by polymer conditioning. *Water Science and Technology,* 44 (10), 315-319.

APPENDICES

A. Filtration Data of Raw and Conditioned Aerobic Sludge with KWD 3500 Cationic Polyelectrolyte

Table A.1 Filtration Data of Sample I

t	v	t/v	t	v	t/v
10	14	0,714286	200	65	3,076923
20	20	1	210	67	3,134328
30	25	1,2	220	68,5	3,211679
40	29	1,37931	230	70	3,285714
50	33	1,515152	240	71,5	3,356643
60	36	1,666667	250	72,5	3,448276
70	39	1,794872	260	73,5	3,537415
80	41,5	1,927711	270	75	3,6
90	44	2,045455	280	76	3,684211
100	47	2,12766	290	77	3,766234
110	49	2,244898	300	78	3,846154
120	51	2,352941	310	79	3,924051
130	53	2,45283	320	79,5	4,025157
140	54	2,592593	330	80,5	4,099379
150	56	2,678571	340	81,5	4,171779
160	58	2,758621	350	82	4,268293
170	60	2,833333	360	83	4,337349
180	62	2,903226	370	83	4,457831
190	64	2,96875	380	83	4,578313

Table A.2 Filtration Data of 5 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	10	1	80	28	2,857143
20	15	1,333333	90	29	3,103448
30	18	1,666667	100	31	3,225806
40	20	2	110	33	3,333333
50	23	2,173913	120	34	3,529412
60	24	2,5	130	34	3,823529
70	26	2,692308	140	34	4,117647

Table A.3 Filtration Data of 10 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v	t	v	t/v
10	11	0,909091	180	46	3,913043	360	64,5	5,581395
20	15	1,333333	190	47	4,042553	370	65,5	5,648855
30	18	1,666667	200	47,5	4,210526	380	66	5,757576
40	21	1,904762	210	49	4,285714	390	67	5,820896
50	24	2,083333	220	51	4,313725	400	67,5	5,925926
60	26	2,307692	230	52	4,423077	410	68,5	5,985401
70	28	2,5	240	53	4,528302	420	69	6,086957
80	30	2,666667	250	54	4,62963	430	69,5	6,18705
90	33	2,727273	260	55	4,727273	440	70	6,285714
100	34	2,941176	270	56	4,821429	450	71	6,338028
110	36	3,055556	280	57	4,912281	460	71,5	6,433566
120	38	3,157895	290	58	5	470	72	6,527778
130	39	3,333333	300	59	5,084746	480	72,5	6,62069
140	41	3,414634	310	60	5,166667	490	73	6,712329
150	42	3,571429	320	61	5,245902	500	73,5	6,802721
160	43	3,72093	330	62	5,322581	510	74	6,891892
170	44,5	3,820225	340	63	5,396825	520	74	7,027027
			350	64	5,46875	530	74	7,162162

Table A.4 Filtration Data of 15 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v	t	v	t/v
10	13	0,769231	190	46,5	4,086022	370	61	6,065574
20	19	1,052632	200	47,5	4,210526	380	61,5	6,178862
30	22	1,363636	210	48,5	4,329897	390	62	6,290323
40	25	1,6	220	49,5	4,444444	400	62,5	6,4
50	27	1,851852	230	50,5	4,554455	410	63,5	6,456693
60	29	2,068966	240	51,5	4,660194	420	64	6,5625
70	31	2,258065	250	52	4,807692	430	64,5	6,666667
80	33	2,424242	260	53	4,90566	440	65	6,769231
90	34	2,647059	270	54	5	450	65	6,923077
100	36	2,777778	280	55	5,090909	460	65,5	7,022901
110	37	2,972973	290	55,5	5,225225	470	66	7,121212
120	38	3,157895	300	56,5	5,309735	480	66,5	7,218045
130	40	3,25	310	57	5,438596	490	67	7,313433
140	41	3,414634	320	58	5,517241	500	67	7,462687
150	42	3,571429	330	58,5	5,641026	510	67	7,61194
160	43	3,72093	340	59	5,762712			
170	44	3,863636	350	60	5,833333			
180	45,5	3,956044	360	60,5	5,950413			

Table A.5 Filtration Data of 20 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	16	0,625	190	55	3,454545
20	21	0,952381	200	56,5	3,539823
30	25	1,2	210	57,5	3,652174
40	29	1,37931	220	59	3,728814
50	31	1,612903	230	60	3,833333
60	34	1,764706	240	61	3,934426
70	36	1,944444	250	62	4,032258
80	38	2,105263	260	63	4,126984
90	40	2,25	270	64	4,21875
100	42	2,380952	280	65	4,307692
110	44	2,5	290	65,5	4,427481
120	45,5	2,637363	300	66	4,545455
130	47	2,765957	310	67	4,626866
140	48,5	2,886598	320	67,5	4,740741
150	50	3	330	68	4,852941
160	51,5	3,106796	340	69	4,927536
170	53	3,207547	350	69	5,072464
180	54	3,333333	360	69	5,217391

Table A.6 Filtration Data of 50 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v	t	v	t/v
10	14	0,714286	160	46	3,478261	310	59,5	5,210084
20	19	1,052632	170	47	3,617021	320	60	5,333333
30	22	1,363636	180	49	3,673469	330	61	5,409836
40	25	1,6	190	50	3,8	340	62	5,483871
50	28	1,785714	200	50,5	3,960396	350	62,5	5,6
60	30	2	210	51	4,117647	360	63	5,714286
70	32	2,1875	220	53	4,150943	370	63,5	5,826772
80	34	2,352941	230	53,5	4,299065	380	64	5,9375
90	36	2,5	240	54	4,444444	390	64,5	6,046512
100	37,5	2,666667	250	55	4,545455	400	65	6,153846
110	39	2,820513	260	56	4,642857	410	65,5	6,259542
120	40,5	2,962963	270	57	4,736842	420	66	6,363636
130	42	3,095238	280	57,5	4,869565	430	66	6,515152
140	43	3,255814	290	58	5	440	66	6,666667
150	45	3,333333	300	59	5,084746			

Table A.7 Filtration Data of 100 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	23	0,434783	130	63	2,063492
20	31	0,645161	140	65	2,153846
30	36	0,833333	150	66	2,272727
40	40,5	0,987654	160	67	2,38806
50	44	1,136364	170	68	2,5
60	47,5	1,263158	180	69	2,608696
70	50	1,4	190	70	2,714286
80	53	1,509434	200	71	2,816901
90	55,5	1,621622	210	72	2,916667
100	58	1,724138	220	72	3,055556
110	60	1,833333	230	72	3,194444
120	61,5	1,95122			

Table A.8 Filtration Data of 150 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	39	0,25641	90	76	1,184211
20	54	0,37037	100	77,5	1,290323
30	62	0,483871	110	78	1,410256
40	67	0,597015	120	79	1,518987
50	70	0,714286	130	79,5	1,63522
60	73	0,821918	140	80	1,75
70	74	0,945946	150	80	1,875
80	75	1,066667	160	80	2

Table A.9 Filtration Data of 200 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	74	0,135135
20	79	0,253165
30	81	0,37037
40	82	0,487805
50	83	0,60241
60	83	0,722892
70	83	0,843373

Table A.10 Filtration Data of 210 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	59	0,169492
20	73	0,273973
30	76	0,394737
40	78	0,512821
50	78	0,641026
60	78	0,769231

