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PRETREATMENT OPTIMIZATION OF FIBERGLASS
MANUFACTURING INDUSTRIAL WASTEWATER

THESIS

Presented to the Graduate Council of the
University of North Texas in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Ron Dragoo, B.S.

Denton, Texas

December, 1998

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Wastewater effluent produced in the fiberglass manufacturing industry contains a significant amount of total suspended solids. Environmental regulations require pretreatment of effluent before it is discharged to the municipal wastewater treatment plant. Chemical precipitation by coagulation and flocculation is the method of pretreatment used at the Vetrotex CertainTeed Corporation (VCT). A treatability study was conducted to determine conditions at which the VCT Wastewater Pretreatment Plant could operate to consistently achieve a total suspended solids concentration $\leq 200\text{-mg/L}$.

Jar tests varied pH, polymer dosage, and ferric sulfate dosage. Total suspended solids and turbidity were measured to evaluate treatment performance. The data were used to determine an optimum set of conditions under project guidelines. Of twelve polymers screened, BPL 594 was selected as the most effective polymer. For cost efficiency in the wastewater pretreatment operation, recommendations suggested that treatment chemical injection be electronically controlled according to turbidity of the treated effluent.

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CHAPTER I

INTRODUCTION

A bench-scale wastewater treatability study was conducted to optimize the Wastewater Pretreatment Plant (WWPTP) conditions of Vetrotex CertainTeed Incorporated (VCT). Vetrotex CertainTeed Incorporated is a fiberglass manufacturing plant located in Wichita Falls, Texas, and is a subsidiary of the Saint Gobain Corporation. This treatability study was part of a wastewater characterization study performed for the Environmental Services Department at VCT.

State and Federal regulations require the wastewater to be “pretreated” prior to discharging to a municipal wastewater treatment plant. Industrial User Permit No. 97-S01 and City of Wichita Falls Ordinance Nos. 156-93 and 94-94 allow for VCT wastewater effluent to reach concentrations up to 425-mg/L for total suspended solids (TSS), and a pH range from 5 to 12. A sewer surcharge is applicable if the TSS concentration exceeds 300 mg/L. The treatment criterion for this study was a final wastewater effluent TSS concentration of 200 mg/L and between 7 and 10 for pH.

The purpose of this treatability study was to investigate and determine the optimum conditions and chemical dosages for the pretreatment of the wastewater effluent and make informed suggestions that would help improve the pretreatment. The wastewater was optimized for total suspended solids removal to a concentration of 200 mg/L designated by VCT.

The addition of coagulant, polymer, and pH adjuster is “metered” into the VCT wastewater treatment system at fixed rates because the WWPTP does not have the capability of adjusting injection based on flow fluctuation or some treatment need indicating wastewater parameter. Attempts to keep a constant concentration for each chemical injected into the system are made based on average wastewater flow. Therefore, a single set of final optimum conditions was determined based on the ability to treat the “worst-case” sample conditions to the designated target concentration of TSS.

“Worst-case” sample conditions were defined as samples that were the most difficult to treat. The cause of the wastewater being occasionally more difficult to treat than at other times was unknown, and no association was made between these occurrences and any wastewater parameters that were measured in the study. This criterion for analysis was followed so that once the optimum treatment conditions were implemented, the wastewater effluent would be kept in compliance at all times. A binary statistical analysis, or pass/no pass result, was used to evaluate treatment performances.

No wastewater parameter-treatment efficiency correlation has ever been established at VCT, and with the complexity of wastewater, one may never be discovered. Since neither a zeta potential meter nor streaming current detector (often used for establishing wastewater influent treatability) was available for this study due to the lack of resources, attempting to uncover an indicating parameter was not in the scope of this project.

Scope

The scope of this project was to select a polymer, from a collection of twelve polymers, as a flocculant aid in the pretreatment of VCT wastewater. The polymers were optimized with ferric sulfate as the predetermined coagulant of choice. The VCT Environmental Services Department discouraged screening different metal coagulants because past experiences using alum were unsuccessful, and because ferric sulfate had already proven to be effective for VCT.

Polymer coagulants (lower molecular weight polymers with high charge densities) were not screened because they are not typically used as primary coagulants in highly turbid water due to higher costs. Polymer coagulants can be used as coagulant aids, but based on project guidelines made by the VCT Environmental Services Department, coagulant aids were not to be included in the study.

pH is an important treatment variable that was optimized throughout the experiments using sodium hydroxide as the predetermined pH adjuster. The use of lime at VCT to adjust pH in the past was abandoned due to the excessive amounts of sludge it produced. The project variables were: coagulant concentration, type of polymer, polymer concentration, and pH. The only treatment chemicals screened were polymers in order to find the most effective one for wastewater treatment at VCT.

This treatability study only addressed TSS, turbidity, and pH levels of treated wastewater. Other environmental stressors such as sludge toxicity and toxicity of the constituents in the wastewater may be present, however these issues will be addressed in the wastewater characterization study that is discussed briefly later in this chapter.

Project Phases

The project consisted of five major phases (Figure 1). The first phase was the initial screening of twelve polymers. Phase I used turbidity for performance evaluation, instead of TSS concentration. Phase II was designed to determine the optimum ferric sulfate dosage and pH. Phase III tested a narrowed polymer selection (two new polymers, and the one that was used at VCT) for their optimum dosages, using the optimum ferric sulfate dosages and pH levels from Phase II. At this point, one polymer was ultimately selected based on a treatment performance. The fourth phase tested a limited selection of dosages and pH levels over 5 samples. This phase was completed to determine the optimum treatment conditions based on a binary, or pass/no pass, statistical analysis, using the project treatment criterion of 200 mg/L of TSS. The fifth, and final phase, tested the characteristics of the chosen polymer. Phase V determined if the chosen polymer's characteristics of molecular weight, charge density, and type of charge were responsible for its effectiveness. This phase was accomplished by comparing the chosen polymer's performance with the performance of similar polymers.

Wastewater Characterization

Wastewater effluent produced from manufacturing fiberglass contains a significant amount of suspended solids that originate from the chemical formulations used to coat fiberglass. There are over 100 different "size" formulations used to coat fiberglass products. "Size" is a term used to describe the material that coats the fiberglass. The chemicals are primarily organic compounds and are disposed of through the process wastewater effluent. In general, VCT's wastewater contains primarily

polymers, epoxy resins, and organosilanes. The settling of these suspended solids in untreated wastewater was practically nonexistent.

A comprehensive wastewater characterization was not included in the treatability study, but was performed by a private consulting firm for VCT. The results of the characterization study are proprietary and were not available for publication in this study, because of trade secret information it may disclose.

The only wastewater characteristics available for publication are the parameter measurements that were recorded for this study. Parameter measurements for each wastewater sample are shown in Table 1.

Wastewater Pretreatment Plant Facility Description

Treatment conditions in the WWPTP include the injection of 50% liquid ferric sulfate as coagulant to destabilize the charge on suspended solids. Wastewater operators had used alum in the past, but abandoned it because the sludge it produced was too buoyant. It adhered to the sweeps in the bottom of settling basins, which caused them to stop moving correctly. It also produced a harder sludge and did not dewater as well as ferric sulfate.

VCT injects a 50% sodium hydroxide solution at a constant rate in an attempt to keep pH at a specific level, where additives of ferric sulfate and polymer work best. VCT has plans of gaining more pH control by adding a self-cleaning pH meter and electronic equipment to adjust the injection of sodium hydroxide according to pH readings.

The WWPTP used an anionic polymer with a medium charge density of 30%. It had an average molecular weight of 15 million g/mol. The rate of injection was

approximately 3–4 mg/L based on average wastewater flow and was adjusted according to visual inspection of water quality in the settling basin. All chemicals were injected into a pipe prior to the “rapid-mixing” basin. Figure 2 presents a flowchart of the compartments that the wastewater travels through, points of chemical injection into the wastewater, and the sampling location at the WWPTP.

The following chapters contain: a review of related literature from text and past studies, a description of the methods and procedures used to carry out the objectives of this research, a discussion of results, a and summary with recommendations.

CHAPTER II

LITERATURE REVIEW

The removal of suspended solids from industrial wastewater is an important process in the effort to improve the quality of water, prior to discharge into the environment. Coagulation and flocculation of the suspended solids to facilitate settling is used most by wastewater and water treatment plants.

Using the literature search engines, First Search, Dialog, and Carl Uncover, few studies on the pretreatment of industrial wastewater were revealed. No studies were revealed for pretreatment of fiberglass manufacturing industrial wastewater. This lack of information presented a need for this study. The information used for understanding water treatment mechanisms and theory was textbook literature and studies of chemically treated water. In addition to literature, the WWPTP operators at VCT, chemical vendors, and university professors lended their assistance to this study.

Many variables must be taken into account when optimizing a wastewater treatment system. The following sections discuss/review some appropriate water treatment issues. These include discussions on treatment optimization variables, stability of hydrophobic colloids, coagulation and flocculation, treatment chemical selection, mixing conditions, and settling conditions.

Treatment Optimization Variables

Optimum coagulation treatment of raw water represents the attainment of a complex equilibrium in which many variables are involved. Thus, for any given water matrix, there will be interrelated optima of conditions, such as pH, turbidity, chemical composition of the water, type of coagulant, temperature, and mixing conditions. Early investigators of the coagulation process in water treatment showed that pH was the single most important variable of the many considered. Failure to carry out coagulation within the optimum pH zone would result in excessive use of treatment chemicals and lowered quality of the water-plant effluent. The extent of the pH range is affected by the type and concentration of coagulant and by the chemical composition of the water (Corbitt, 1990).

Stability of Hydrophobic Colloids

Both repulsive and attractive forces act upon individual hydrophobic particles in an aqueous solution. The repulsive forces are a result of the electrical double layer described by Benefield et al (1982), and the principle attractive forces result from van der Waals' forces of intermolecular attraction. Interactions between these forces contribute to the overall stability of a colloidal dispersion, according to the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory developed by Derjaguin and Landau (1941) and Verwey and Overbeek (1948). This theory explains why some colloids agglomerate and others do not (Zeta-meter, Inc., 1993). Colloidal particles in suspension are constantly moving as a result of Brownian motion, which contributes to inhibition of their settling (aquaben.com, 1998). As two similarly charged particles approach each other, they are repulsed by interferences in their diffuse counter-ion atmospheres (Benefield et al, 1982).

The repulsion and attraction energy curves can be combined to form a “total energy curve” representing the resultant energy of interaction. This curve indicates that repulsion forces predominate at certain distances of separation. However, if the particles can be brought close enough together, the van der Waals’ attractive forces will predominate and the particles will coalesce (Benefield et al, 1982). For colloidal particles to aggregate, they must possess enough kinetic energy to overcome the energy barrier of this “total energy curve” (Benefield et al, 1982). A period of rapid mixing in the coagulation stage of treatment will aid by increasing the kinetic energy and the potential for more collisions. Also, the addition of a coagulant, such as the trivalent cation of Fe^{3+} in ferric sulfate, will help lower the energy barrier of the negatively charged colloids. This occurs through charge neutralization and allows particle collisions to occur much more readily. When the forces that stabilize colloidal particles in solution are overcome, the individual particles will aggregate and can be separated from suspension.

Coagulation and Flocculation

The object of coagulation (and subsequently flocculation) is to turn the particles of turbidity into larger “flocs” of suspended particles. These flocs are then “conditioned” so that they may be readily removed in subsequent processes. Most colloids are stable, because the negative charge they possess repels the colloids before they collide (Davis and Cornwell, 1991). The use of cations neutralizes the surface charge of the suspended particles, therefore allowing the suspended particles to collide and form “microflocs”. Destabilization of charged particles in water occurs as a result of the addition of treatment

chemicals. The selection of type and dosage must be made by experimentation, most commonly with jar tests (Corbitt, 1990). The use of trivalent cations, such as aluminum and iron, reduces the charge on the suspended particles faster than mono- or divalent cations (Davis and Cornwell, 1991). The coagulating power of the cations increased in the ratio of 1:10:1000 as the valence increased from 1 to 2 to 3 as noted by Schultze (1882) (Benefield et al, 1982). The metal coagulants, aluminum and iron salts, have been shown to precipitate and coagulate most rapidly and with minimum solubility in some characteristic pH range, depending on the specific coagulant. Extensive and continuing investigations beginning in the early 1920s and extending to the present have shown that the pH zone of least solubility for the hydrolysis products of aluminum ranges from 5.5 to 7.8. Iron salts behave similarly, although the pH zone of coagulation is generally broader (Corbitt, 1990). The ferric coagulant has the advantage that coagulation is possible over a wider pH range, usually from pH 4 to 9. The solubility product of $\text{Fe}(\text{OH})_3$ is 1.1×10^{-36} and is completely precipitated at pH levels as low as 5. Very little Fe^{3+} remains in the coagulated water (Payan, 1975). The precipitation of iron hydroxides is greatest at a pH around 8 (Corbitt, 1990).

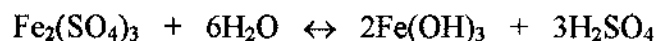
When ferric sulfate solutions are added to water, the molecules dissociate to yield SO_4^{2-} , Fe^{3+} , and various ferric hydroxide complexes such as $\text{Fe}(\text{OH})^{2+}$ and $\text{Fe}(\text{OH})_3$. Hydrolysis products also combine to form longer-chain polymeric ferric hydroxide species of higher charge. The various positive species which are formed may combine with negatively charged colloids to neutralize part of the charge on the colloidal particle,

reducing the zeta potential to a value at which agglomeration of the colloidal particles will occur (Payan, 1975).

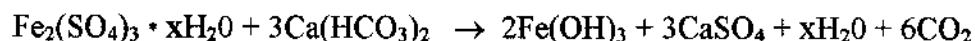
The basis of the coagulation reaction is the formation of a flocculent precipitate by the action of the chemical with either natural or added alkali. Alkali may be added in the form of sodium hydroxide, carbonate, or bicarbonate. It is essential to have a residual alkalinity during chemical coagulation. The residual alkalinity serves to buffer the system at pH levels above 5 and ensures essentially complete coagulating ions (Payan, 1975).

Alkalinity is required for the ferric reaction to successfully proceed. Otherwise, the pH will be lowered to the point where soluble ferric ion (Fe^{3+}) is formed instead of ferric hydroxide. Dissolved ferric ion is an ineffective coagulant and can cause iron to show up in the supernatant rather than precipitate out of solution (Zeta-meter, Inc., 1993).

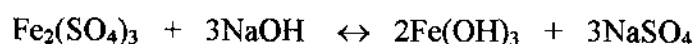
Davis and Cornwell (1991) state that when ferric sulfate is added to water it can be considered to combine with hydroxyl ions of water to form poorly ionized $\text{Fe}(\text{OH})_3$ and sulfuric acid:



Benefield et al (1982) shows that the hydrogen ions liberated by the addition of ferric sulfate will react with natural alkalinity in water as follows:



Davis and Cornwell (1991) also show that the sodium hydroxide ions can serve as buffers and act in this capacity:



The overall coagulation process is quite complex, and the adsorption of ions and colloids is also of great importance. For this reason, it is important that the ferric sulfate be distributed throughout the water mass in order for contact to be made with all the colloidal particles before any other less desirable changes occur.

Particle destabilization can be achieved through four mechanisms: (1) double-layer compression, (2) adsorption and charge neutralization, (3) enmeshment in a precipitate, and (4) adsorption and interparticle bridging (Benefield et al, 1982). At this point, it is necessary to define certain terms used in destabilization. *Coagulation* is a term used to describe the processes by which the charge on particles is destroyed, or when then the DLVO energy barrier is effectively eliminated, and *flocculation* to describe the aggregation of particles into larger units (Zeta-meter, Inc., 1993). In this sense, double-layer compression and charge neutralization would be classified as coagulation, while enmeshment and bridging would be considered to be flocculation (Benefield et al, 1982).

The flocculation process can be optimized with the addition of an effective polyelectrolyte, or polymer. The selection of polymer relies on its ability to form larger macroflocs from the smaller microflocs formed during coagulation. The larger flocs will subsequently settle much faster. Flocculant particles in relatively dilute solutions will not act as discrete particles, but will coalesce during sedimentation (Tchobanoglous and Burton, 1991). As coalescence or flocculation occurs, the particles' masses increase and settle faster.

The extent to which flocculation will occur depends on the opportunity for contact. Less intense mixing is used for the flocculation mixing stage compared to the rapid mixing stage. The less intense mixing must be provided to increase particulate contact without disrupting the aggregates being formed (Montgomery, 1985).

Mechanical mixing, called “orthokinetic” flocculation, is necessary to provide the opportunity for collisions in larger particulates. Brownian motion, in addition to mechanical mixing, aids in flocculation of colloidal particulates (< 1 micron). This is called “perikinetic” flocculation (Montgomery, 1985). Contact varies with velocity gradients in the system, surface-loading rate, depth of the settling basin, concentration of particles, and the range of particle sizes.

Treatment Chemical Selection

Ferric sulfate was the only coagulant used in this project. Prior to this study, VCT proved it favorable in comparison to alum. Alum was abandoned because of the undesirable sludge characteristics it had with VCT’s wastewater. Once ferric sulfate was introduced, these problems did not exist and treatment was still effective. Coagulant screening was not included in this project due to the proven effectiveness of ferric sulfate in comparison to alum in the past.

The polymer selection for treatment effectiveness comparison was based on molecular weight, charge density, and type of charge. All of the polymers chosen had high average molecular weights with flocculating characteristics. High molecular weight polymers are used to alter the strength and size of particle aggregates, usually by bridging the aggregates together (American Water Works Association, 1992). Lower and medium

molecular weight polymers are used for aiding in coagulation, using the same mechanisms as a metal coagulant (American Water Works Association, 1992). However, polymer coagulants were disregarded in this study because effective treatment has been achieved without their use, and using polymer coagulants would be too expensive in this highly turbid wastewater.

When selecting the polymers, an effort was made to obtain broad ranges in their characteristics. They ranged in average molecular weights from high (5,000,000 g/mol) to very high (20,000,000 g/mol), charge densities from five percent to sixty percent, and had either cationic or anionic charges. Sixty percent charge density is considered high for high molecular weight polymers, so a relatively large range in charge densities exists in the selections. Six anionic and six cationic polymers were tested in the initial screening. All of the polymers obtained were in emulsion form. Stock solutions made from this viscous liquid form are easier to prepare than dry forms of polymers.

Sodium hydroxide remained in use for pH adjustment in the treatment operation. Lime was used in the past at VCT for pH adjustment but was hard to work with in its dry form and produced excess amounts of sludge.

Mixing Conditions

The mixing intensities used in the pretreatment plant were found using a G-value. The G-value is calculated by using mixing motor horsepower in the rapid-mix and flocculating-mix basins. Camp and Stein (1943) recognized that a single velocity gradient did not exist in most real flocculators because the flow is so turbulent. As a result, they developed the concept of the “root mean square” velocity gradient, G , as an

average of the distribution of the velocity gradients and proposed that it be calculated as follows:

$$G = (E/V)^{1/2}$$

where E is the power input per unit mass of suspension, and V is the kinematic viscosity (Lawler, 1993). Kinetic viscosity values are located in a table in Clark et al (1977) according to water temperature. The G-values calculated for the mixing conditions at the WWPTP were converted to revolutions per minute (rpm) for a gang stirrer, using a “flat-paddle mixers in a 1-L beaker” graph presented in American Water Works Association (1992).

Settling Conditions

Using formulas published in Tchobanoglous and Burton (1991), settling conditions were calculated using wastewater flow and tank volumes. The two settling basins operating in parallel have a volume of 50,000 gallons total with a surface-loading rate of 1261 gpd/ft². A flow rate of approximately 800,000 gpd was found using flowmeter data. The current surface-loading rate allows only particles with a settling velocity of 3.57 cm/min to be removed. The detention or retention time of water in the settling basins, using the average flow rate, was 91 minutes. To account for less than optimum conditions encountered in the field, the surface-loading rate can be multiplied by a factor of 0.65 to 0.85, and the detention time multiplied by 1.25 to 1.5 when designing a water treatment plant (Tchobanoglous and Burton, 1991).

The removal of suspended solids from wastewater is an important aspect of water treatment. In the industrial world, the pretreatment of process wastewater by removing

TSS is often necessary before discharging it to municipal wastewater plants. The review of the nature of hydrophobic colloids was necessary for understanding the mechanisms of coagulation and flocculation in chemical treatment of wastewater. The selection of the appropriate chemicals and replication of full-scale wastewater treatment plant conditions for jar testing are critical steps in completing a successful treatability study. Finally, the optimization of treatment variables, such as coagulant and polymer concentrations and pH level, is needed to achieve adequate removal of suspended solids.

CHAPTER III

METHODS AND MATERIALS

Sampling

The equalization basin at the wastewater pretreatment plant is the first place at the WWPTP to receive incoming wastewater from the main plant. Samples were taken from this area, because good turbulent mixing of wastewater effluents from each part of the plant are combined there. Samples were taken from this equalization basin at depths of approximately 1 meter. Total suspended solids, turbidity, pH, temperature, alkalinity, and conductivity were measured for each sample batch.

The preferred sample holding time for TSS and turbidity is one day, according to the American Public Health Association (1985). Therefore, a new sample batch was taken each day experiments were performed. The total number of samples (31) gave a good representation of the wastewater parameters measured, but made it difficult to compare results from different samples because of varying sample characteristics, especially in Phase I. Since the number of samples taken in Phase I (13) made polymer comparison more difficult, characteristics of treatment performance, other than turbidity removal efficiency, were used in the selection method in Phase I.

A 10-gallon container was used to hold a large amount of sample for each set of experiments. An adjustable electric stirrer was inserted through an opening in the lid of the container. A plastic bag was used to help seal the container by wrapping it around the

stirring rod and over the sample container, then placing the container lid over the plastic bag. The stirrer kept the wastewater sample homogenous and did not allow settling to take place. The stirring speed was set just enough to keep the wastewater samples moving. The speed was consistent for all samples. This preservation method kept samples from significantly changing characteristics while minimizing volatilization.

Parameter Measurements and Instrumentation

All parameters measured including turbidity, TSS, alkalinity, conductivity, pH, and settleable solids, follow standard method procedures (American Public Health Association, 1985). Turbidity was measured with a Hach 2100A Turbidimeter in Phase I, but a more precise instrument became available and was used for the remainder of the study. This instrument was the Hach DR4000 Spectrophotometer.

The mechanics between the two instruments used to measure turbidity were different. The turbidimeter reads scattered light at a 90-degree angle from the light beam, and measures turbidity in Nephelometric Turbidity Units (NTU). The spectrophotometer measures the light transmitted through the sample, and measures turbidity in Formazin Attenuation Units (FAU). The spectrophotometer uses only light with a wavelength of 860 nm for turbidity measurements, but the turbidimeter uses “white” light, which contains a large range of the wavelengths of visible light.

Using ferric sulfate in high concentrations could have caused error when using the turbidimeter, since ferric sulfate adds color to the wastewater. The iron in ferric sulfate absorbs light in the 590 nm wavelength range, which is included in the white light spectrum, and therefore may lower the turbidity reading. The turbidimeter was an older

model and was not compatible with additives or filters for color interference like newer turbidimeter models. The wavelength at which the spectrophotometer operates (860 nm) could not have had interference due to color from ferric sulfate.

Another reason for changing instruments during the course of the study was the turbidimeter did not have a linear response and required frequent calibration with a range of formazin standards as the turbidity varied. Its readings drifted, making it hard to obtain reproducible turbidity measurements. The VCT owned spectrophotometer was used for the remainder of the study to allow wastewater pretreatment plant operators to use a turbidity-TSS relationship, developed using spectrophotometer data, for future treatment monitoring.

The parameters used for performance evaluation in the experiments included: TSS and turbidity removal, sludge volume, time for the majority of settling (all visible “flocs” settled), time of first visible floc formation, and chemical costs.

Initial Polymer Screening (Phase I)

This initial screening phase was based on turbidity, rather than TSS, as the tool for determining treatment performance. The Hach 2100A Turbidimeter was used for this phase allowing tests to proceed to immediate decisions about optimum treatment levels from one jar test to the next. A turbidity level of 550 NTU (in association with the 200 mg/L of TSS) was selected as the target treatment level based upon overall project treatment criteria. The turbidity value was found using a linear regression model of turbidity-TSS relationships of the untreated wastewater (Figure 2). The model was developed using turbidity and TSS data measured on a range of wastewater dilutions

from three samples. Treated wastewater data for each polymer, which would have provided a more accurate turbidity-TSS relationship, was not available at the beginning of the study.

The turbidity level used to determine optimum treatment in Phase I was not quite accurate based on later findings, because each polymer has its own turbidity-TSS relationship in treated water. However, turbidity measurements did offer a more practical method for screening, opposed to measuring the TSS concentration to get results of each jar test. Even though the turbidity level selected to determine optimum treatment was found not to be accurate later in the study, it did provide a level of treatment performance for polymer comparison.

The time constraint of measuring TSS concentration (approximately a 3-hour cycle time) would have made the measurement impractical for the step-by-step procedure used in Phase I. However, TSS concentration of treated wastewater was measured after Phase I when test matrices were being used. TSS measurements took place after Phase I because immediate results were not needed to proceed with experiments on the same sample, so the cycle time of measuring TSS concentration was not an issue.

In Phase I, the step-by-step jar test method for optimization of pH, ferric sulfate dose, and polymer dose provided data that was used to screen the initial set of polymers. Each polymer screened used the same method for determining optimum pH, ferric sulfate dose, and polymer dose. Two of three variables were held constant, while one varied in order to select the optimum value for each variable. Three sets of jar tests were needed to determine the optimum value for each of the three variables.

pH was the first variable optimized. This set of six jar tests varied pH levels from 6.7 to 10.2 in increments of 0.7. The project criterion required the optimum pH to fall between 7 and 10. The beginning ferric sulfate dosage was usually 30 mg/L. The reason for setting the concentration this low is that the optimum pH for treatment is more evident at low coagulant concentrations (Kemmer, 1988). Using a lower coagulant dosage, optimum pH was easier to decipher, opposed to a high dosage where the zone of optimum pH may appear more broad. The polymer dosage in the beginning of each optimization test series was 4 mg/L. This was the approximate polymer concentration that was used in the WWPTP. Also, this concentration appeared to be effective in some preliminary jar tests.

The second variable optimized was ferric sulfate dosage. The second jar tests used the optimum pH from the first jar tests and a polymer dosage of 4 mg/L. Six ferric sulfate dosages in increments of no less than 5 mg/L were chosen from a range of 0 mg/L to 100 mg/L. These dosages were chosen according to how well the ferric sulfate dosage used in the first jar tests performed.

Finally, the third variable optimized in Phase I was polymer dosage. The dosages ranged from 0 mg/L to 7 mg/L according to how well 4 mg/L performed in the previous tests. Since optimum pH and ferric sulfate dosage in previous tests were optimized to fit around a polymer dosage of 4 mg/L, this third set of jar tests only verified if 4 mg/L was the lowest concentration of polymer that could be used.

There were some exceptions to the dosing concentration ranges discussed. The first was in the beginning of the screening experiments when polymer CA 9760 was

tested. Higher coagulant and polymer dosages were used to help narrow down the ranges (Table 3). Testing of polymer BPL 5149 also had slightly higher polymer dosages to test the possibility of using less coagulant with higher polymer dosages (Table 4). The third exception was when a coagulant/polymer mixture (CA 8351) was tested (Table 12). The final exception to the standard method followed in Phase I was when a cationic polymer (BPL 5504) was used without ferric sulfate to test its performance as a positive ion in stabilizing negative colloids in suspension (Table 13). Since no ferric sulfate was added in either of these last two tests, higher dosages of the products were used.

In each of the three Phase I variable optimization tests, the times of first visible floc formations, sludge volumes, and settling times were recorded during the experiments. Time of first visible floc formation (first floc) was the length of time it took for visible flocs to occur in the mixing phases of jar testing. Sludge volume was recorded during the settling phase using Imhoff cones as described in the Jar Test Procedure section of this chapter. Settling time was defined as the time that had expired (5, 10, 15, 20, or 30 minutes) when the sludge at the bottom of the Imhoff cones ceased to increase. First floc, sludge volume, and settling time data were used to evaluate every polymer in Phase I in addition to full-scale daily chemical costs that would be required for each polymer's treatment conditions to achieve the turbidity criterion.