Table A.11 Filtration Data of 220 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	61	0,163934
20	73	0,273973
30	76	0,394737
40	78	0,512821
50	79	0,632911
60	79	0,759494
70	79	0,886076

Table A.12 Filtration Data of 230 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	85	0,117647
20	92	0,217391
30	93	0,322581
40	94	0,425532
50	94	0,531915
60	94	0,638298

Table A.13 Filtration Data of 240 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	80	0,125
20	93	0,215054
30	94	0,319149
40	95	0,421053
50	96	0,520833
60	96	0,625
70	96	0,729167

Table A.14 Filtration Data of 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	42	0,238095
20	64	0,3125
30	70	0,428571
40	75	0,533333
50	78	0,641026
60	78	0,769231
70	78	0,897436

Table A.15 Filtration Data of 300 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	74	0,135135
20	80	0,25
30	83	0,361446
40	83,5	0,479042
50	83,5	0,598802
60	83,5	0,718563

Table A.16 Filtration Data of 350 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	23	0,434783	120	41	2,926829
20	26	0,769231	130	42	3,095238
30	29	1,034483	140	42,5	3,294118
40	31	1,290323	150	43	3,488372
50	33	1,515152	160	43,5	3,678161
60	35	1,714286	170	44	3,863636
70	36	1,944444	180	45	4
80	37	2,162162	190	46	4,130435
90	38	2,368421	200	46	4,347826
100	39	2,564103	210	46	4,565217
110	40	2,75			

Table A.17 Filtration Data of 400 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	12	0,833333	90	23	3,913043
20	15	1,333333	100	24	4,166667
30	16	1,875	110	25	4,4
40	17	2,352941	120	26	4,615385
50	19	2,631579	130	27	4,814815
60	20	3	140	27	5,185185
70	21	3,333333	150	27	5,555556
80	22	3,636364			

Table A.18 Filtration Data of 450 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	10	1
20	12	1,666667
30	13	2,307692
40	13,5	2,962963
50	14	3,571429
60	15	4
70	15,5	4,516129
80	16	5
90	16	5,625
100	16	6,25

Table A.19 Filtration Data of 150 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Preconditioned with 50 mg/L Alum Dosage

t	v	t/v
10	40	0,25
20	55	0,363636
30	65	0,461538
40	70	0,571429
50	72	0,694444
60	73	0,821918
70	74	0,945946
80	75	1,066667
90	76	1,184211
100	77,5	1,290323
110	78	1,410256
120	78	1,538462
130	78	1,666667

Table A.20 Filtration Data of 200 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Preconditioned with 50 mg/L Alum Dosage

t	v	t/v
10	74	0,135135
20	79	0,253165
30	81	0,37037
40	82	0,487805
50	83	0,60241
60	83,5	0,718563
70	84	0,833333
80	84,5	0,946746
90	85	1,058824
100	85	1,176471
110	85	1,294118

Table A.21 Filtration Data of 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Preconditioned with 50 mg/L Alum Dosage

t	v	t/v
10	43	0,232558
20	63	0,31746
30	69	0,434783
40	74	0,540541
50	76	0,657895
60	78	0,769231
70	78	0,897436
80	78	1,025641

Table A.22 Filtration Data of 300 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Preconditioned with 50 mg/L Alum Dosage

t	v	t/v
10	74	0,135135
20	80	0,25
30	81	0,37037
40	82	0,487805
50	83	0,60241
60	84	0,714286
70	85	0,823529
80	86	0,930233
90	87	1,034483
100	88	1,136364
110	88	1,25
120	88	1,363636

Table A.23 Filtration Data of 200 mg/L Alum Dosage Applied to the Sludge Sample Preconditioned with 240 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	79	0,126582
20	92	0,217391
30	93	0,322581
40	94	0,425532
50	95	0,526316
60	96	0,625
70	96,5	0,725389
80	96,5	0,829016
90	96,5	0,932642

Table A.24 Filtration Data of 400 mg/L Alum Dosage Applied to the Sludge Sample Preconditioned with 240 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	79	0,126582
20	93	0,215054
30	95	0,315789
40	96	0,416667
50	96,5	0,518135
60	97	0,618557
70	97,5	0,717949
80	97,5	0,820513
90	97,5	0,923077

Table A.25 Filtration Data of 600 mg/L Alum Dosage Applied to the Sludge Sample Preconditioned with 240 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	75	0,133333
20	81	0,246914
30	86	0,348837
40	90	0,444444
50	92	0,543478
60	94	0,638298
70	95	0,736842
80	96	0,833333
90	97	0,927835
100	98	1,020408
110	98	1,122449
120	98	1,22449

Table A.26 Filtration Data of 800 mg/L Alum Dosage Applied to the Sludge Sample Preconditioned with 240 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	72	0,138889
20	79	0,253165
30	83	0,361446
40	86	0,465116
50	88	0,568182
60	90	0,666667
70	91	0,769231
80	92	0,869565
90	93	0,967742
100	94	1,06383
110	95	1,157895
120	96	1,25
130	97	1,340206
140	97	1,443299
150	97	1,546392

B. Filtration Data of Raw and Conditioned Aerobic Sludge with SNF 5980 Cationic Polyelectrolyte

Table B.1 Filtration Data of 5 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	96	0,104167
20	98	0,204082
30	99	0,30303
40	99	0,40404
50	99	0,505051

Table B.2 Filtration Data of 10 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	99	0,10101
20	100	0,2
30	100	0,3
40	100	0,4

Table B.3 Filtration Data of 25 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	99	0,10101
20	100	0,2
30	100	0,3
40	100	0,4

Table B.4 Filtration Data of 30 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	98	0,102041
20	99	0,20202
30	99	0,30303
40	100	0,4
50	100	0,5
60	100	0,6

Table B.5 Filtration Data of 35 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	96	0,104167
20	97,5	0,205128
30	98	0,306122
40	99	0,40404
50	99	0,505051
60	99	0,606061

Table B.6 Filtration Data of 40 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	96	0,104167
20	98	0,204082
30	98,5	0,304569
40	99	0,40404
50	99	0,505051
60	99	0,606061

Table B.7 Filtration Data of 45 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	98	0,102041
20	99	0,20202
30	100	0,3
40	100	0,4
50	100	0,5

Table B.8 Filtration Data of 50 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	99	0,10101
20	100	0,2
30	100	0,3
40	100	0,4

Table B.9 Filtration Data of 100 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	97	0,103093
20	99	0,20202
30	100	0,3
40	100	0,4
50	100	0,5

Table B.10 Filtration Data of 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	55	0,181818
20	70	0,285714
30	80	0,375
40	89	0,449438
50	94	0,531915
60	96	0,625
70	98	0,714286
80	99	0,808081
90	100	0,9
100	100	1
110	100	1,1

Table B.11 Filtration Data of 10 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	92	0,108696
20	95	0,210526
30	96	0,3125
40	97	0,412371
50	97	0,515464
60	97	0,618557

Table B.12 Filtration Data of 25 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	96	0,104167
20	97	0,206186
30	98	0,306122
40	99	0,40404
50	99	0,505051
60	99	0,606061

Table B.13 Filtration Data of 50 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	85	0,117647
20	96	0,208333
30	97	0,309278
40	98	0,408163
50	98	0,510204
60	98	0,612245

Table B.14 Filtration Data of 200 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 45 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	94	0,106383
20	99	0,20202
30	99	0,30303
40	99	0,40404

Table B.15 Filtration Data of 400 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 45 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	97	0,103093
20	99	0,20202
30	99	0,30303
40	99	0,40404