Optimum dosages and pH levels were used to approximate full-scale total daily cost of operation for each polymer. These costs were calculated by converting ferric sulfate, polymer, and sodium hydroxide bench-scale dosage amounts to full-scale amounts using the stock concentrations for each chemical and average daily wastewater

flow. The full-scale chemical amounts were then converted to full-scale daily costs. Since pH levels of Phase I samples varied, relative amounts of sodium hydroxide were found for each polymer's optimum pH level using the same sample. Several titrations had to be performed, using each polymer's corresponding optimum ferric sulfate dosage, to determine the amount of sodium hydroxide required to obtain each optimum pH level.

Only three polymers were chosen to proceed into Phase II. This selection consisted of one anionic polymer, one cationic polymer, and the polymer in use at VCT. Choosing one polymer of each type of charge would allow the following tests to make certain that one type of polymer charge is actually better than the other type over several samples.

A scoring method was used to choose the polymers. This included ranking the results of total cost per day, sludge volume, settling time, and time of first floc formation from 1 to 4, 1 being the better score, and averaging them for a final score. The four categories were weighted equally in giving a final score to each polymer. The equal weights were justified by the need for good treatment performance characteristics in a pretreatment plant with high wastewater flow in addition to the need for low costs. The score-ranking ranges are shown in Table 17. Chemical usage (cost of operation) and characteristics of treatment performance (first floc, settling time, and sludge volume) played the major role in polymer screening, while percent turbidity removal of each polymer's optimum set of treatment conditions was ranked for use as a secondary comparing tool.

Percent turbidity removals were not used in primary ranking of polymers because removal efficiencies were less meaningful due to different samples and different treatment conditions for each polymer. However, removal efficiencies were calculated as a secondary screening method when choosing between polymers that achieved meriting scores was needed. Percent turbidity removal was almost solely dependent on the initial turbidity of each sample because the final turbidities of each treated sample were all approximately the same.

Transitional Matrix Testing

After Phase I, a test matrix, using optimum variable ranges obtained in Phase I, was developed to try to establish turbidity-TSS relationships for three polymers selected during Phase I. The actual matrix used for the jar tests was a random subset of the total matrix presented in the Table 19 notes. These relationships were supposed to be made to estimate TSS concentrations from turbidity measurements of treated wastewater samples in later phases. The attempt of finding turbidity-TSS relationships in the range associated with the project's treatment criteria failed because a trend of poor treatment had occurred (discussed in Chapter IV). The effort to develop the relationships was abandoned after another try in Matrix 2 due to the same trend in results.

Matrix 2 was developed in an attempt to obtain better results. The matrix was altered slightly (Table 20 Notes) to test on a new sample. The attempt at producing usable turbidity-TSS relationships failed again. The reasons that Matrices 1 and 2 failed are discussed more thoroughly in Chapter IV and V. Trends observed in this Transitional Matrix Testing Phase suggested the need for Phase II optimization of ferric sulfate.

Ferric sulfate concentrations were increased in Phase II without the use of any polymer in an attempt to find a ferric sulfate dosage that would surpass a treatment threshold that appeared to be present. Not using any polymer in Phase II meant the turbidity-TSS relationships of the three polymers would not be created until after Phase III data was obtained, when the polymers were reintroduced. Hence, it was decided to measure TSS concentration directly and use a matrix testing approach for the remainder of the study. This transitional matrix testing phase provided insightful information, but since the results were unsuccessful in providing data used directly in variable optimization, the testing of these matrices was not considered a formal phase of the project.

Ferric Sulfate and pH Optimization (Phase II)

Since the Transitional Matrix Testing Phase proved that that ferric sulfate dosages were not at appropriate concentrations, the next phase was determining two likely optimum ferric sulfate dosages and one pH to be used in Phase III. These optimum values were found from tests run on a set of five samples.

Testing involved ferric sulfate dosages of 50 mg/L, 100 mg/L, 150 mg/L, and 200 mg/L and pH levels of 6, 7, and 8. The ferric sulfate concentration range selected for Phase II extended much higher than the concentrations that were not achieving acceptable results in the Transitional Matrix Testing Phase. The pH range selected was based on treatment performance in Phase I. Polymers were not used in this phase in order to reduce the number of variables, find approximate ferric sulfate dosages, and find a pH to achieve the overall project criterion of 200 mg/L of TSS when the polymers were added

in later phases. Ferric sulfate concentrations were selected based on the ability to achieve TSS concentrations near or below 300 mg/L throughout the Phase II tests. This higher TSS criterion was used to select ferric sulfate dosages only in this testing phase since polymers were not being added.

A systematic grading method was used to select the appropriate pH level. In each of five tests, the pH levels of 6, 7, and 8 were given a score of 1, 2, or 3 for each subset of jar tests using the same ferric sulfate dosage. The lower score was the more effective pH in each case. All of the scores for each pH were then added, and the pH with the lowest sum was used for Phase III. The results of the scoring method for pH selection are presented in Chapter IV.

Polymer Optimization (Phase III)

Two polymers chosen from Phase I, along with the polymer that was used at VCT (CA 9760), were tested further with the optimum conditions from Phase II to evaluate their performance over a set of three samples. The polymer concentrations for Phase IV were selected based on their ability to achieve a TSS concentration of 200 mg/L on the sample that was the most difficult to treat. To make this selection, a pass/no-pass binary statistical analysis was used. The test matrix included ferric sulfate concentrations of 100 mg/L and 150 mg/L with 2 mg/L, 4 mg/L, and 6 mg/L of polymer. A pH of 8 was used for these experiments based on the scoring method for pH used Phase II.

Phase III determined two polymers for Phase IV. Since CA 9760 was used at VCT, project guidelines required that it be included in the selection regardless of Phase III results. This requirement allowed CA 9760 final optimization results to be

implemented immediately into the VCT Wastewater Pretreatment Plant until the polymer selected in this study could be introduced. The second polymer was chosen based on a comparison of TSS results between the two remaining polymers selected for Phase III.

A pH of 7 would be reintroduced in Phase IV because it had performed almost as well as a pH of 8 in Phase II, and because no polymer was added in Phase II where it was eliminated. It was suspected that a pH of 7 might perform better than 8 when a polymer was used in addition to ferric sulfate. Two polymer dosages and the same two ferric sulfate dosages were selected for Phase IV. The reason two concentrations of polymer and ferric sulfate would be used in Phase IV is to ensure that appropriate dosages were selected in the event that a pH of 7 was chosen to ultimately be the optimum pH.

Final Optimization (Phase IV)

Once optimum polymer dosing concentrations were determined for Phase III polymers, a collective matrix of optimum treatment conditions was tested on five samples in Phase IV. The test matrix included ferric sulfate concentrations of 150 mg/L and 200 mg/L, polymer concentrations of 4 mg/L and 6 mg/L, and pH levels of 7 and 8. 200 mg/L of ferric sulfate was included in addition to 150 mg/L to insure that the project treatment criterion was met in this final optimization phase. This safeguard would prevent having to repeat this phase if 150 mg/L did not perform as well as expected.

This phase produced a final set of optimum treatment conditions for implementation at the WWPTP. The selection of optimum conditions would be accomplished by analyzing the results of each subset of resembling treatment conditions

with a pass/no-pass binary statistical approach. The analysis would use the project's overall treatment criterion of 200 mg/L of TSS.

Comparison of Polymers with Similar Characteristics (Phase V)

Once a polymer was selected in Phase IV, similar polymers in terms of average molecular weight, charge density, and type of charge were also tested. This phase considered the possibility that any polymer, with the same characteristics as the polymer chosen in Phase IV, would treat VCT's wastewater with the same effectiveness. In order to test this possibility, the polymer from Phase IV along with the two similar polymers were tested in duplicate on the three samples using the treatment conditions provided by Phase IV.

The two similar polymers chosen for this phase were CA 7194 and CA 7190. CA 7194 has an average molecular weight of 10 million g/mol, and an anionic charge density of 20%. CA 7190 has an average molecular weight of 20 million g/mol, and an anionic charge density of 10%. Polymer CA 7190 was included in this experiment because it should have an equal amount of negatively charged sites, since it is twice the size and has half the charge density.

These polymers compare with characteristics of an average molecular weight of 7 million g/mol and 21% anionic charge density possessed by the polymer chosen from Phase IV. The two new polymers were less expensive than the polymer chosen, so this test was also performed to evaluate the possibility of using one of them instead to lower operational costs.

Mixing Intensity

A G-value formula created by Camp and Stein (1943) determined mixing intensities for the rapid-mix stage and the flocculation stage of jar testing. A theoretical discussion and the formula's variables are discussed in the Literature Review. A G-value of 501 sec^{-1} for the rapid-mixing basin at the WWPTP, and 363 sec^{-1} for the flocculation basin were determined. These G-values were converted to revolutions per minute (rpm) for a gang stirrer using the "flat-paddle mixers in a 1-L beaker" graph presented in American Water Works Association (1992). Mixing speed was set at 140 rpm for the rapid-mixing phase and 90 rpm for the flocculation-mixing phase.

Mixing and Settling Detention Times

Mixing detention times were found by dividing the volume of each basin by the average incoming wastewater flow per minute (550 gpm). Detention time for the rapid-mixing basin (660 gallons) was 1.2 minutes, and detention time for the flocculation basin (3000 gallons) was 5.4 minutes.

Detention time of water in the settling basins (50,000 gallons) was determined to be 91 minutes. For the jar tests, 30 minutes was used because at least 95% of settling in preliminary jar tests occurred in less than 30 minutes.

Jar Test Procedure

Every new wastewater sample was analyzed before each series of tests for pH, temperature, turbidity, TSS, conductivity, and alkalinity. Ferric sulfate and polymer stocks were prepared daily. Titration was used with each new sample to determine the amount of 0.2 N sodium hydroxide required to obtain the desired pH in 1 liter of

wastewater using each specific concentration of ferric sulfate. All chemical dosages were prepared by filling syringes according to the concentration desired. Stock solutions of ferric sulfate were a concentration of 10,000 mg/L, so 1 mg/L of the ferric sulfate stock made the concentration in a 1-liter beaker of wastewater equal to 10 mg/L of ferric sulfate. Stock solutions of polymer were a concentration of 1000 mg/L. 1 mg of polymer stock made the concentration in a 1-liter beaker of wastewater equal to 1 mg/L of polymer. 0.2 N sodium hydroxide was added at the same amount used in the titrations.

When ready to begin, a Phipps and Bird gang stirrer was set at 140 rpm to simulate the rapid-mixing phase. Ferric sulfate was added to all jars first. 0.2 N sodium hydroxide was added next. Polymer was added last. A timer was started for 1 minute, 12 seconds (1.2 minutes). When rapid-mixing time had expired, the flocculation-mixing phase began by setting the stirrer to 90 rpm, and the timer to 5 minutes and 24 seconds (5.4 minutes). Time of first visible floc formation and floc size in each jar was recorded at this time. When flocculation-mixing time had expired, the stirrer was stopped, and water from each jar was gently transferred to Imhoff cones to observe settling. The settling phase timer was set for 30 minutes. Sludge volume was recorded using the graduation markings on the Imhoff cones at time increments between 5 and 30 minutes (5, 10, 15, 20, and 30 minutes). When time had expired, treated water samples were collected from each cone and analyzed for TSS and/or turbidity.

CHAPTER IV

RESULTS AND DISCUSSION

Five phases were used to meet the wastewater treatability study objectives. The first phase narrowed the selection of polymers for the remaining phases. Between Phase I and II, an equipment change and results of what was called the “Transitional Matrix Testing Phase” led to reorganization of remaining phases in the study. Phase II defined two appropriate dosages of ferric sulfate and two effective pH levels for Phases III and IV. Phase III defined adequate polymer dosage for the remainder of the study. Phase IV tested a matrix of treatment conditions on five samples to evaluate each condition and make a decision on which should be optimal at VCT. Finally, Phase V compared the treatment performances of two polymers, having similar characteristics to the polymer chosen in Phase III (BPL 594).

Sample parameters of temperature, pH, alkalinity, conductivity, total suspended solids, and turbidity were measured. Parameter values for every wastewater sample tested from Phase I to Phase V are found in Table 1. A correlation matrix (Table 2) shows that turbidity and TSS had a relatively high correlation in relation to all other parameters, but none of the correlations were highly significant. The correlation between turbidity and TSS in an untreated sample was less important, however, than turbidity-TSS linear regressions of treated samples in justifying the use of turbidity in Phase I. Treated wastewater showed much greater turbidity-TSS relationships (Figures 18, 19, and 20)

than would be expected from the untreated wastewater correlation. This means that turbidity, as a measure of treatment performance in regard to TSS removal, was satisfactory for screening purposes as utilized in Phase I.

In Phase I, of the twelve polymers tested (Tables 3–15), three were selected for the Transitional Matrix Testing Phase. Polymer CA 9760 was included throughout the project based on project guidelines, and the other two polymers were chosen using the results from each polymer's optimum jar test results presented in Table 16. Results including first floc, settling time, sludge volume, and total daily cost from Table 16 were ranked using the Table 17 ranking scheme. Table 18 presents the final score given to each polymer, and was used to make the selections. BPL 594 was chosen as the anionic polymer with a score of 1.25, and BPL 5504 was chosen as the cationic polymer with a score of 1.

The use of removal efficiency (percent turbidity removal) was not very beneficial in Phase I because of the lack of polymer performance data on the same sample, and because different treatment conditions were produced for each polymer using the step-by-step jar test method. Different treatment conditions did not allow removal efficiency to be utilized to compare polymers under the same conditions.

Polymer BPL 5114 (Table 6) presented a polymer dosage (2 mg/L) in the third jar tests significantly different from the standard dosage used for first and second jar tests of polymer screening, however BPL 5114 was not selected due to scores of 2 and 3 associated with cost and sludge volume. Polymer BPL 5530 (Table 15) also had a different polymer dosage in the third jar tests (6 mg/L). BPL 5530 was not selected

because at high dosages of ferric sulfate and polymer relative to the other polymers' dosages, and the target turbidity level of 550 NTU was never met. The third set of jar tests in Phase I did not prove very useful because pH and ferric sulfate levels were actually optimized around the polymer dosage of 4 mg/L used in the first two jar tests of each screening test.