Table B.16 Filtration Data of 600 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 45 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	97	0,103093
20	98	0,204082
30	99	0,30303
40	99	0,40404
50	99	0,505051

Table B.17 Filtration Data of 800 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 45 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	97	0,103093
20	98	0,204082
30	98,5	0,304569
40	99	0,40404
50	99	0,505051
60	99	0,606061

C. Filtration Data of Conditioned Aerobic Sludge with 5980 SB Cationic Polyelectrolyte

Table C.1 Filtration Data of 50 mg/L 5980 SB Cationic Polyelectrolyte Dosage

T	v	t/v	t	v	t/v
10	9	1,111111	270	53	5,09434
20	13	1,538462	280	54	5,185185
30	16	1,875	290	55	5,272727
40	19,5	2,051282	300	56,5	5,309735
50	22	2,272727	310	57	5,438596
60	24	2,5	320	57	5,614035
70	26	2,692308	330	58	5,689655
80	28	2,857143	340	59	5,762712
90	30	3	350	60	5,833333
100	32	3,125	360	60,5	5,950413
110	33,5	3,283582	370	61	6,065574
120	35	3,428571	380	61,5	6,178862
130	37	3,513514	390	62	6,290323
140	38	3,684211	400	62,5	6,4
150	39	3,846154	410	63	6,507937
160	41	3,902439	420	64	6,5625
170	42	4,047619	430	64,5	6,666667
180	43	4,186047	440	65	6,769231
190	44	4,318182	450	65,5	6,870229
200	46	4,347826	460	66	6,969697
210	47	4,468085	470	66,5	7,067669
220	48	4,583333	480	67	7,164179
230	49	4,693878	490	67	7,313433
240	50	4,8	500	67	7,462687
250	51	4,901961			
260	52	5			

Table C.2 Filtration Data of 100 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	21	0,47619	150	71	2,112676
20	30	0,666667	160	72	2,222222
30	36	0,833333	170	73	2,328767
40	42	0,952381	180	74	2,432432
50	46	1,086957	190	75	2,533333
60	50	1,2	200	76	2,631579
70	54	1,296296	210	76,5	2,745098
80	57	1,403509	220	77	2,857143
90	60	1,5	230	77,5	2,967742
100	62	1,612903	240	78	3,076923
110	64	1,71875	250	78,5	3,184713
120	66	1,818182	260	79	3,291139
130	68	1,911765	270	79	3,417722
140	69	2,028986	280	79	3,544304

Table C.3 Filtration Data of 150 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	34	0,294118	130	73	1,780822
20	44	0,454545	140	74	1,891892
30	51	0,588235	150	75	2
40	56	0,714286	160	75,5	2,119205
50	60	0,833333	170	76	2,236842
60	63	0,952381	180	76,5	2,352941
70	65	1,076923	190	77	2,467532
80	67	1,19403	200	77,5	2,580645
90	69	1,304348	210	78	2,692308
100	71	1,408451	220	78	2,820513
110	71,5	1,538462	230	78	2,948718
120	72	1,666667			

Table C.4 Filtration Data of 200 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	50	0,2
20	61	0,327869
30	67	0,447761
40	71	0,56338
50	73	0,684932
60	74	0,810811
70	74	0,945946
80	74	1,081081

Table C.5 Filtration Data of 250 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	73	0,136986
20	80	0,25
30	82	0,365854
40	83	0,481928
50	83	0,60241
60	83	0,722892

Table C.6 Filtration Data of 300 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	83	0,120482
20	84	0,238095
30	86	0,348837
40	86	0,465116
50	86	0,581395

Table C.7 Filtration Data of 310 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	83	0,120482
20	84	0,238095
30	85	0,352941
40	86	0,465116
50	86	0,581395
60	86	0,697674

Table C.8 Filtration Data of 320 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	80	0,125
20	82	0,243902
30	83	0,361446
40	84	0,47619
50	85	0,588235
60	85	0,705882
70	85	0,823529

Table C.9 Filtration Data of 330 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	84	0,119048
20	85	0,235294
30	86	0,348837
40	87	0,45977
50	87	0,574713
60	87	0,689655

Table C.10 Filtration Data of 340 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	83	0,120482
20	88	0,227273
30	88	0,340909
40	88	0,454545

Table C.11 Filtration Data of 350 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	83	0,120482
20	88	0,227273
30	88	0,340909
40	88	0,454545

Table C.12 Filtration Data of 400 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	35	0,285714	120	77	1,558442
20	49	0,408163	130	78	1,666667
30	58	0,517241	140	80	1,75
40	63	0,634921	150	81	1,851852
50	65	0,769231	160	83	1,927711
60	68	0,882353	170	84	2,02381
70	70	1	180	86	2,093023
80	72	1,111111	190	87	2,183908
90	73	1,232877	200	88	2,272727
100	75	1,333333	210	88	2,386364
110	76	1,447368	220	88	2,5

Table C.13 Filtration Data of 450 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	16	0,625
20	19	1,052632
30	22	1,363636
40	23	1,73913
50	24	2,083333
60	25	2,4
70	26	2,692308
80	26,5	3,018868
90	27	3,333333
100	27,5	3,636364
110	28	3,928571
120	28,5	4,210526
130	29	4,482759
140	29	4,827586
150	29	5,172414

Table C.14 Filtration Data of 150 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	34	0,294118	150	74,5	2,013423
20	40	0,5	160	75,5	2,119205
30	45	0,666667	170	76	2,236842
40	49	0,816327	180	76,5	2,352941
50	53	0,943396	190	77	2,467532
60	56	1,071429	200	77,5	2,580645
70	59	1,186441	210	78	2,692308
80	61	1,311475	220	78,5	2,802548
90	63	1,428571	230	79	2,911392
100	66	1,515152	240	79,5	3,018868
110	68	1,617647	250	80	3,125
120	70	1,714286	260	80	3,25
130	71,5	1,818182	270	80	3,375
140	73	1,917808			

Table C.15 Filtration Data of 200 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	50	0,2
20	59	0,338983
30	65	0,461538
40	69	0,57971
50	73	0,684932
60	74	0,810811
70	75	0,933333
80	76	1,052632
90	76,5	1,176471
100	77	1,298701
110	77	1,428571
120	77	1,558442

Table C.16 Filtration Data of 250 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	70	0,142857
20	77	0,25974
30	79	0,379747
40	80	0,5
50	81	0,617284
60	82	0,731707
70	82,5	0,848485
80	83	0,963855
90	83	1,084337
100	83	1,204819

Table C.17 Filtration Data of 300 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	79	0,126582
20	84	0,238095
30	86	0,348837
40	87	0,45977
50	88	0,568182
60	89	0,674157
70	89	0,786517
80	89	0,898876