From Table 16 data, it can be seen that using a coagulant/polymer mixture (CA 8351) was too expensive. This is true because coagulant is cheaper in bulk than when purchased in drums mixed with a polymer. When the cationic polymer BPL 5504 was tested without ferric sulfate, the score in Table 18 (1.25) was almost the same as when BPL 5504 was used with ferric sulfate (1). Although, a percent turbidity removal score, used as a secondary ranking method, of 4 showed BPL 5504 not to be quite as effective as when using BPL 5504 with coagulant (2), therefore it was rejected. BPL 5502 also achieved a score of 1.25, but it was rejected due to a slower settling time than BPL 5504. All other polymer scores were not close enough to chosen polymers' scores to question.

Results of Matrix 1 and 2 of the Transitional Matrix Testing Phase are shown in Tables 19 and 20. The TSS concentrations of treated wastewater samples in this transitional phase actually increased as ferric sulfate dosages increased. These increases in TSS concentrations are illustrated in Figures 4-9. The attempt to create useful turbidity-TSS relationships failed in this phase as illustrated in Figures 10-12. None of the polymer turbidity-TSS relationships were significant within each matrix nor would they have been if data from both matrices were combined.

The results from Phase II are shown in Tables 21-25. Figures 13-17 show TSS results of Tests 1-5 graphically by the amount of ferric sulfate used. Test 5 results were not included in the selection of ferric sulfate dosages for Phase III.

The reason Test 5 results were disregarded is because the Main Plant had dumped a batch of “size” in its concentrated form into the wastewater preceding sampling on that particular day. Even though the sample parameters measured on this particular sample did not indicate much deviation from the overall sample parameter averages, these results were not included in optimum treatment condition selection because the “size” dumps are not a regular occurrence. A procedure for wastewater treatment in the circumstance of “size” dumps is discussed in Chapter V. Treatment of Sample II-5 was distinctively ineffective (Figure 17). Test 5 showed results similar to those in the Transitional Matrix Testing Phase because they also had an increase in treated wastewater TSS concentrations.

Phase II Tests 1-4 results demonstrate that almost every time 100 mg/L of ferric sulfate was used, the TSS criterion for Phase II (TSS near or below 300 mg/L) was met. When 150 mg/L of ferric sulfate was used, the criterion was accomplished every time. Therefore, 100 mg/L and 150 mg/L of ferric sulfate were chosen for Phase III.

Using the systematic approach discussed in Chapter III of scoring the different pH levels on Tests 1-5 of Phase II, a pH of 8 was chosen as the optimum pH. The scores given to each pH were 29 for a pH of 8, 34 for a pH of 7, and 43 for a pH of 6.

Phase III Tests 1-3 results are shown in Tables 26-28. Figure 21 illustrates Test 1 TSS results in relation to ferric sulfate dosage. The Test 1 sample (Sample III-1) was

considered the sample that was most difficult to treat based on higher TSS results than Tests 2 or 3, therefore Test 1 was used to analyze the data and choose treatment concentrations for Phase IV.

In Figure 21, the polymer dosages of 2 mg/L, 4 mg/L, and 6 mg/L can be visualized as the TSS concentrations decrease vertically on the graph at each ferric sulfate concentration. 100 mg/L of ferric sulfate with 6 mg/L of polymer met the criterion when BPL 594 was used, but not when using CA 9760. Since results were needed for CA 9760 based on project guidelines, 100 mg/L of ferric sulfate at 6 mg/L of polymer was not selected. 150 mg/L of ferric sulfate at polymer dosages of 4 mg/L and 6 mg/L were chosen for Phase IV because they represented TSS results at or below 200 mg/L of TSS with both CA 9760 and BPL 594. Polymer BPL 5504 was eliminated after Phase III because all but one of its TSS results were higher than BPL 594's.

Turbidity-TSS relationships for three polymers are presented in Figures 18, 19, and 20 combining TSS and turbidity data from all three tests in Phase III. The R^2 (coefficient of determination) values for each figure may be thought of as the strengths of each sum of least squares regression line (Zar, 1996). The R^2 values (0.99, 0.98, and 0.99) suggest strong relationships for TSS and turbidity using each polymer treatment, however they were not used this late in the study due to the reorganization of the project after the Transitional Matrix Testing Phase. The relationships can be used to defend the use of turbidity in Phase I polymer screening, because they proved that a turbidity-TSS relationship exists for wastewater treated using each polymer.

Tables 29-33 present Phase IV Tests 1-5 data. The data is also grouped by similar treatment conditions in Table 34 for BPL 594 and Table 35 for CA 9760. The data in Tables 34 and 35 was subjected to a pass/no-pass binary statistical analysis in accordance with the overall project treatment criterion for TSS concentration of 200 mg/L. Tables 34 and 35 also present the average percent TSS removal for each grouping of similar treatment conditions. Since the pH of 7 was reintroduced in Phase IV, a selection of optimum pH had to be made again. These percent TSS removals suggested that a pH of 8 was optimal for BPL 594, and a pH of 7 was optimal for CA 9760.

The Phase IV pass/no-pass binary statistical analysis on CA 9760 treatment groupings rejected all that included 150 mg/L of ferric sulfate, and all the treatment groupings using 200 mg/L of ferric sulfate passed the test. The CA 9760 treatment grouping selected as optimal was 200 mg/L of ferric sulfate, 4 mg/L of polymer, and a pH of 7, because it would subject the WWPTP to lower operational costs than the other treatment groupings that passed the test.

Phase IV results using 150 mg/L of ferric sulfate with 4 mg/L of BPL 594 at both pH levels did not pass the binary statistical test using the TSS concentration criterion of 200 mg/L. The results using 150 mg/L of ferric sulfate with 6 mg/L of BPL 594 at both pH levels did pass the test. Also, 200 mg/L of ferric sulfate with 4 mg/L and 6 mg/L of BPL 594 at both pH levels passed the binary test. The concentrations of 150 mg/L of ferric sulfate and 6 mg/L of BPL 594 were selected as the final optimum conditions at a pH of 7, because they met the treatment criterion and operate at a lower cost than the other successful treatment groupings.

Lower costs of the treatment groupings selected in Phase IV are due to less sodium hydroxide, polymer, and/or ferric sulfate, whichever the case may be, needed for treatment to meet the project's overall treatment criterion. Less ferric sulfate ($\text{pH} \approx 2$) requires less sodium hydroxide to bring the pH back to an effective level. Also, less ferric sulfate produces less sludge that must be disposed of in a landfill. The additional 2 mg/L of polymer being used does not add up to the cost that an additional 50 mg/L of ferric sulfate would incur in operation of the WWPTP. A pH level of 7 was selected in the case of BPL 594 even though a pH of 8 may have been slightly more effective because it has a lower operational cost and still met the criterion set for treatment performance.

The results of Phase V showed successful treatment effectiveness with each polymer over a set of three wastewater samples. To compare the effectiveness of two new polymers (CA 7190 and CA 7194) with the effectiveness of BPL 594, TSS removal efficiencies of each polymer were calculated for each test. Test data and results of Tests 1-3 are presented in Table 36. The TSS removal efficiencies of all the polymers were comparatively effective.

The average % TSS removals of each duplicated polymer test in Phase V are:

<u>Test No.</u>	<u>Polymer Name</u>	<u>% TSS Removal</u>
1	BPL 594	38%
1	CA 7194	46%
1	CA 7190	36%
2	BPL 594	74%
2	CA 7194	62%
2	CA 7190	55%
3	BPL 594	71%

3	CA 7194	80%
3	CA 7190	76%

The average % TSS removal for BPL 594 in all 3 tests was 61%. The average % TSS removal for CA 7194 was 63%. The average % TSS removal for CA 7190 was 56%.

These results suggest that as long as a polymer has the same characteristics as any of these three polymers, (i.e. anionically charged with charge density of approximately 20% and an average molecular weight of approximately 7-10 million g/mol, or anionically charged with a charge density of approximately 10% and an average molecular weight of approximately 20 million g/mol) the % TSS removal in this wastewater should be effective.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

This treatability study screened polymers with a variety of characteristics. One polymer was ultimately selected based on its ability to treat VCT's wastewater better than the other polymers. The anionic polymer BPL 594 was chosen because of its effectiveness in Phase I and III. With a ferric sulfate concentration of 150 mg/L and a pH of 7, BPL 594 performed well at 6 mg/L. Treatment conditions in Phases II through IV were selected by analyzing test results from treating the most difficult samples or by using the pass/no-pass binary statistical analysis. Using these types of analyses, the chosen set of conditions should yield WWPTP effluent that is consistently below permit levels. 200 mg/L of ferric sulfate with 4 mg/L of CA 9760 at a pH of 7, chosen from Phase IV results, will be implemented at the WWPTP until BPL 594 can be introduced. The best way to validate predictions made by this study is to implement them at the WWPTP for a period of time and monitor the WWPTP effluent for turbidity (using turbidity-TSS relationships developed in Phase III) and/or TSS concentration.

The turbidity-TSS relationships (Figures 18-20) developed after Phase III illustrated that turbidities corresponding to the TSS criterion of 200 mg/L in treated wastewater were actually lower than in the untreated wastewater (Figure 3). Therefore Phase I did not achieve treatment levels set forth by the project's overall TSS criterion. This realization was not made until the Transitional Matrix Testing Phase, because TSS

concentrations were not measured in the treated samples of Phase I. The inability in Phase I to treat the samples enough to achieve the criteria was considered acceptable, however, because the phase was mainly intended for screening rather than optimization.

Lower turbidity values of treated wastewater illustrated in the Phase III figures that correspond to 200 mg/L of TSS, opposed to the turbidity value used for Phase I, explain the need for higher coagulant dosages in Phase II. Phase I and II used higher TSS criterions than 200 mg/L, but only Phase II was purposely designed that way. However, TSS removal was proven to be related to turbidity removal in treated wastewater turbidity-TSS relationships for VCT's wastewater in Phase III, so the use of turbidity to screen polymers in Phase I was validated.

Polymers CA 7194 and CA 7190, having similar characteristics to BPL 594, proved to be as effective as BPL 594 in treatment of the wastewater. The suggestion from this observation is that any polymer possessing the characteristics of these polymers will perform well at treating wastewater produced at this fiberglass manufacturing plant, so using the one that costs least would make the most sense. Using either CA 7194 or CA 7190 would save money in WWPTP operation because they cost only about half as much as BPL 594.

The results of the Transitional Matrix Testing Phase were unsuccessful in helping define any optimum treatment conditions because the rising TSS trend had occurred, but did however provide information useful in reorganizing the next phase. Phase II results helped determine why experiments in the Transitional Matrix Testing Phase were unsuccessful. The discovery made in Phase II was that coagulant could have an

undesirable impact on treatment performance if it was not added at the proper concentration in this wastewater. As exhibited in Phase II Test 3 results, until enough coagulant was added, the treated wastewater TSS concentration increased until a threshold coagulant concentration was reached. One explanation for this could be that Fe^{3+} ions added weight to suspended particles by attaching to them, while not stabilizing them enough to coagulate and subsequently settle. The threshold concentration of ferric sulfate provided enough destabilizing power to allow coagulation of the suspended particles. Therefore, if the WWPTP's treatment is not optimized to exceed this threshold by adding enough coagulant, then it may worsen the TSS problem by making particles in suspension heavier.

A procedure for wastewater treatment in the occurrence of "size" dumps from the Main Plant into the wastewater has been established to mitigate the impact of the wastewater on treatment performance. When the Environmental Services Department at VCT is informed of each "size" dump, WWPTP operators will be directed to increase ferric sulfate injection to achieve a concentration of between 250 mg/L and 300 mg/L for that day. This increase should ensure that treatment of the concentrated "size" material is achieved to at least TSS concentrations below the permit surcharge level of 300 mg/L. Monitoring of WWPTP effluent should be performed after the dosing adjustment is made to determine a more accurate ferric sulfate concentration for the procedure.

The wastewater effluent at VCT is complex because it has so many constituents at inconsistent concentrations, and because its characteristics greatly vary. This wastewater complexity results in a need to change treatment conditions based on characteristics of

the wastewater. This study was designed to find treatment conditions that would treat worst-case wastewater samples down to TSS concentrations of 200 mg/L. The project was designed this way because the WWPTP at VCT is limited to injecting its chemicals at constant feed rates.

When VCT decides to upgrade the WWPTP and add electronic control of chemical injection, a study to adjust treatment according to treatment needs should be performed to avoid over-treating and over-spending. The study could establish a calibration curve between a treatment parameter (found to be indicative of treatment need) and one or more of the treatment variables (ferric sulfate concentration, polymer concentration, and pH level).

An indicating parameter such as zeta potential or streaming current detection could be found to indicate the need for higher or lower concentrations of treatment chemicals. These methods are often used, based on a discussion with one of VCT's water treatment consultants, to find the necessary coagulant concentrations in wastewater. If a relationship between one of these measurements and coagulant concentration requirements, for example, could be made experimentally, then measuring these parameters prior to treatment would allow electronic controls to inject chemicals accordingly. This type of study might prove favorable for VCT in an effort to save money by not over-treating the wastewater.

If studies to find an indicating parameter fail or can not be performed, it is suggested that an effluent turbidity meter be installed to measure the WWPTP's effluent. High and low turbidity level alarms could be used to adjust ferric sulfate dosing,

according to which alarm is active. Chemical injections should be electronically controlled based on turbidity status and wastewater flow to achieve the correct ferric sulfate concentration. The pH level would need to be stabilized to the optimum pH electronically, using separate controls. Implementation of this type of treatment system would reduce unnecessary wastewater treatment costs without requiring additional experiments.