Table C.18 Filtration Data of 200 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 350 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v	t	v	t/v
10	8	1,25	200	44	4,545455	390	60	6,5
20	11	1,818182	210	45	4,666667	400	60,5	6,61157
30	15	2	220	46	4,782609	410	61	6,721311
40	18	2,222222	230	47	4,893617	420	62	6,774194
50	20	2,5	240	48	5	430	62,5	6,88
60	22	2,727273	250	49	5,102041	440	63	6,984127
70	24	2,916667	260	50	5,2	450	63,5	7,086614
80	26	3,076923	270	51	5,294118	460	64	7,1875
90	28	3,214286	280	52	5,384615	470	64,5	7,286822
100	30	3,333333	290	53	5,471698	480	65	7,384615
110	31	3,548387	300	54	5,555556	490	65,5	7,480916
120	33	3,636364	310	55	5,636364	500	66	7,575758
130	34	3,823529	320	55	5,818182	510	66,5	7,669173
140	36	3,888889	330	56	5,892857	520	67	7,761194
150	37	4,054054	340	57	5,964912	530	67	7,910448
160	38	4,210526	350	58	6,034483	540	67,5	8
170	39	4,358974	360	58,5	6,153846	550	68	8,088235
180	41	4,390244	370	59	6,271186	560	68	8,235294
190	42	4,52381	380	59,5	6,386555	570	68	8,382353

Table C.19 Filtration Data of 400 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 350 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v	t	v	t/v
10	8	1,25	180	43	4,186047	350	60	5,833333
20	12	1,666667	190	44	4,318182	360	60,5	5,950413
30	15	2	200	46	4,347826	370	61	6,065574
40	17,5	2,285714	210	47	4,468085	380	61,5	6,178862
50	21	2,380952	220	48	4,583333	390	62	6,290323
60	23	2,608696	230	49	4,693878	400	62,5	6,4
70	25	2,8	240	50	4,8	410	63	6,507937
80	27	2,962963	250	51	4,901961	420	64	6,5625
90	29	3,103448	260	52	5	430	64,5	6,666667
100	32	3,125	270	53	5,09434	440	65	6,769231
110	33,5	3,283582	280	54	5,185185	450	65,5	6,870229
120	35	3,428571	290	55	5,272727	460	66	6,969697
130	37	3,513514	300	56,5	5,309735	470	66,5	7,067669
140	38	3,684211	310	57	5,438596	480	67	7,164179
150	39	3,846154	320	57	5,614035	490	67	7,313433
160	41	3,902439	330	58	5,689655	500	67	7,462687
170	42	4,047619	340	59	5,762712			

Table C.20 Filtration Data of 600 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 350 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	10	1	240	50	4,8
20	13	1,538462	250	51	4,901961
30	16	1,875	260	52	5
40	18	2,222222	270	53	5,09434
50	23	2,173913	280	54	5,185185
60	24	2,5	290	55	5,272727
70	25	2,8	300	56,5	5,309735
80	27	2,962963	310	57	5,438596
90	29	3,103448	320	57	5,614035
100	33	3,030303	330	58	5,689655
110	34	3,235294	340	59	5,762712
120	35	3,428571	350	60	5,833333
130	37	3,513514	360	60,5	5,950413
140	38	3,684211	370	61	6,065574
150	39	3,846154	380	61,5	6,178862
160	41	3,902439	390	62	6,290323
170	42	4,047619	400	62,5	6,4
180	43	4,186047	410	63	6,507937
190	44	4,318182	420	64	6,5625
200	46	4,347826	430	64,5	6,666667
210	47	4,468085	440	65	6,769231
220	48	4,583333	450	65	6,923077
230	49	4,693878	460	65	7,076923

Table C.21 Filtration Data of 800 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 350 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	9	1,111111	250	51	4,901961
20	11	1,818182	260	52	5
30	13	2,307692	270	53	5,09434
40	15	2,666667	280	54	5,185185
50	17	2,941176	290	55	5,272727
60	19	3,157895	300	56	5,357143
70	21	3,333333	310	57	5,438596
80	23	3,478261	320	58	5,517241
90	24	3,75	330	58,5	5,641026
100	26	3,846154	340	59	5,762712
110	28	3,928571	350	59,5	5,882353
120	29	4,137931	360	60	6
130	31	4,193548	370	60,5	6,115702
140	33	4,242424	380	61	6,229508
150	35	4,285714	390	61,5	6,341463
160	36,5	4,383562	400	62	6,451613
170	38	4,473684	410	62,5	6,56
180	40	4,5	420	63	6,666667
190	42	4,52381	430	63,5	6,771654
200	44	4,545455	440	64	6,875
210	45,5	4,615385	450	64,5	6,976744
220	48	4,583333	460	65	7,076923
230	49	4,693878	470	65	7,230769
240	50	4,8	480	65	7,384615

D. Filtration Data of Conditioned Anaerobic Sludge with KWD 3500 Cationic Polyelectrolyte

Table D.1 Filtration Data of 150 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	9	1,111111	130	25	5,2
20	13	1,538462	140	25,5	5,490196
30	15	2	150	26	5,769231
40	16	2,5	160	26,5	6,037736
50	17,5	2,857143	170	27	6,296296
60	19	3,157895	180	27,5	6,545455
70	20	3,5	190	28	6,785714
80	21	3,809524	200	28,5	7,017544
90	22	4,090909	210	29	7,241379
100	22,5	4,444444	220	30	7,333333
110	23,5	4,680851	230	30	7,666667
120	24	5	240	30	8

Table D.2 Filtration Data of 200 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	16	0,625	180	72	2,5
20	27	0,740741	190	73,5	2,585034
30	34	0,882353	200	74,5	2,684564
40	40	1	210	76	2,763158
50	44	1,136364	220	77	2,857143
60	47	1,276596	230	78	2,948718
70	50	1,4	240	79	3,037975
80	53	1,509434	250	80	3,125
90	56	1,607143	260	81	3,209877
100	58	1,724138	270	82	3,292683
110	60	1,833333	280	82,5	3,393939
120	62	1,935484	290	83	3,493976
130	64	2,03125	300	84	3,571429
140	66	2,121212	310	85	3,647059
150	67,5	2,222222	320	85	3,764706
160	69	2,318841	330	85	3,882353
170	70,5	2,411348			

Table D.3 Filtration Data of 210 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	13	0,769231	160	67	2,38806
20	25	0,8	170	68,5	2,481752
30	32	0,9375	180	70	2,571429
40	38	1,052632	190	71,5	2,657343
50	42	1,190476	200	72	2,777778
60	45	1,333333	210	72,5	2,896552
70	48	1,458333	220	73	3,013699
80	51	1,568627	230	73,5	3,129252
90	54	1,666667	240	73,5	3,265306
100	56	1,785714	250	74	3,378378
110	58	1,896552	260	74,5	3,489933
120	60	2	270	75	3,6
130	62	2,096774	280	75	3,733333
140	64	2,1875	290	75	3,866667
150	65,5	2,290076			

Table D.4 Filtration Data of 220 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	17	0,588235	170	71	2,394366
20	28	0,714286	180	73	2,465753
30	35	0,857143	190	74	2,567568
40	41	0,97561	200	75	2,666667
50	45	1,111111	210	78	2,692308
60	48	1,25	220	78,5	2,802548
70	51	1,372549	230	79,5	2,893082
80	54	1,481481	240	79,5	3,018868
90	57	1,578947	250	81	3,08642
100	59	1,694915	260	82	3,170732
110	61	1,803279	270	83	3,253012
120	63	1,904762	280	83,5	3,353293
130	65	2	290	84	3,452381
140	67	2,089552	300	85	3,529412
150	68	2,205882	310	85	3,647059
160	69	2,318841	320	85	3,764706

Table D.5 Filtration Data of 230 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	35	0,285714
20	57	0,350877
30	67	0,447761
40	73	0,547945
50	79	0,632911
60	83	0,722892
70	84	0,833333
80	85	0,941176
90	85	1,058824
100	85	1,176471