The need for this treatability study became apparent when the literature review did not uncover any literature on studies using the same type of wastewater or project criteria. If the optimum treatment results found for BPL 594, CA 7194, and CA 7190 were attempted to be replicated on another fiberglass manufacturing plant's wastewater, there is a possibility that the results produced would be similar. The possibility assumes that a plant has reason to believe that its wastewater is similar to VCT's wastewater. The wastewater flow, constituents, and wastewater parameter characteristics would all need to be alike. The project criteria must also be similar for the attempt at implementing these treatment conditions to be worthwhile. Since constituents in wastewater of a fiberglass manufacturing plant are usually confidential, the likelihood of being able to compare constituents is low. Treatability experiments are invariably necessary to pinpoint an accurate set of conditions for every particular wastewater with this magnitude of complexity. However, the potential of achieving similar results exists because treatment conditions selected in this study were determined based on VCT's worst-case wastewater samples.

Suggestions must be made for meeting the same type of objectives more efficiently in future treatability studies. If TSS concentration of treated wastewater is the parameter being used to determine treatment performance, then the problem of relating turbidity to TSS using wastewater dilutions should be avoided. Also, each polymer being screened should be tested on the same samples to eliminate the problems associated with sample variation. Holding times for turbidity and TSS and the large number of polymers being tested prevented using the same sample for each polymer test in Phase I. The alternative of attempting to preserve a large sample to use with each polymer may have produced more reliable results. This study lacked evidence to prove that optimum treatment conditions of each polymer in Phase I would be present if the polymers were tested on the same sample. Therefore, a matrix should be used for screening instead of step-by-step jar testing. The matrix approach would allow each polymer's results to be observed using the same set of treatment conditions. When polymers are tested on the same sample(s) with the same treatment conditions, results would only vary by the type of polymer and treatment characteristics (removal efficiencies, first floc times, settling times, and sludge volumes) of each polymer. Removal efficiency can be used more effectively when a matrix is tested on the same sample, opposed to the step-by-step method of jar testing used Phase I.

Once a polymer is selected, treatment variable ranges would then need to be narrowed down. This optimization of the polymer should be performed on several samples to justify a choice of treatment conditions, using either a step-by-step method or a test matrix.

The treatment conditions for CA 9760, BPL 594, CA 7194, and CA 7190 suggested from this study are assumed to prevent the pretreated wastewater effluent at VCT from exceeding the project's overall treatment criteria of 200 mg/L of TSS. Even when treating VCT's most difficult wastewater effluents. One of the additional studies suggested should be performed following the anticipated VCT WWPTP upgrade to allow VCT's wastewater pretreatment to be less wasteful of chemicals and more cost efficient.

Table 1: Raw Wastewater Sample Parameter Measurements - Phases 1 - 5

	Sample No.	Temp.(F)	pH	Alkalinity	Cond.	TSS	FAU	NTU
	I-1	70	6.9	55	634	240		1080
	I-2	73	7.35	68	668	394		1140
	I-3	73.5	10	37	970	336		1030
	I-4	77	6.95	58	658	472		1560
	I-5	72	6.78	61	721	486		1900
	I-6	74	6.94	63	694	244		1270
	I-7	74	3.2	0	1165	577		1470
	I-8	75	6.76	65	699	364		1360
	I-9	74	7.08	71	674	312		1565
	I-10	71	7.03	53	659	382		1390
	I-11	75	2.7	0	1880	354		1025
	I-12	74	6.93	53	726	456		1340
	I-13	73	6.57	47	747	332		1220
	M-1	75	6.95	31.5	675	380	2500	1380
	M-2	78	6.85	28	652	251	1578	1050
	II-1	83	6.94	37.5	708	480	1796	
	II-2	80	6.8	34	790	724	2832	
	II-3	77	7.6	31	723	366	1805	
	II-4	77	9.4	50	808	401	2123	
	II-5	81	7.25	28	695	339	1943	
	III-1	82	6.95	28	677	319	1735	
	III-2	83	8.26	34.5	728	386	1830	
	III-3	79	7.2	31.5	843	490	2000	
	IV-1	82	6.78	34	712	248	1627	
	IV-2	82	6.9	33	1400	380	1938	
	IV-3	83	6.46	25.5	770	308	1532	
	IV-4	83	9.78	73	927	313	1546	
	IV-5	83	7.5	48	840	311	1580	
	V-1	82	6.9	32	865	245	1785	
	V-2	80	6.6	23	698	264	1695	
	V-3	81	3.6	0	1020	305	1702	
Mean		77.7	6.9	39.8	820	370	1864	1319
Median		77.2	6.9	34.5	723	354	1790.5	1340
Std. Dev.		4.2	1.5	19.76	257	107	339	244
Variance		17.6	2.3	390.5	66247	11379	115043	59537
Max.		83.3	10.0	73.0	1880	724	2832	1900
Min.		70.0	2.7	0	634	240	1532	1025

Table 2: Correlation Matrix of Raw Wastewater Sample Parameters - Phases 1 - 5

	Temperature	pH	Alkalinity	Conductivity	TSS	Turbidity
Temperature	1					
pH	0.116	1				
Alkalinity	-0.319	0.628	1			
Conductivity	0.082	-0.498	-0.526	1		
TSS	-0.085	-0.126	-0.073	0.093	1	
Turbidity	-0.355	-0.053	0.231	-0.191	0.690	1

Table 3: Phase 1 - Polymer 9760 - Sample I-1

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Floc Size
1	1	30	3	6.7	780	3	10	60	Small
1	2	30	3	7.4	760	3	10	60	Small
1	3	30	3	8	710	3	10	60	Small
1	4	30	3	8.8	765	3.5	10	60	Small
1	5	30	3	9.5	720	2.8	10	60	Small
1	6	30	3	10.2	755	2.9	10	60	Small
2	1	0	3	8	1050	0	NA	60	No Flocc
2	2	50	3	8	640	4	10	60	Small
2	3	100	3	8	425	9	10	60	Small
2	4	150	3	8	340	14.8	5	60	Medium
2	5	200	3	8	245	21	5	60	Medium
2	6	250	3	8	150	23.5	5	60	Large
3	1	65	0	8	840	0.4	30	NA	Very Small
3	2	65	3	8	595	4.2	10	60	Small
3	3	65	6	8	480	6	5	30	Sm & Med
3	4	65	9	8	405	6.5	5	30	Med & Lg
3	5	65	12	8	320	10	5	30	Large
3	6	65	15	8	290	10	5	30	Medium
4	1	40	4	8	630	4.1	5	30	Sm & Med
4	2	50	4	8	610	4.9	5	30	Sm & Med
4	3	60	4	8	565	5.6	5	30	Med & Lg
4	4	70	4	8	545	5	5	30	Med & Lg
4	5	80	4	8	480	6	5	30	Med & Lg
4	6	90	4	8	465	6.5	5	30	Med & Lg
Wastewater Sample I-1		Temperature = 70° F, pH = 6.9, Alkalinity = 55 mg CaCO ₃ /L, Conductivity = 634 mohms, Turbidity = 1080 NTU, TSS = 240 mg/L							

Table 5: Phase 1 - Polymer 5900 - Sample I-3

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Floc (sec)	Floc Size
1	1	30	4	6.7	470	6	5	60	Medium
1	2	30	4	7.4	400	7	5	60	Med & Sm
1	3	30	4	8.1	410	7.5	5	60	Sm & Med
1	4	30	4	8.8	425	7	5	120	Sm & Med
1	5	30	4	9.5	480	7.5	10	150	Sm & Med
1	6	30	4	10.2	530	7.8	15	150	Sm & Med
2	1	0	4	9.75	1010	0.5	30	>150	Very Small
2	2	10	4	9.7	785	2.4	30	>150	Small
2	3	20	4	9.65	540	4.7	20	>150	Small
2	4	30	4	9.55	445	8.2	10	>150	Small
2	5	40	4	9.4	405	9.6	10	>150	Small
2	6	50	4	9.3	380	10.5	5	150	Small
3	1	20	0	9.65	940	2.7	30	>180	Small
3	2	20	1	9.65	810	3.4	30	>180	Small
3	3	20	2	9.65	725	3.6	30	>180	Small
3	4	20	3	9.65	750	2.9	30	>180	Small
3	5	20	4	9.65	575	4.9	20	>180	Sm & Med
3	6	20	5	9.65	540	4.9	15	>180	Sm & Med
Wastewater Sample I-3		Temperature = 74° F, pH = 10, Alkalinity = 37 mg CaCO ₃ /L, Conductivity = 970 mohms,							
		Turbidity = 1030 NTU, TSS = 336 mg/L							

Note:

Tests 2 and 3 were run at higher a pH because they would have needed acid. Because the WWPTP was not designed to inject acid, the tests were allowed to run at the pH present after the ferric sulfate was added.

Table 7: Phase 1 - Polymer 5118 - Sample I-5

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Floc Size
1	1	40	4	6.8	595	13.3	10	60	Very Small
1	2	40	4	7.4	700	14	15	60	Very Small
1	3	40	4	8	760	13.5	15	60	Very Small
1	4	40	4	8.8	800	12.9	15	60	Very Small
1	5	40	4	9.5	935	11.1	30	60	Very Small
1	6	40	4	10.2	1000	10.3	30	60	Very Small
2	1	0	4	7	1020	6.4	30	60	Very Small
2	2	30	4	7	630	12.3	10	45	Small
2	3	40	4	7	540	13.7	10	30	Medium
2	4	50	4	7	490	13	10	30	Medium
2	5	60	4	7	425	13.5	5	30	Medium
2	6	70	4	7	405	14	5	30	Medium
3	1	60	0	7	1500	0.2	30	NA	Not Visible
3	2	60	1	7	1400	1.2	30	NA	Not Visible
3	3	60	2	7	1110	5.9	30	60	Very Small
3	4	60	3	7	940	10	20	60	Very Small
3	5	60	4	7	650	13	15	45	Small
3	6	60	5	7	520	14	10	30	Medium

Temperature = 72° F, pH = 6.8, Alkalinity = 61 mg CaCO₃/L, Conductivity = 721 mohms, Turbidity = 1900 NTU, TSS = 486 mg/L

Table 8: Phase 1 - Polymer 5502 - Sample I-6

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Floc Size
1	1	30	4	6.8	350	5.9	5	30	Large
1	2	30	4	7.4	430	7.9	15	50	Medium
1	3	30	4	8.1	465	9.3	20	60	Medium
1	4	30	4	8.8	585	6.7	30	60	Small
1	5	30	4	9.5	570	8.6	20	60	Small
1	6	30	4	10.2	535	8.9	20	60	Small
2	1	0	4	7	625	0.5	30	45	Very Small
2	2	10	4	7	505	4.8	15	30	Small
2	3	20	4	7	435	5.5	5	30	Medium
2	4	30	4	7	395	5.6	5	30	Med & Lg
2	5	40	4	7	320	7.6	5	30	Large
2	6	50	4	7	300	8.5	5	30	Very Large
3	1	10	0	7	1230	0.1	30	NA	Not Visible
3	2	10	1	7	1060	0.8	30	NA	Not Visible
3	3	10	2	7	810	2.6	30	60	Very Small
3	4	10	3	7	645	4.5	30	45	Very Small
3	5	10	4	7	530	4.7	10	30	Small
3	6	10	5	7	505	4.6	10	30	Small
Wastewater Sample I-6		Temperature = 74° F, pH = 6.9, Alkalinity = 63 mg CaCO ₃ /L, Conductivity = 694 mohms, Turbidity = 1270 NTU, TSS = 244 mg/L							

Table 9: Phase 1 - Polymer 5505 - Sample I-7

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Floc Size
1	1	30	4	6.8	1450	0.2	30	NA	Not Visible
1	2	30	4	7.4	1460	0.2	15	NA	Not Visible
1	3	30	4	8	1400	0.2	20	NA	Not Visible
1	4	30	4	8.8	1360	0.4	30	NA	Not Visible
1	5	30	4	9.5	1360	0.4	30	NA	Not Visible
1	6	30	4	10.2	1250	0.5	30	NA	Not Visible
2	1	60	4	6.8	1050	2.6	10	180	Not Visible
2	2	60	4	7.4	960	3.4	10	180	Not Visible
2	3	60	4	8.1	950	3.1	15	180	Not Visible
2	4	60	4	8.8	770	6.5	15	120	Very Small
2	5	60	4	9.5	595	12.4	10	120	Very Small
2	6	60	4	10.2	430	16	10	120	Small
Wastewater Sample I-7		Temperature = 74° F, pH = 3.2, Alkalinity = 0 mg CaCO ₃ /L, Conductivity = 1165 mohms, Turbidity = 1470 NTU, TSS = 577 mg/L							

Notes:

It became apparent that this polymer would not be selected due to a higher optimum coagulant dose and pH than many of the other polymers already tested, so testing was stopped after Test #2.

Table 10: Phase 1 - Polymer 5504 - Sample I-8

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Flocc Size
1	1	30	4	6.7	420	6.7	5	20	Very Large
1	2	30	4	7.4	325	7.9	5	25	Medium
1	3	30	4	8.1	365	8.2	5	25	Small
1	4	30	4	8.8	390	8.6	5	25	Small
1	5	30	4	9.5	380	10.8	10	30	Very Small
1	6	30	4	10.2	385	10	10	30	Very Small
2	1	0	4	7	575	0.7	30	90	Very Small
2	2	8	4	7	520	5	5	20	Medium
2	3	16	4	7	445	5.8	5	20	Med & Lg
2	4	24	4	7	425	6.1	5	20	Large
2	5	32	4	7	360	7.4	5	20	Very Large
2	6	40	4	7	355	7.9	5	20	Very Large
3	1	6	0	7	1285	0	NA	NA	No Flocc
3	2	6	1	7	1050	1.5	30	90	Not Visible
3	3	6	2	7	735	3.4	15	80	Very Small
3	4	6	3	7	650	4.5	10	60	Medium
3	5	6	4	7	530	4.8	5	30	Medium
3	6	6	5	7	440	4.8	5	20	Medium
Wastewater Sample I-8		Temperature = 75° F, pH = 6.8, Alkalinity = 65 mg CaCO ₃ /L, Conductivity = 699 mohms, Turbidity = 1360 NTU, TSS = 364 mg/L							

Table 11: Phase 1 - Polymer 594 - Sample I-9

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Floc (sec)	Floc Size
1	1	30	4	6.7	405	5.7	5	20	Very Large
1	2	30	4	7.4	360	6.3	5	35	Lg & Med
1	3	30	4	8.1	380	7.1	5	45	Small
1	4	30	4	8.8	395	7.5	5	80	Small
1	5	30	4	9.5	425	7.8	10	90	Very Small
1	6	30	4	10.2	455	7.4	10	90	Very Small
2	1	0	4	7	1070	0.3	10	90	Very Small
2	2	8	4	7	625	4.2	5	30	Small
2	3	16	4	7	553	4.2	5	25	Medium
2	4	24	4	7	540	4.3	5	25	Large
2	5	32	4	7	457	5.4	5	20	Large
2	6	40	4	7	430	5.3	5	20	Very Large
3	1	24	0	7	1330	0	NA	NA	No Floc
3	2	24	1	7	950	1.7	30	60	Very Small
3	3	24	2	7	675	4.8	10	60	Medium
3	4	24	3	7	590	3.8	5	40	Medium
3	5	24	4	7	515	5.2	5	30	Large
3	6	24	5	7	505	4.8	5	20	Very Large
Wastewater		Temperature = 74° F, pH = 7.1, Alkalinity = 71 mg CaCO ₃ /L, Conductivity = 674 mohms,							
Sample I-9		Turbidity = 1565 NTU, TSS = 312 mg/L							

Notes:

Test #2 was conducted in triplicate. The turbidity results shown are averages. The average standard deviation of the turbidity results of all six jars in Test #2 is 10.6 NTU.