Table D.6 Filtration Data of 240 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	39	0,25641
20	60	0,333333
30	70	0,428571
40	80	0,5
50	89	0,561798
60	93	0,645161
70	95	0,736842
80	95	0,842105
90	95	0,947368

Table D.7 Filtration Data of 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	37	0,27027
20	59	0,338983
30	70	0,428571
40	79	0,506329
50	85	0,588235
60	87	0,689655
70	88	0,795455
80	89	0,898876
90	89	1,011236
100	89	1,123596

Table D.8 Filtration Data of 300 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	16	0,625	110	37	2,972973
20	20	1	120	38	3,157895
30	23	1,304348	130	39	3,333333
40	26	1,538462	140	40	3,5
50	29	1,724138	150	41	3,658537
60	31	1,935484	160	42	3,809524
70	32	2,1875	170	44	3,863636
80	33	2,424242	180	44	4,090909
90	35	2,571429	190	44	4,318182
100	36	2,777778			

Table D.9 Filtration Data of 350 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	15	0,666667	120	35	3,428571
20	20	1	130	36	3,611111
30	22	1,363636	140	37	3,783784
40	24	1,666667	150	38	3,947368
50	26	1,923077	160	38,5	4,155844
60	28	2,142857	170	39,5	4,303797
70	29,5	2,372881	180	41	4,390244
80	30,5	2,622951	190	42	4,52381
90	32	2,8125	200	43	4,651163
100	33	3,030303	210	43	4,883721
110	34	3,235294	220	43	5,116279

Table D.10 Filtration Data of 400 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	57	0,175439
20	65	0,307692
30	67	0,447761
40	69	0,57971
50	69,5	0,719424
60	70	0,857143
70	71	0,985915
80	71	1,126761
90	71	1,267606

Table D.11 Filtration Data of 450 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v
10	27	0,37037
20	29	0,689655
30	30	1
40	31	1,290323
50	32,5	1,538462
60	33,5	1,791045
70	35	2
80	36	2,222222
90	36	2,5
100	36	2,777778

Table D.12 Filtration Data of 150 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	7	1,428571	140	23,5	5,957447
20	11	1,818182	150	24	6,25
30	13	2,307692	160	24,5	6,530612
40	15	2,666667	170	25	6,8
50	16	3,125	180	25,5	7,058824
60	17	3,529412	190	26	7,307692
70	18	3,888889	200	26	7,692308
80	19	4,210526	210	26,5	7,924528
90	20	4,5	220	27	8,148148
100	21	4,761905	230	27,5	8,363636
110	22	5	240	28	8,571429
120	22,5	5,333333	250	28	8,928571
130	23	5,652174	260	28	9,285714

Table D.13 Filtration Data of 200 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	16	0,625	200	73	2,739726
20	25	0,8	210	74	2,837838
30	32	0,9375	220	75	2,933333
40	38	1,052632	230	75,5	3,046358
50	41	1,219512	240	76	3,157895
60	44	1,363636	250	76,5	3,267974
70	47	1,489362	260	77	3,376623
80	50	1,6	270	77,5	3,483871
90	53	1,698113	280	78	3,589744
100	56	1,785714	290	78,5	3,694268
110	58	1,896552	300	79	3,797468
120	60	2	310	79,5	3,899371
130	62	2,096774	320	80	4
140	64	2,1875	330	80,5	4,099379
150	66	2,272727	340	80,5	4,223602
160	67,5	2,37037	350	81	4,320988
170	69	2,463768	360	81	4,444444
180	70,5	2,553191	370	81	4,567901
190	72	2,638889			

Table D.14 Filtration Data of 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	27	0,37037	140	76	1,842105
20	37	0,540541	150	77	1,948052
30	46	0,652174	160	78	2,051282
40	55	0,727273	170	78,5	2,165605
50	61	0,819672	180	79	2,278481
60	63	0,952381	190	79,5	2,389937
70	65	1,076923	200	80	2,5
80	67	1,19403	210	81	2,592593
90	69	1,304348	220	81,5	2,699387
100	70,5	1,41844	230	82	2,804878
110	72	1,527778	240	82	2,926829
120	73,5	1,632653	250	82	3,04878
130	75	1,733333			

Table D.15 Filtration Data of 300 mg/L KWD 3500 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	13	0,769231	120	36,5	3,287671
20	17	1,176471	130	37	3,513514
30	21	1,428571	140	37,5	3,733333
40	24	1,666667	150	38	3,947368
50	27	1,851852	160	38	4,210526
60	29	2,068966	170	38,5	4,415584
70	31	2,258065	180	39	4,615385
80	33	2,424242	190	39,5	4,810127
90	35	2,571429	200	40	5
100	35,5	2,816901	210	40	5,25
110	36	3,055556	220	40	5,5

Table D.16 Filtration Data of 200 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	32	0,3125	140	73	1,917808
20	42	0,47619	150	75	2
30	48	0,625	160	76	2,105263
40	52	0,769231	170	77	2,207792
50	55	0,909091	180	78	2,307692
60	58	1,034483	190	79	2,405063
70	60	1,166667	200	80	2,5
80	63	1,269841	210	81	2,592593
90	65	1,384615	220	82	2,682927
100	67	1,492537	230	83	2,771084
110	69	1,594203	240	83	2,891566
120	70	1,714286	250	83	3,012048
130	72	1,805556			

Table D.17 Filtration Data of 400 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	16	0,625	160	57,5	2,782609
20	27	0,740741	170	58	2,931034
30	34	0,882353	180	58,5	3,076923
40	39	1,025641	190	59	3,220339
50	42	1,190476	200	59,5	3,361345
60	45	1,333333	210	60	3,5
70	47	1,489362	220	60,5	3,636364
80	49	1,632653	230	61	3,770492
90	51	1,764706	240	61	3,934426
100	53	1,886792	250	62	4,032258
110	54	2,037037	260	62,5	4,16
120	55	2,181818	270	63	4,285714
130	56	2,321429	280	63	4,444444
140	56,5	2,477876	290	63	4,603175
150	57	2,631579			

Table D.18 Filtration Data of 600 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	8	1,25	130	42	3,095238
20	14	1,428571	140	42,5	3,294118
30	19	1,578947	150	43	3,488372
40	23	1,73913	160	43,5	3,678161
50	27	1,851852	170	44	3,863636
60	30	2	180	44,5	4,044944
70	33	2,121212	190	45	4,222222
80	35	2,285714	200	45	4,444444
90	37	2,432432	210	45,5	4,615385
100	39	2,564103	220	46	4,782609
110	40	2,75	230	46	5
120	41	2,926829	240	46	5,217391

Table D.19 Filtration Data of 800 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 250 mg/L KWD 3500 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	8	1,25	140	37	3,783784
20	13	1,538462	150	37,5	4
30	18	1,666667	160	38	4,210526
40	22	1,818182	170	38,5	4,415584
50	25	2	180	39	4,615385
60	28	2,142857	190	40	4,75
70	29,5	2,372881	200	40,5	4,938272
80	31	2,580645	210	41	5,121951
90	32	2,8125	220	41,5	5,301205
100	33	3,030303	230	42	5,47619
110	34	3,235294	240	42	5,714286
120	35	3,428571	250	42	5,952381
130	36	3,611111			