Table 12: Phase I - Coagulant/Polymer 8351 - Sample I-10

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Floc (sec)	Floc Size
1	1	X	30	7	1360	0.2	30	120 to 180	Many Very Sm
1	2	X	30	7.7	1350	0.4	30	120 to 180	Many Very Sm
1	3	X	30	8.33	1025	7	30	120 to 180	Many Very Sm
1	4	X	30	8.9	710	13.8	30	120 to 180	Many Very Sm
1	5	X	30	9.5	825	12.3	30	120 to 180	Many Very Sm
1	6	X	30	10.1	655	17.2	30	120 to 180	Many Very Sm
2	1	X	10	9	>900	0.1	30	120 to 180	Not Visible
2	2	X	20	9	>900	0.3	30	120 to 180	Not Visible
2	3	X	30	9	900	9.2	30	120 to 180	Very Small
2	4	X	40	9	515	22.5	20	120	Very Small
2	5	X	50	9	315	33	15	90	Very Small
2	6	X	60	9	225	38	15	90	Very Small
3	1	X	40	8.2	485	17.5	15	120	Very Small
3	2	X	40	8.4	490	21	15	120	Very Small
3	3	X	40	8.7	425	24	15	120	Very Small
3	4	X	40	8.9	425	22.8	15	120	Very Small
3	5	X	40	9.2	390	23.9	15	90	Very Small
3	6	X	40	9.5	405	23.7	15	90	Very Small
Wastewater		Temperature = 71° F, pH = 7, Alkalinity = 53 mg CaCO ₃ /L, Conductivity = 659 mohms,							
Sample I-10		Turbidity = 1390 NTU, TSS = 382 mg/L							

Notes:

The chemical being used is a coagulant/polymer mixture. It includes aluminum chlorhydrate and an anionic polymer. No ferric sulfate was used in these tests.

Table 13: Phase 1 - Polymer 5504 - Sample I-11

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Floc Size
1	1	X	5	7	330	9.2	15	15	Med & Stringy
1	2	X	5	7.4	380	9.6	15	15	Med & Stringy
1	3	X	5	8.2	460	8.5	15	30	Med & Stringy
1	4	X	5	8.8	475	8.4	20	30	Med & Stringy
1	5	X	5	9.5	490	8.3	20	30	Med & Stringy
1	6	X	5	10.2	640	5.3	20	45	Med & Stringy
2	1	X	2	7	780	1.8	10	30	Med & Stringy
2	2	X	3	7	710	4	10	30	Med & Stringy
2	3	X	4	7	605	4.5	5	30	Med & Stringy
2	4	X	4	7	545	5.5	10	30	Med & Stringy
2	5	X	4	7	565	5.5	5	30	Med & Stringy
2	6	X	5	7	515	5.5	10	30	Med & Stringy
Wastewater Sample I-11		Temperature = 75° F, pH = 2.7, Alkalinity = 0 mg CaCO ₃ /L, Conductivity = 1880 mohms, Turbidity = 1025 NTU, TSS = 354 mg/L							

Notes:

This was a test using the cationic polymer that performed best in the screening experiments when no coagulant was used. The performances of the cationic polymers were compared based on % removals in the jars using only polymer with no ferric sulfate.

Jar # 3, 4, and 5 in Test #2 were triplicates (Mean = 572 NTU and standard deviation = 30.6 NTU).

Table 14: Phase 1 - Polymer 607 - Sample I-12

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Floc (sec)	Floc Size
1	1	30	4	6.9	890	6	5	30	Med & Lg
1	2	30	4	7.5	790	5.4	10	30	Med & Lg
1	3	30	4	8.2	880	5.8	5	30	Med & Lg
1	4	30	4	8.8	830	5.2	5	30	Med & Lg
1	5	30	4	9.5	845	5	5	30	Med & Lg
1	6	30	4	10.2	910	5	5	30	Med & Lg
2	1	0	4	7.5	>870	0.3	5	NA	Not Visible
2	2	30	4	7.5	870	6.2	5	15	Medium
2	3	40	4	7.5	820	6.8	5	15	Med & Lg
2	4	50	4	7.5	810	6.2	5	15	Med & Lg
2	5	60	4	7.5	770	6.8	5	15	Med & Lg
2	6	70	4	7.5	790	7.1	5	15	Large
Wastewater Sample I-12		Temperature = 74° F, pH = 6.9, Alkalinity = 53 mg CaCO ₃ /L, Conductivity = 726 mohms, Turbidity = 1340 NTU, TSS = 456 mg/L							

Notes:

It became apparent that this polymer would not be selected based on its lack of performance at high dosage levels, so testing was stopped after Test #2.

Table 15: Phase I - Polymer 5530 - Sample I-13

Test #	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Turbidity (NTU)	Sludge Volume (cm ³)	Settling Time (min)	First Flocc (sec)	Floc Size
1	Control	0	0	6.6	1200	0	NA	NA	No Floc
1	2	30	4	6.6	970	2.8	5	35	Medium
1	3	30	4	7.5	845	3.8	5	30	Medium
1	4	30	4	8.5	820	3.4	5	30	Medium
1	5	30	4	9.4	790	3.4	5	30	Med & Lg
1	6	30	4	10.4	850	3.7	5	30	Large
2	1	30	4	9.4	810	3.4	5	25	Med & Lg
2	2	40	4	9.4	820	3.6	5	25	Med & Lg
2	3	50	4	9.4	790	4	5	25	Med & Lg
2	4	60	4	9.4	760	4.4	5	25	Med & Lg
2	5	70	4	9.4	725	4.3	5	25	Med & Lg
2	6	80	4	9.4	745	4.4	5	25	Med & Lg
3	1	70	2	9.4	927	1.9	20	35	Very Small
3	2	70	3	9.4	875	3.2	10	30	Small
3	3	70	4	9.4	802	4.3	5	25	Sm & Med
3	4	70	5	9.4	798	4.9	5	25	Medium
3	5	70	6	9.4	710	5.2	5	15	Large
3	6	70	7	9.4	723	5.4	5	15	Very Large
Wastewater Sample I-13		Temperature = 73° F, pH = 6.6, Alkalinity = 47 mg CaCO ₃ /L, Conductivity = 747 mohms, Turbidity = 1220 NTU, TSS = 332 mg/L							

Notes:

The third test was done in triplicate. The turbidity results shown are the averages. The average standard deviation of the turbidity results in all six jars in Test #3 is 8.6 NTU.

A control was not run in Phase I until this test, but this one and the others following it demonstrate that control results are only slightly different from the raw wastewater samples with the wastewater at VCT.

Tables 16 - 18: Summary of Results from Phase I Polymer Screening Analysis

TABLE 16

Treatment Chemical	Initial Turb (NTU)	Post-Turb (NTU)	% Removal	Coag Dose (ppm)	Cost/Day (\$)	Poly Dose (ppm)	Cost/Day (\$)	pH	Cost/Day (\$)	Total Cost/Day (\$/800K gal)	Sludge Vol. (ml)	Settling Time (min)	First Flocc (sec)
Fe ³⁺ /An-9760	1080	540	50%	70	\$57.56	3.9	\$48.86	8	\$224.62	\$331.04	5	5	30
Fe ³⁺ /An-5114	1560	550	65%	60	\$49.34	2	\$33.91	7	\$153.51	\$236.75	13.2	5	30
Fe ³⁺ /An-594	1565	540	65%	24	\$19.73	4	\$105.40	7	\$81.27	\$206.41	4.3	5	20
Fe ³⁺ /An-5530	1200	710	41%	70	\$57.56	6	\$91.92	9.4	\$349.80	\$499.38	5.2	5	15
Fe ³⁺ /An-607	1340	770	43%	60	\$49.34	4	\$93.96	7.4	\$182.29	\$325.59	6.8	5	15
Fe ³⁺ /Ca-5149	1140	525	54%	40	\$32.89	4	\$120.52	7	\$113.44	\$266.85	10.2	30	120
Fe ³⁺ /Ca-5900	1030	558	46%	20	\$16.45	4	\$80.07	7	\$74.50	\$171.02	4.9	15	180
Fe ³⁺ /Ca-5118	1900	595	68%	40	\$32.89	4	\$114.39	7	\$113.44	\$260.72	14	10	60
Fe ³⁺ /Ca-5502	1270	518	59%	10	\$9.22	4	\$122.97	7	\$53.05	\$184.24	4.7	10	30
Fe ³⁺ /Ca-5505	1470	595	68%	60	\$49.34	4	\$91.92	9.5	\$354.42	\$495.68	12.4	10	120
Fe ³⁺ /Ca-5504	1360	530	61%	6	\$4.93	4	\$119.29	7	\$48.84	\$171.07	4.8	5	30
Ca-5504 only	1025	572	44%	X	\$0.00	4	\$119.29	7	\$39.51	\$158.80	5.2	5	15
AlCl ₃ /An-8351	1390	485	65%	X	\$0.00	40	\$454.04	8.2	\$102.71	\$556.75	17.5	15	90

TABLE 18

Polymer	Rem.	Cost	Sludge	Settling	Floc	Score
5114	4	2	3	1	1	1.75
5530	4	2	1	1	1	2
607	4	4	2	1	1	2
5149	3	3	3	4	4	3.5
5900	4	1	1	3	4	2.25
5118	1	3	3	2	2	2.5
5502	2	1	1	2	1	1.25
5505	2	4	3	2	4	3.25
5504	4	1	1	1	1	1.25
8351	1	4	4	3	3	3.5

TABLE 17

% Turb. Removal (NTU)	62-69	55-61	48-54	41-47
Score	1	2	3	4
Total Cost / Day (\$)	150-199	200-249	250-299	300+
Score	1	2	3	4
Sludge Volume (ml/L)	0-4.9	5-9.9	10-14.9	15+
Score	1	2	3	4
Settling Time (min)	5	10	15	20+
Score	1	2	3	4
First Flocc (sec)	0-30	31-60	61-90	91+
Score	1	2	3	4

Notes:

- 1) TSS concentration was not measured on the treated wastewater during screening.
- 2) The treatment criteria was 550 NTU turbidity, which corresponds to 200 mg/L of TSS from Figure 2.
- 3) % Turbidity Removal was not included in final ranking score.
The % Turbidity Removal was therefore too heavily dependent on initial turbidity, while the final turbidities of each polymer were all nearly the same.
- 4) Costs of the optimum conditions are full-scale daily costs that were converted from bench-scale amounts.
- 5) pH costs for each polymer were found using results of titrating optimum ferric sulfate dosages to optimum pH levels on the same sample.
- 6) Polymer 9760 was chosen as one of the final three because it was used at VCT.

Table 19: Transitional Matrix 1 Results - Sample M-1

Polymer	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)
9760	15	4	6	275	2008
9760	30	3	6	386	2115
9760	45	4	6	406	2077
9760	75	2	6	511	2265
9760	90	4	6	488	2168
9760	30	3	7	311	2199
9760	45	3	7	331	2116
9760	60	2	7	436	2263
9760	90	3	7	443	2166
9760	45	4	8	370	2181
9760	60	4	8	325	2015
9760	90	3	8	438	2195
594	15	4	6	445	1678
594	30	3	6	395	1734
594	45	4	6	435	1556
594	75	2	6	440	1877
594	90	4	6	396	1689
594	30	3	7	363	1844
594	45	3	7	371	1766
594	60	2	7	419	2027
594	90	3	7	455	1863
594	45	4	8	381	1954
594	60	4	8	430	1767
594	90	3	8	449	1836
5504	15	4	6	481	1722
5504	30	3	6	458	1744
5504	45	4	6	436	1447
5504	75	2	6	529	2050
5504	90	4	6	465	1482
5504	30	3	7	421	2012
5504	45	3	7	456	1963
5504	60	2	7	498	2161
5504	90	3	7	509	1973
5504	45	4	8	560	2319
5504	60	4	8	513	2017
5504	90	3	8	546	2060

Wastewater Sample M-1	Temperature = 75° F, pH = 7, Alkalinity = 31.5 mg CaCO ₃ /L, Conductivity = 675 mohms, Turbidity = 2500 FAU, TSS = 380 mg/L
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Test Matrix

Ferric Sulfate (mg/L) 15, 30, 45, 60, 75 and 90

Polymer (mg/L) 2, 3, and 4

pH 6, 7, and 8

The 12 tests run for each polymer are a random selection from this matrix.

Table 20: Transitional Matrix 2 Results - Sample M-2

Polymer	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)
9760	20	5	7	185	1315
9760	40	5	7	225	1336
9760	40	6	7	208	1268
9760	60	3	7	313	1466
9760	80	5	7	300	1397
9760	20	4	8	184	1334
9760	60	2	8	270	1436
9760	80	4	8	288	1360
9760	100	4	8	323	1370
9760	20	2	9	234	1389
9760	60	5	9	215	1244
9760	80	3	9	293	1400
594	20	5	7	291	1107
594	40	5	7	291	1091
594	40	6	7	329	997
594	60	3	7	336	1238
594	80	5	7	374	1126
594	20	4	8	285	1150
594	60	2	8	315	1291
594	80	4	8	385	1141
594	100	4	8	395	1407
594	20	2	9	329	1282
594	60	5	9	359	1018
594	80	3	9	383	1180
5504	20	5	7	299	1151
5504	40	5	7	316	1111
5504	40	6	7	333	984
5504	60	3	7	324	1258
5504	80	5	7	390	1166
5504	20	4	8	249	1256
5504	60	2	8	304	1392
5504	80	4	8	349	1265
5504	100	4	8	366	1244
5504	20	2	9	278	1381
5504	60	5	9	270	1147
5504	80	3	9	309	1291

Wastewater Sample M-2	Temperature = 78° F, pH = 6.9, Alkalinity = 28 mg CaCO ₃ /L, Conductivity = 652 mohms, Turbidity = 1578 FAU, TSS = 248 mg/L
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Test Matrix

Ferric Sulfate (mg/L) 20, 40, 60, 80 and 100

Polymer (mg/L) 2, 3, 4, 5, and 6

pH 7, 8 and 9

The 12 tests run for each polymer are a random selection from this matrix.

Table 22: Phase II - Test 2 - Sample II-2

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Settling Time (min)	Floc Size	% TSS Removal
1	50	X	6	471	1621	0	NA	Very Small	-48%
2	50	X	7	471	1536	0.2	20	Very Small	-48%
3	50	X	8	451	1608	0	NA	Very Small	-41%
4	100	X	6	206	640	16.5	30	Very Small	35%
5	100	X	7	226	786	15.5	25	Very Small	29%
6	100	X	8	434	1426	1.0	25	Very Small	-36%
7	150	X	6	208	616	22.0	15	Very Small	35%
8	150	X	7	168	512	26.0	15	Very Small	47%
9	200*	X	6	81	204	41.0	13	Very Small	75%
10	200	X	6	89	238	38.0	17	Very Small	72%
11	200	X	7	80	215	41.0	13	Very Small	75%
12	200	X	8	78	197	44.0	12	Very Small	76%
Control	X	X	7	319	1617	0	NA	NA	NA
Wastewater		Temperature = 80° F, pH = 6.8, Alkalinity = 34 mg CaCO ₃ /L, Conductivity = 790 mohms,							
Sample II-2		Turbidity = 2832 FAU, TSS = 724 mg/L							

Notes:

* Jar #9 had 200 mg/L of ferric sulfate added on accident. This overdosing gave the test a pH of 6.

Jars #1-3, & 6 showed characteristics, similar to the matrices tested prior to this phase, of TSS concentration rising with an inadequate amount of ferric sulfate added.

Table 23: Phase II - Test 3 - Sample II-3

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Settling Time (min)	Floc Size	% TSS Removal
1	50	X	6	508	1797	0	NA	*Not Visible	-41%
2	50	X	7	503	1768	0.1	30	*Not Visible	-39%
3	50	X	8	483	1749	0	NA	*Not Visible	-34%
4	100	X	6	329	1119	5.7	20	*Not Visible	9%
5	100	X	7	408	1455	0.4	30	*Not Visible	-13%
6	100	X	8	289	1080	8.0	20	*Not Visible	20%
7	150	X	6	311	1112	8.0	30	Very Small	14%
8	150	X	7	264	950	12.6	20	Very Small	27%
9	150	X	8	266	1044	12.3	20	Very Small	26%
10	200	X	6	208	674	19.5	5	Very Small	42%
11	200	X	7	164	577	22.3	5	Very Small	55%
12	200	X	8	131	487	25.0	5	Very Small	64%
Control	X	X	7.6	361	1775	0	NA	NA	NA
Wastewater				Temperature = 77° F, pH = 7.6, Alkalinity = 31 mg CaCO ₃ /L, Conductivity = 723 mohms,					
Sample II-3				Turbidity = 1805 FAU, TSS = 366 mg/L					

Notes:

* Floc not visible during the mixing stages, but only during settling.

Jars #1-3, & 5 showed characteristics similar to the matrices tested prior to this phase, where the TSS concentration increased when an inadequate amount of ferric sulfate was added.

Table 24: Phase II - Test 4 - Sample II-4

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Settling Time (min)	Floc Size	% TSS Removal	Replicate TSS Average
1	50	X	6	*Would have needed acid	*Would have needed acid	8.5	NA	NA	NA	
2	50	X	7				NA	NA	NA	
3	50	X	8	236	1289		20	Very Small	39%	
4	100	X	6	226	1026	13.0	20	Very Small	41%	
5	100	X	7	253	1147	12.0	20	Very Small	34%	
5B	100	X	7	203	966	14.0	10	Very Small	47%	
5C	100	X	7	231	1011	12.5	10	Very Small	40%	229
6	100	X	8	229	1071	13.4	20	Very Small	41%	
7	150	X	6	171	800	18.0	5	Very Small	56%	
8	150	X	7	204	930	16.0	10	Very Small	47%	
8B	150	X	7	163	787	20.0	10	Very Small	58%	
8C	150	X	7	194	907	17.5	10	Very Small	50%	187
9	150	X	8	219	985	14.5	10	Very Small	43%	
9B	150	X	8	203	956	16.0	10	Very Small	47%	
9C	150	X	8	166	776	20.0	10	Very Small	57%	196
10	200	X	6	209	847	19.0	10	Very Small	46%	
11	200	X	7	228	927	19.0	10	Very Small	41%	
12	200	X	8	193	840	22.0	10	Very Small	50%	
Control	X	X	9.4	386	2063	0	NA	NA	NA	
Wastewater Sample II-4 Temperature = 77° F, pH = 9.4, Alkalinity = 50 mg CaCO ₃ /L, Conductivity = 808 mohms, Turbidity = 2123 FAU, TSS = 401 mg/L										

Notes:

* Jars 1 and 2 would have needed acid to reach the desired pH. Test were omitted because WWPTP does not have acid injection capability.

Table 25: Phase II - Test 5 - Sample II-5

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Settling Time (min)	Floc Size	% TSS Removal
1	50	X	6	436	1965	0	NA	NA	-29%
2	50	X	7	426	1962	0	NA	NA	-26%
3	50	X	8	406	1930	0	NA	NA	-20%
4	100	X	6	478	1939	0	NA	NA	-41%
5	100	X	7	466	1980	0	NA	NA	-37%
6	100	X	8	461	1960	0	NA	NA	-36%
7	150	X	6	534	1948	0	NA	NA	-58%
8	150	X	7	541	1951	0	NA	NA	-60%
9	150	X	8	525	1954	0.1	30	*Not Visible	-55%
10	200	X	6	513	1707	1.7	30	*Not Visible	-51%
11	200	X	7	405	1478	4.5	30	*Not Visible	-19%
12	200	X	8	244	958	13.3	30	*Not Visible	28%
Control	X	X	7	339	1925	0	NA	NA	NA
Wastewater				Temperature = 81° F, pH = 7.3, Alkalinity = 28 mg CaCO ₃ /L, Conductivity = 695 mohms,					
Sample II-5				Turbidity = 1943 FAU, TSS = 339 mg/L					

Notes:

* Floc not visible during the mixing stages, but only during settling.

Jars #1-11 showed characteristics, similar to the matrices tested prior to this phase, of TSS concentration rising with an inadequate amount of ferric sulfate added.

This test was not included in the optimization analysis because the sample was taken following a "size" dump.

Table 26: Phase III - Test 1 - Sample III-1

Polymer Name	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Settling Time (min)	Floc Size	% TSS Removal
9760	1	100	2	8	390	1581	2.0	30	Small	-29%
9760	2	100	4	8	315	1280	4.0	30	Medium	-4%
9760	3	100	6	8	246	1092	6.0	30	Large	19%
9760	4	150	2	8	248	1023	9.0	20	Small	18%
9760	5	150	4	8	178	797	13.0	10	Small	41%
9760	6	150	6	8	205	861	10.0	20	Medium	32%
594	7	100	2	8	391	1338	3.0	30	Medium	-29%
594	8	100	4	8	281	875	5.5	30	Med & Lg	7%
594	9	100	6	8	135	477	8.5	5	Very Large	55%
594	10	150	2	8	283	953	8.0	20	Medium	7%
594	11	150	4	8	205	630	10.0	30	Very Large	32%
594	12	150	6	8	146	388	12.0	20	Very Large	52%
5504	13	100	2	8	414	1532	2.3	30	Small	-37%
5504	14	100	4	8	304	954	8.5	30	Large	0%
5504	15	100	6	8	144	419	15.0	10	Large	52%
5504	16	150	2	8	258	883	10.0	20	Small	15%
5504	17	150	4	8	241	708	12.0	20	Medium	20%
5504	18	150	6	8	153	417	14.0	10	Large	50%
X	Control	X	X	7	303	1742	0	NA	NA	NA

Temperature = 82° F, pH = 7, Alkalinity = 28 mg CaCO₃/L, Conductivity = 677 mohms, Turbidity = 1735 FAU, TSS = 319 mg/L

Wastewater Sample III-1

Table 28: Phase III - Test 3 - Sample III-3

Polymer Name	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Settling Time (min)	Floc Size	% TSS Removal
9760	1	100	2	8	116	645	17.0	5	Very Small	71%
9760	2	100	4	8	123	632	13.5	5	Small	69%
9760	3	100	6	8	100	540	12.5	5	Sm & Med	75%
9760	4	150	2	8	130	654	20.5	5	Very Small	68%
9760	5	150	4	8	106	536	20.0	5	Very Small	74%
9760	6	150	6	8	115	560	17.0	5	Small	71%
594	7	100	2	8	114	417	12.5	5	Medium	72%
594	8	100	4	8	114	366	10.7	5	Large	72%
594	9	100	6	8	128	376	11.0	5	Very Large	68%
594	10	150	2	8	106	387	14.5	5	Medium	74%
594	11	150	4	8	94	297	12.5	5	Large	77%
594	12	150	6	8	90	245	10.0	5	Very Large	78%
5504	13	100	2	8	146	485	15.0	5	Small	64%
5504	14	100	4	8	131	360	12.0	5	Medium	67%
5504	15	100	6	8	153	408	14.0	5	Large	62%
5504	16	150	2	8	154	465	18.0	5	Small	62%
5504	17	150	4	8	110	287	15.5	5	Medium	73%
5504	18	150	6	8	100	223	17.0	5	Large	75%
X	Control	X	X	7.2	400	1938	0	NA	NA	NA
Wastewater Sample III-3										
Temperature = 79° F, pH = 7.2, Alkalinity = 32 mg CaCO ₃ /L, Conductivity = 843 mohms, Turbidity = 2000 FAU, TSS = 490 mg/L										

Table 29: Phase IV - Test 1 - Sample IV-1

Polymer Name	Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	TSS (mg/L)	Turbidity (FAU)	Sludge Volume (cm ³)	Floc Size	% TSS Removal
9760	1	150	4	7	113	508	13	Small	54%
9760	2	150	4	8	138	624	12	Small	43%
9760	3	150	6	7	115	512	11	Sm & Med	53%
9760	4	150	6	8	140	574	11	Medium	43%
9760	5	200	4	7	98	377	17	Small	60%
9760	6	200	4	8	100	419	19	Very Small	59%
9760	7	200	6	7	96	362	17	Sm & Med	61%
9760	8	200	6	8	95	361	17	Small	61%
594	1	150	4	7	105	289	10	Large	57%
594	2	150	4	8	83	228	11	Large	66%
594	3	150	6	7	139	390	9	Very Large	43%
594	4	150	6	8	79	198	11	Very Large	68%
594	5	200	4	7	134	358	12	Very Large	45%
594	6	200	4	8	65	147	13	Large	73%
594	7	200	6	7	132	308	12	Very Large	46%
594	8	200	6	8	62	127	11	Very Large	75%
X	Control	X	X	6.8	244	1620	0	NA	NA

Temperature = 82° F, pH = 6.8, Alkalinity = 34 mg CaCO₃/L, Conductivity = 712 mohms,
Turbidity = 1627 FAU, TSS = 248 mg/L

Table 31: Phase IV - Test 3 - Sample IV-3

[illegible]

Table 34: Phase IV Polymer BPL 594 Treatment Groupings

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Final TSS (mg/L)	% TSS Removal
1	150	4	7	105	57%
1	150	4	7	214	41%
1	150	4	7	234	17%
1	150	4	7	141	51%
1	150	4	7	116	60%
Every TSS < 200 mg/L? No					Mean TSS Removal
					45%
2	150	4	8	83	66%
2	150	4	8	165	54%
2	150	4	8	330	-17%
2	150	4	8	95	67%
2	150	4	8	133	54%
Every TSS < 200 mg/L? No					Mean TSS Removal
					45%
3	150	6	7	139	43%
3	150	6	7	191	47%
3	150	6	7	151	46%
3	150	6	7	127	56%
3	150	6	7	79	73%
Every TSS < 200 mg/L? Yes					Mean TSS Removal
					53%
4	150	6	8	79	68%
4	150	6	8	179	51%
4	150	6	8	185	34%
4	150	6	8	122	58%
4	150	6	8	77	74%
Every TSS < 200 mg/L? Yes					Mean TSS Removal
					57%
Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Final TSS (mg/L)	% TSS Removal
5	200	4	7	134	45%
5	200	4	7	144	60%
5	200	4	7	114	59%
5	200	4	7	119	59%
5	200	4	7	87	70%
Every TSS < 200 mg/L? Yes					Mean TSS Removal
					59%
6	200	4	8	65	73%
6	200	4	8	109	70%
6	200	4	8	140	50%
6	200	4	8	92	68%
6	200	4	8	77	74%
Every TSS < 200 mg/L? Yes					Mean TSS Removal
					67%
7	200	6	7	132	46%
7	200	6	7	125	65%
7	200	6	7	102	64%
7	200	6	7	113	61%
7	200	6	7	82	72%
Every TSS < 200 mg/L? Yes					Mean TSS Removal
					62%
8	200	6	8	62	75%
8	200	6	8	114	69%
8	200	6	8	59	79%
8	200	6	8	115	60%
8	200	6	8	62	79%
Every TSS < 200 mg/L? Yes					Mean TSS Removal
					72%