E. Filtration Data of Conditioned Anaerobic Sludge with SNF 5980 Cationic Polyelectrolyte

Table E.1 Filtration Data of 150 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	23	0,434783	170	84	2,02381
20	36	0,555556	180	86	2,093023
30	43	0,697674	190	87	2,183908
40	49	0,816327	200	89	2,247191
50	54	0,925926	210	90,5	2,320442
60	58	1,034483	220	92	2,391304
70	61	1,147541	230	93	2,473118
80	64	1,25	240	94	2,553191
90	67	1,343284	250	95	2,631579
100	70	1,428571	260	95,5	2,722513
110	72	1,527778	270	96	2,8125
120	75	1,6	280	97	2,886598
130	76	1,710526	290	97	2,989691
140	78	1,794872	300	97,5	3,076923
150	81	1,851852	310	98	3,163265
160	82,5	1,939394	320	98	3,265306

Table E.2 Filtration Data of 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	39	0,25641
20	59	0,338983
30	77	0,38961
40	90	0,444444
50	99	0,505051
60	100	0,6

Table E.3 Filtration Data of 210 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	39	0,25641
20	57	0,350877
30	67	0,447761
40	75	0,533333
50	85	0,588235
60	92	0,652174
70	94	0,744681
80	95	0,842105
90	95,5	0,942408
100	96	1,041667
110	96,5	1,139896
120	97	1,237113
130	97	1,340206
140	97	1,443299

Table E.4 Filtration Data of 220 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	33	0,30303	100	92	1,086957
20	46	0,434783	110	93	1,182796
30	58	0,517241	120	93	1,290323
40	69	0,57971	130	93,5	1,390374
50	77	0,649351	140	94	1,489362
60	83	0,722892	150	94,5	1,587302
70	87	0,804598	160	95	1,684211
80	89	0,898876	170	95	1,789474
90	91	0,989011	180	95	1,894737

Table E.5 Filtration Data of 230 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	28	0,357143	80	89	0,898876
20	41	0,487805	90	92	0,978261
30	52	0,576923	100	94	1,06383
40	61	0,655738	110	95	1,157895
50	71	0,704225	120	96	1,25
60	79	0,759494	130	96	1,354167
70	85	0,823529	140	96	1,458333

TableE.6 Filtration Data of 240 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	24	0,416667	80	94	0,851064
20	34	0,588235	90	95	0,947368
30	53	0,566038	100	96	1,041667
40	67	0,597015	110	96,5	1,139896
50	79	0,632911	120	97	1,237113
60	87	0,689655	130	97	1,340206
70	91	0,769231	140	97	1,443299

Table E.7 Filtration Data of 250 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	34	0,294118
20	49	0,408163
30	62	0,483871
40	74	0,540541
50	83	0,60241
60	92	0,652174
70	97	0,721649
80	100	0,8

Table E.8 Filtration Data of 260 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	42	0,238095
20	65	0,307692
30	85	0,352941
40	94	0,425532
50	96	0,520833
60	96,5	0,621762
70	97	0,721649
80	98	0,816327
90	98	0,918367
100	98	1,020408

Table E.9 Filtration Data of 270 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	33	0,30303	100	97,5	1,025641
20	49	0,408163	110	98	1,122449
30	63	0,47619	120	98	1,22449
40	76	0,526316	130	98,5	1,319797
50	87	0,574713	140	98,5	1,42132
60	94	0,638298	150	99	1,515152
70	96	0,729167	160	99	1,616162
80	96,5	0,829016	170	99	1,717172
90	97	0,927835			

Table E.10 Filtration Data of 280 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	23	0,434783
20	34	0,588235
30	43	0,697674
40	50	0,8
50	57	0,877193
60	63	0,952381
70	69	1,014493
80	75	1,066667
90	80	1,125
100	84	1,190476
110	89	1,235955
120	94	1,276596
130	97	1,340206
140	99	1,414141
150	100	1,5

TableE.11 Filtration Data of 290 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	25	0,4
20	37	0,540541
30	47	0,638298
40	57	0,701754
50	66	0,757576
60	73	0,821918
70	81	0,864198
80	88	0,909091
90	94	0,957447
100	97	1,030928
110	99	1,111111
120	100	1,2

Table E.12 Filtration Data of 300 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v
10	28	0,357143
20	43	0,465116
30	55	0,545455
40	67	0,597015
50	79	0,632911
60	89	0,674157
70	94	0,744681
80	97	0,824742
90	99	0,909091
100	100	1

Table E.13 Filtration Data of 350 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	19	0,526316	200	80,5	2,484472
20	26	0,769231	210	82	2,560976
30	32	0,9375	220	84	2,619048
40	37	1,081081	230	85,5	2,690058
50	42	1,190476	240	87	2,758621
60	46	1,304348	250	88,5	2,824859
70	50	1,4	260	90	2,888889
80	53	1,509434	270	91	2,967033
90	56	1,607143	280	92,5	3,027027
100	59	1,694915	290	93,5	3,101604
110	61	1,803279	300	95	3,157895
120	64	1,875	310	96	3,229167
130	66	1,969697	320	96,5	3,316062
140	69	2,028986	330	97	3,402062
150	71	2,112676	340	98	3,469388
160	73	2,191781	350	99	3,535354
170	75	2,266667	360	99	3,636364
180	77	2,337662	370	99	3,737374
190	79	2,405063			

Table E.14 Filtration Data of 400 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	34	0,294118	120	81	1,481481
20	40	0,5	130	84	1,547619
30	46	0,652174	140	87	1,609195
40	50	0,8	150	89	1,685393
50	55	0,909091	160	92	1,73913
60	60	1	170	94	1,808511
70	64	1,09375	180	97	1,85567
80	68	1,176471	190	98	1,938776
90	71	1,267606	200	99	2,020202
100	75	1,333333	210	100	2,1
110	79	1,392405			

Table E.15 Filtration Data of 450 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	27	0,37037	110	78	1,410256
20	35	0,571429	120	82	1,463415
30	42	0,714286	130	86	1,511628
40	48	0,833333	140	89	1,573034
50	54	0,925926	150	93	1,612903
60	58	1,034483	160	95	1,684211
70	63	1,111111	170	97	1,752577
80	67	1,19403	180	99	1,818182
90	73	1,232877	190	100	1,9
100	75	1,333333			

Table E.16 Filtration Data of 150 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	30	0,333333	120	56	2,142857
20	35	0,571429	130	58	2,241379
30	39	0,769231	140	59	2,372881
40	42	0,952381	150	60	2,5
50	44	1,136364	160	61	2,622951
60	46	1,304348	170	62	2,741935
70	48	1,458333	180	64	2,8125
80	50	1,6	190	64,5	2,945736
90	51,5	1,747573	200	65	3,076923
100	53	1,886792	210	65	3,230769
110	55	2	220	65	3,384615

Table E.17 Filtration Data of 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	28	0,357143	90	87	1,034483
20	41	0,487805	100	88	1,136364
30	52	0,576923	110	88	1,25
40	62	0,645161	120	90	1,333333
50	70	0,714286	130	90,5	1,436464
60	77	0,779221	140	91	1,538462
70	82	0,853659	150	91	1,648352
80	85	0,941176	160	91	1,758242

Table E.18 Filtration Data of 250 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	40	0,25
20	57	0,350877
30	71	0,422535
40	83	0,481928
50	90	0,555556
60	92	0,652174
70	93	0,752688
80	95	0,842105
90	95	0,947368
100	95	1,052632

Table E.19 Filtration Data of 300 mg/L SNF 5980 Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v
10	34	0,294118
20	53	0,377358
30	69	0,434783
40	83	0,481928
50	89	0,561798
60	91	0,659341
70	92	0,76087
80	93	0,860215
90	94	0,957447
100	94	1,06383
110	94	1,170213

Table E.20 Filtration Data of 200 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	33	0,30303	140	74	1,891892
20	43	0,465116	150	76	1,973684
30	49	0,612245	160	77	2,077922
40	53	0,754717	170	78	2,179487
50	56	0,892857	180	79	2,278481
60	59	1,016949	190	80	2,375
70	61	1,147541	200	81	2,469136
80	64	1,25	210	82	2,560976
90	66	1,363636	220	83	2,650602
100	68	1,470588	230	84	2,738095
110	70	1,571429	240	85	2,823529
120	71	1,690141	250	85	2,941176
130	73	1,780822	260	85	3,058824

Table E.21 Filtration Data of 400 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	19	0,526316	150	62,5	2,4
20	30	0,666667	160	63,5	2,519685
30	37	0,810811	170	65	2,615385
40	42	0,952381	180	65,5	2,748092
50	45	1,111111	190	66,5	2,857143
60	48	1,25	200	67	2,985075
70	50	1,4	210	68	3,088235
80	52,5	1,52381	220	69	3,188406
90	54	1,666667	230	70	3,285714
100	56	1,785714	240	71	3,380282
110	57	1,929825	250	72	3,472222
120	59	2,033898	260	72	3,611111
130	60	2,166667	270	72	3,75
140	61	2,295082			

Table E.22 Filtration Data of 600 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	13	0,769231	160	60	2,666667
20	19	1,052632	170	61	2,786885
30	25	1,2	180	62	2,903226
40	30	1,333333	190	63	3,015873
50	34	1,470588	200	64	3,125
60	38	1,578947	210	65	3,230769
70	41	1,707317	220	66	3,333333
80	44	1,818182	230	66,5	3,458647
90	47	1,914894	240	67	3,58209
100	50	2	250	67,5	3,703704
110	52	2,115385	260	68	3,823529
120	54,5	2,201835	270	68,5	3,941606
130	56	2,321429	280	69	4,057971
140	57,5	2,434783	290	69	4,202899
150	58,5	2,564103	300	69	4,347826

Table E.23 Filtration Data of 800 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 200 mg/L SNF 5980 Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	12	0,833333	140	57	2,45614
20	17	1,176471	150	59	2,542373
30	23	1,304348	160	60,5	2,644628
40	28	1,428571	170	62	2,741935
50	32	1,5625	180	63	2,857143
60	36	1,666667	190	64	2,96875
70	39	1,794872	200	64,5	3,100775
80	42	1,904762	210	65	3,230769
90	44	2,045455	220	65,5	3,358779
100	47	2,12766	230	66	3,484848
110	50	2,2	240	66	3,636364
120	52,5	2,285714	250	66	3,787879
130	55	2,363636			

F. Filtration Data of Conditioned Anaerobic Sludge with 5980 SB Cationic Polyelectrolyte

Table F.1 Filtration Data of 160 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	9	1,111111	140	21,5	6,511628
20	11	1,818182	150	22	6,818182
30	13	2,307692	160	22,5	7,111111
40	14	2,857143	170	23	7,391304
50	15	3,333333	180	23,5	7,659574
60	16	3,75	190	24	7,916667
70	16,5	4,242424	200	24	8,333333
80	17,5	4,571429	210	24,5	8,571429
90	18,5	4,864865	220	25	8,8
100	19	5,263158	230	25,5	9,019608
110	20	5,5	240	26	9,230769
120	20,5	5,853659	250	26	9,615385
130	21	6,190476	260	26	10

Table F.2 Filtration Data of 180 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	15	0,666667	250	38	6,578947
20	19	1,052632	260	38,5	6,753247
30	21	1,428571	270	39	6,923077
40	23	1,73913	280	39	7,179487
50	24	2,083333	290	39	7,435897
60	25	2,4	300	39,5	7,594937
70	26	2,692308	310	40	7,75
80	27	2,962963	320	40,5	7,901235
90	28	3,214286	330	41	8,04878
100	29	3,448276	340	41,5	8,192771
110	30	3,666667	350	42	8,333333
120	31	3,870968	360	42	8,571429
130	31,5	4,126984	370	42,5	8,705882
140	32	4,375	380	43	8,837209
150	32,5	4,615385	390	43	9,069767
160	33	4,848485	400	43,5	9,195402
170	33,5	5,074627	410	44	9,318182
180	34	5,294118	420	44	9,545455
190	35	5,428571	430	44,5	9,662921
200	35,5	5,633803	440	45	9,777778
210	36	5,833333	450	45,5	9,89011
220	36,5	6,027397	460	46	10
230	37	6,216216	470	46	10,21739
240	37,5	6,4	480	46	10,43478

Table F.3 Filtration Data of 200 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	19	0,526316	100	40	2,5
20	23	0,869565	110	41	2,682927
30	27	1,111111	120	42	2,857143
40	30	1,333333	130	45	2,888889
50	33	1,515152	140	46	3,043478
60	35	1,714286	150	48	3,125
70	36	1,944444	160	48	3,333333
80	37	2,162162	170	48	3,541667
90	38	2,368421			

Table F.4 Filtration Data of 210 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	41	0,243902	110	93	1,182796
20	53	0,377358	120	94	1,276596
30	61	0,491803	130	95	1,368421
40	68	0,588235	140	95	1,473684
50	75	0,666667	150	96	1,5625
60	79	0,759494	160	96	1,666667
70	84	0,833333	170	96,5	1,761658
80	88	0,909091	180	97	1,85567
90	90	1	190	97	1,958763
100	92	1,086957	200	97	2,061856

Table F.5 Filtration Data of 220 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	55	0,181818
20	80	0,25
30	93	0,322581
40	96	0,416667
50	98	0,510204
60	98	0,612245
70	98,5	0,71066
80	99	0,808081
90	99	0,909091
100	99	1,010101

Table F.6 Filtration Data of 230 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	53	0,188679	70	95,5	0,732984
20	77	0,25974	80	96	0,833333
30	89	0,337079	90	96	0,9375
40	93	0,430108	100	97	1,030928
50	94,5	0,529101	110	97	1,134021
60	95	0,631579	120	97	1,237113

Table F.7 Filtration Data of 240 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	40	0,25	140	85	1,647059
20	48	0,416667	150	87	1,724138
30	54	0,555556	160	88	1,818182
40	59	0,677966	170	89	1,910112
50	63	0,793651	180	90	2
60	66	0,909091	190	91	2,087912
70	70	1	200	91,5	2,185792
80	73	1,09589	210	92	2,282609
90	75	1,2	220	92,5	2,378378
100	78	1,282051	230	93	2,473118
110	80	1,375	240	94	2,553191
120	82	1,463415	250	94	2,659574
130	83	1,566265	260	94	2,765957

Table F.8 Filtration Data of 250 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	55	0,181818	70	93	0,752688
20	73	0,273973	80	94	0,851064
30	84	0,357143	90	94,5	0,952381
40	89	0,449438	100	95	1,052632
50	91	0,549451	110	95	1,157895
60	92,5	0,648649	120	95	1,263158

Table F.9 Filtration Data of 260 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	47	0,212766	90	91,5	0,983607
20	61	0,327869	100	92	1,086957
30	71	0,422535	110	93	1,182796
40	79	0,506329	120	93	1,290323
50	83	0,60241	130	93,5	1,390374
60	87	0,689655	140	94	1,489362
70	89	0,786517	150	94	1,595745
80	91	0,879121	160	94	1,702128

Table F.10 Filtration Data of 270 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	93	0,107527
20	98,5	0,203046
30	99	0,30303
40	99,5	0,40201
50	100	0,5

Table F.11 Filtration Data of 280 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	20	0,5	150	72	2,083333
20	30	0,666667	170	73	2,328767
30	37	0,810811	180	74	2,432432
40	41	0,97561	190	75	2,533333
50	46	1,086957	200	75,5	2,649007
60	50	1,2	210	76,5	2,745098
70	54	1,296296	220	77	2,857143
80	57	1,403509	230	77,5	2,967742
90	60	1,5	240	78	3,076923
100	63	1,587302	260	79	3,291139
110	65	1,692308	270	79,5	3,396226
120	67	1,791045	280	80	3,5
130	69	1,884058	290	80	3,625
140	70,5	1,985816	300	80	3,75

Table F.12 Filtration Data of 290 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	35	0,285714	100	82,5	1,212121
20	52	0,384615	110	83	1,325301
30	62	0,483871	120	83,5	1,437126
50	76	0,657895	130	84	1,547619
60	78	0,769231	140	84,5	1,656805
70	80	0,875	150	85	1,764706
80	81	0,987654	160	85	1,882353
90	82	1,097561	170	85	2

Table F.13 Filtration Data of 300 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	45	0,222222	100	87,5	1,142857
20	57	0,350877	110	88	1,25
30	65	0,461538	120	88,5	1,355932
40	72	0,555556	130	89	1,460674
50	78	0,641026	140	89,5	1,564246
60	81	0,740741	150	90	1,666667
70	84	0,833333	160	90	1,777778
80	85	0,941176	170	90	1,888889
90	87	1,034483			

Table F.14 Filtration Data of 350 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	18	0,555556
20	42	0,47619
30	63	0,47619
40	82	0,487805
50	93	0,537634
60	95	0,631579
70	97	0,721649
80	99	0,808081
90	99	0,909091
100	99	1,010101

Table F.15 Filtration Data of 400 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	37	0,27027	80	95,5	0,837696
20	57	0,350877	90	96	0,9375
30	73	0,410959	100	96	1,041667
40	85	0,470588	110	96,5	1,139896
50	92	0,543478	120	96,5	1,243523
60	95	0,631579	130	97	1,340206
70	95	0,736842	140	97	1,443299

Table F.16 Filtration Data of 450 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v
10	69	0,144928
20	83	0,240964
30	89	0,337079
40	93	0,430108
50	94	0,531915
60	94,5	0,634921
70	95	0,736842
80	95	0,842105
90	95	0,947368

Table F.17 Filtration Data of 150 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	13	0,769231	130	35,5	3,661972
20	17	1,176471	140	36	3,888889
30	19	1,578947	150	36,5	4,109589
40	22	1,818182	160	37	4,324324
50	25	2	170	37,5	4,533333
60	27	2,222222	180	38	4,736842
70	29	2,413793	190	38,5	4,935065
80	31	2,580645	200	39	5,128205
90	32	2,8125	210	39,5	5,316456
100	33	3,030303	220	40	5,5
110	34	3,235294	230	40	5,75
120	35	3,428571	240	40	6

Table F.18 Filtration Data of 200 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	19	0,526316	60	32	1,875
20	24	0,833333	70	34	2,058824
30	26	1,153846	80	36	2,222222
40	28	1,428571	90	38	2,368421
50	30	1,666667	100	41,5	2,409639

Table F.19 Filtration Data of 250 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	36	0,277778	140	82	1,707317
20	50	0,4	150	83	1,807229
30	55	0,545455	160	84	1,904762
40	61	0,655738	170	84,5	2,011834
50	66	0,757576	180	85	2,117647
60	69	0,869565	190	85,5	2,222222
70	71	0,985915	200	86	2,325581
80	73	1,09589	210	86,5	2,427746
90	75	1,2	220	87	2,528736
100	77	1,298701	230	87,5	2,628571
110	79	1,392405	240	88	2,727273
120	80	1,5	250	88	2,840909
130	81	1,604938	260	88	2,954545

Table F.20 Filtration Data of 300 mg/L 5980 SB Cationic Polyelectrolyte Dosage Applied to the Sludge Sample Pretreated with 50 mg/L Alum Dosage

t	v	t/v	t	v	t/v
10	40	0,25	120	81	1,481481
20	50	0,4	130	82	1,585366
30	57	0,526316	140	83	1,686747
40	63	0,634921	150	84	1,785714
50	67	0,746269	160	84,5	1,893491
60	70	0,857143	170	85	2
70	72	0,972222	180	85,5	2,105263
80	74	1,081081	190	86	2,209302
90	76	1,184211	200	86	2,325581
100	78	1,282051	210	86	2,44186
110	80	1,375			

Table F.21 Filtration Data of 200 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 270 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	72	0,138889	90	92,5	0,972973
20	77	0,25974	100	93	1,075269
30	81	0,37037	110	94	1,170213
40	84	0,47619	120	95	1,263158
50	86	0,581395	130	96	1,354167
60	88	0,681818	140	96	1,458333
70	90	0,777778	150	96	1,5625
80	91,5	0,874317			

Table F.22 Filtration Data of 400 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 270 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	39	0,25641	140	79	1,772152
20	50	0,4	150	80	1,875
30	57	0,526316	160	80,5	1,987578
40	62	0,645161	170	81	2,098765
50	65	0,769231	180	81,5	2,208589
60	68	0,882353	190	82	2,317073
70	70	1	200	82,5	2,424242
80	72	1,111111	210	83	2,53012
90	74	1,216216	220	83,5	2,634731
100	75	1,333333	230	84	2,738095
110	76	1,447368	240	84	2,857143
120	77	1,558442	250	84	2,97619
130	78	1,666667			

Table F.23 Filtration Data of 600 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 270 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	31	0,322581	170	72	2,361111
20	37	0,540541	180	73	2,465753
30	43	0,697674	190	74	2,567568
40	48	0,833333	200	75	2,666667
50	52	0,961538	210	75,5	2,781457
60	56	1,071429	220	76	2,894737
70	58	1,206897	230	76,5	3,006536
80	60	1,333333	240	77	3,116883
90	62	1,451613	250	77,5	3,225806
100	64	1,5625	260	78	3,333333
110	65,5	1,679389	270	78,5	3,43949
120	67	1,791045	280	79	3,544304
130	68	1,911765	290	79,5	3,647799
140	69	2,028986	300	80	3,75
150	70	2,142857	310	80	3,875
160	71	2,253521	320	80	4

Table F.24 Filtration Data of 800 mg/L Alum Dosage Applied to the Sludge Sample Pretreated with 270 mg/L 5980 SB Cationic Polyelectrolyte Dosage

t	v	t/v	t	v	t/v
10	21	0,47619	140	47,5	2,947368
20	26	0,769231	150	48	3,125
30	30	1	160	48,5	3,298969
40	34	1,176471	170	49	3,469388
50	37	1,351351	180	49,5	3,636364
60	39	1,538462	190	50	3,8
70	41	1,707317	200	50,5	3,960396
80	42	1,904762	210	51	4,117647
90	43	2,093023	220	51,5	4,271845
100	44	2,272727	230	52	4,423077
110	45	2,444444	240	52	4,615385
120	46	2,608696	250	52	4,807692
130	47	2,765957			