Table 35: Phase IV Polymer CA 9760 Treatment Groupings

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Final TSS (mg/L)	% TSS Removal
1	150	4	7	113	54%
1	150	4	7	155	57%
1	150	4	7	269	4%
1	150	4	7	100	65%
1	150	4	7	186	36%
Every TSS < 200 mg/L? No					Mean TSS Removal 43%
2	150	4	8	138	43%
2	150	4	8	143	60%
2	150	4	8	361	-28%
2	150	4	8	113	61%
2	150	4	8	213	27%
Every TSS < 200 mg/L? No					Mean TSS Removal 33%
3	150	6	7	115	53%
3	150	6	7	141	61%
3	150	6	7	233	17%
3	150	6	7	89	69%
3	150	6	7	177	39%
Every TSS < 200 mg/L? No					Mean TSS Removal 48%
4	150	6	8	140	43%
4	150	6	8	153	58%
4	150	6	8	269	4%
4	150	6	8	122	58%
4	150	6	8	203	30%
Every TSS < 200 mg/L? No					Mean TSS Removal 39%

Jar #	Fe ₂ (SO ₄) ₃ (mg/L)	Polymer (mg/L)	pH	Final TSS (mg/L)	% TSS Removal
5	200	4	7	98	60%
5	200	4	7	107	70%
5	200	4	7	127	55%
5	200	4	7	77	73%
5	200	4	7	114	61%
Every TSS < 200 mg/L? Yes					Mean TSS Removal 64%
6	200	4	8	100	59%
6	200	4	8	83	77%
6	200	4	8	152	46%
6	200	4	8	68	76%
6	200	4	8	110	62%
Every TSS < 200 mg/L? Yes					Mean TSS Removal 64%
7	200	6	7	96	61%
7	200	6	7	87	76%
7	200	6	7	96	66%
7	200	6	7	63	78%
7	200	6	7	99	66%
Every TSS < 200 mg/L? Yes					Mean TSS Removal 69%
8	200	6	8	95	61%
8	200	6	8	67	81%
8	200	6	8	122	57%
8	200	6	8	75	74%
8	200	6	8	119	59%
Every TSS < 200 mg/L? Yes					Mean TSS Removal 66%

Figure 1: Project Phases

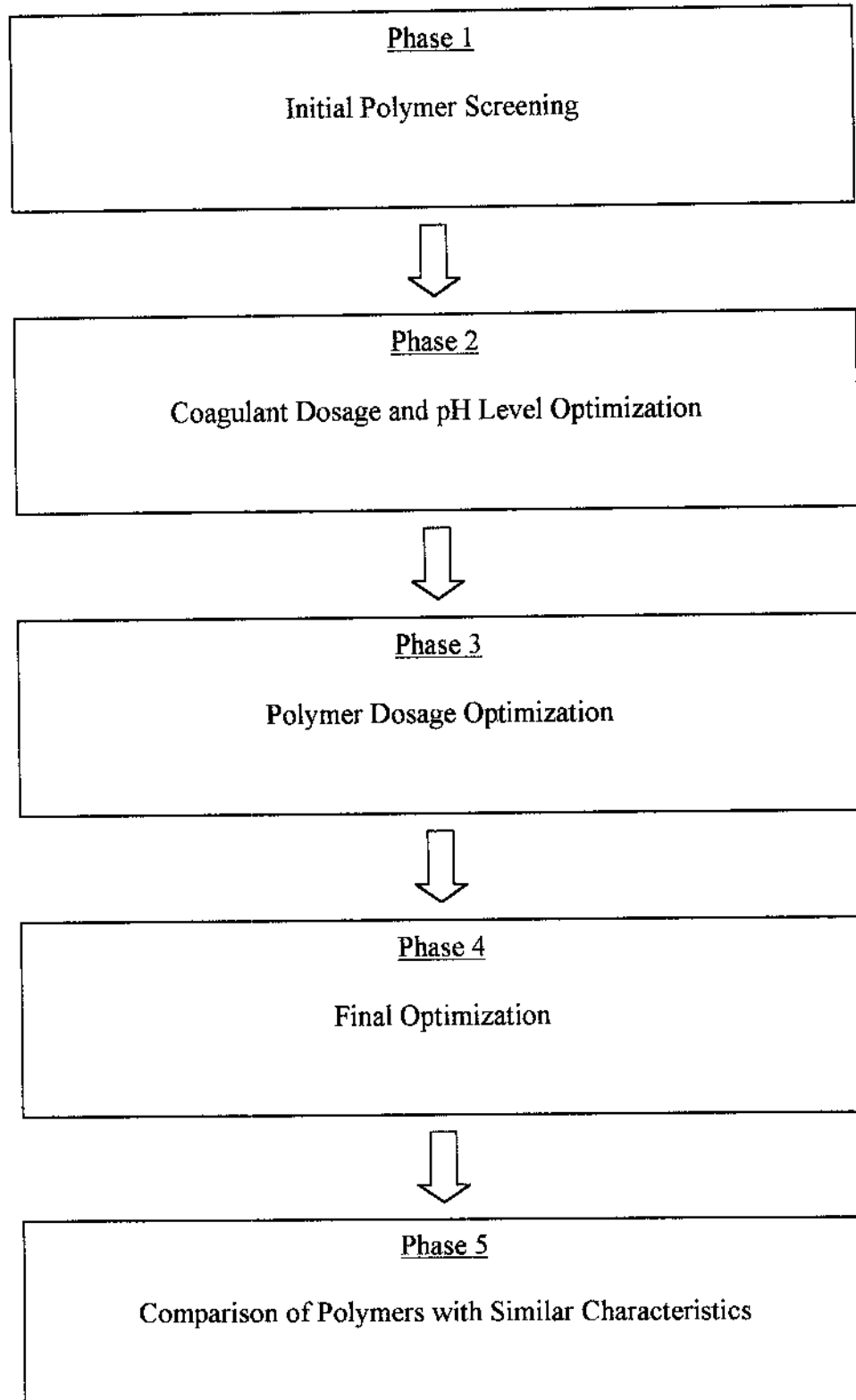


Figure 2: VCT Wastewater Pretreatment Plant Operations Flowchart

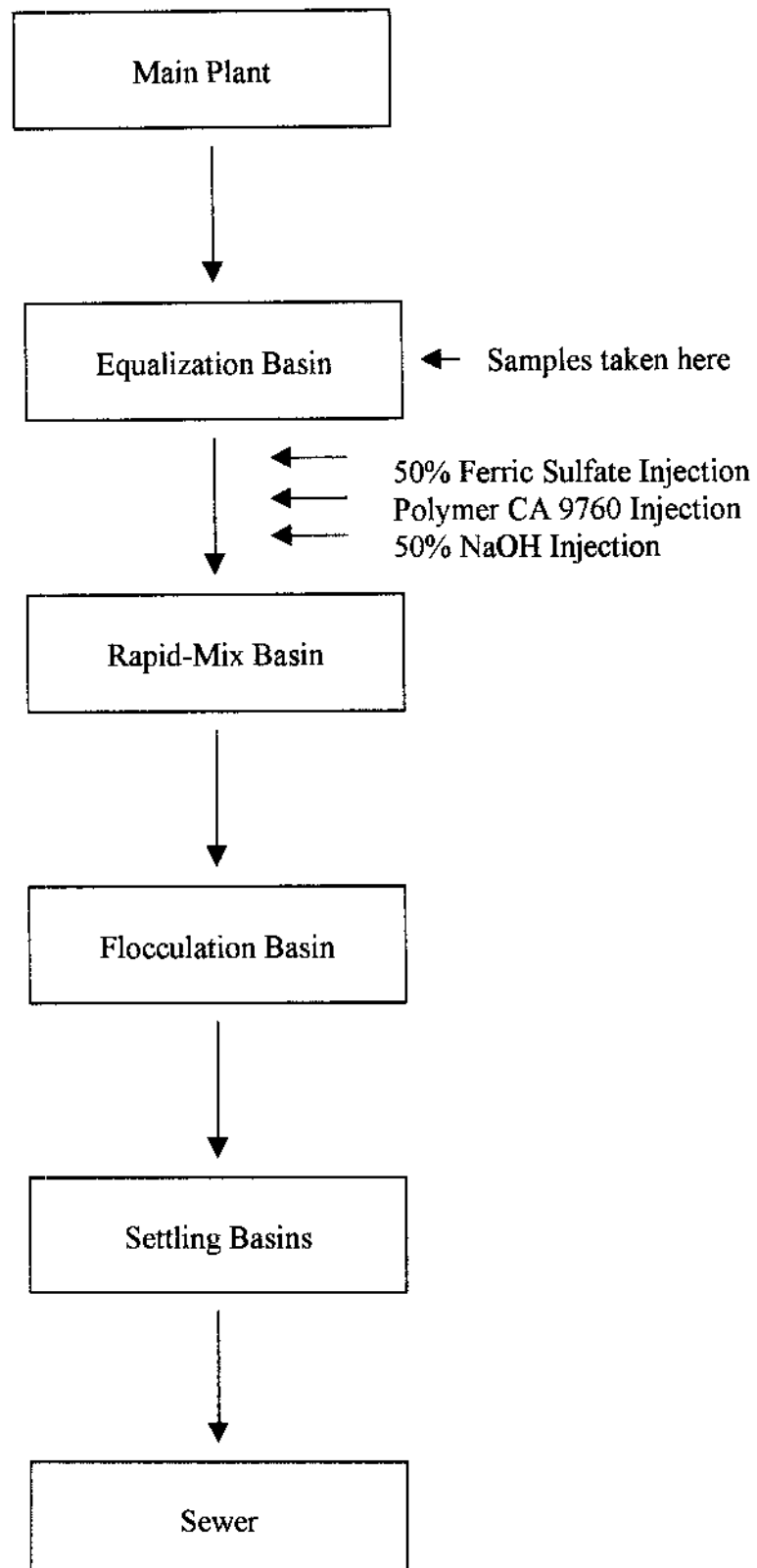


Figure 3: Wastewater Turbidity vs. TSS (Dilutions of Untreated Wastewater)

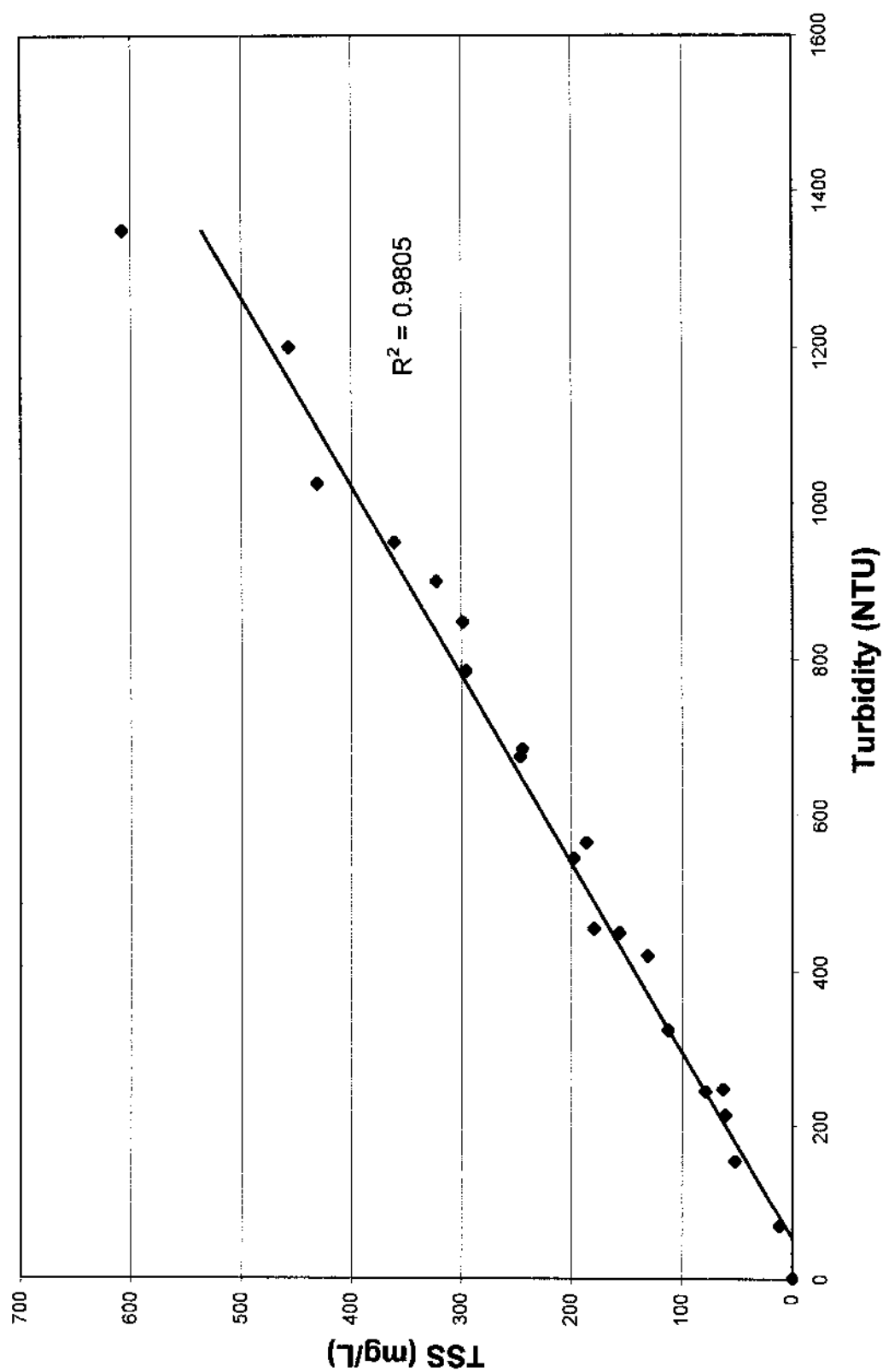


Figure 4: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Transitional Matrix Testing Phase - Matrix 1 - Polymer CA 9760

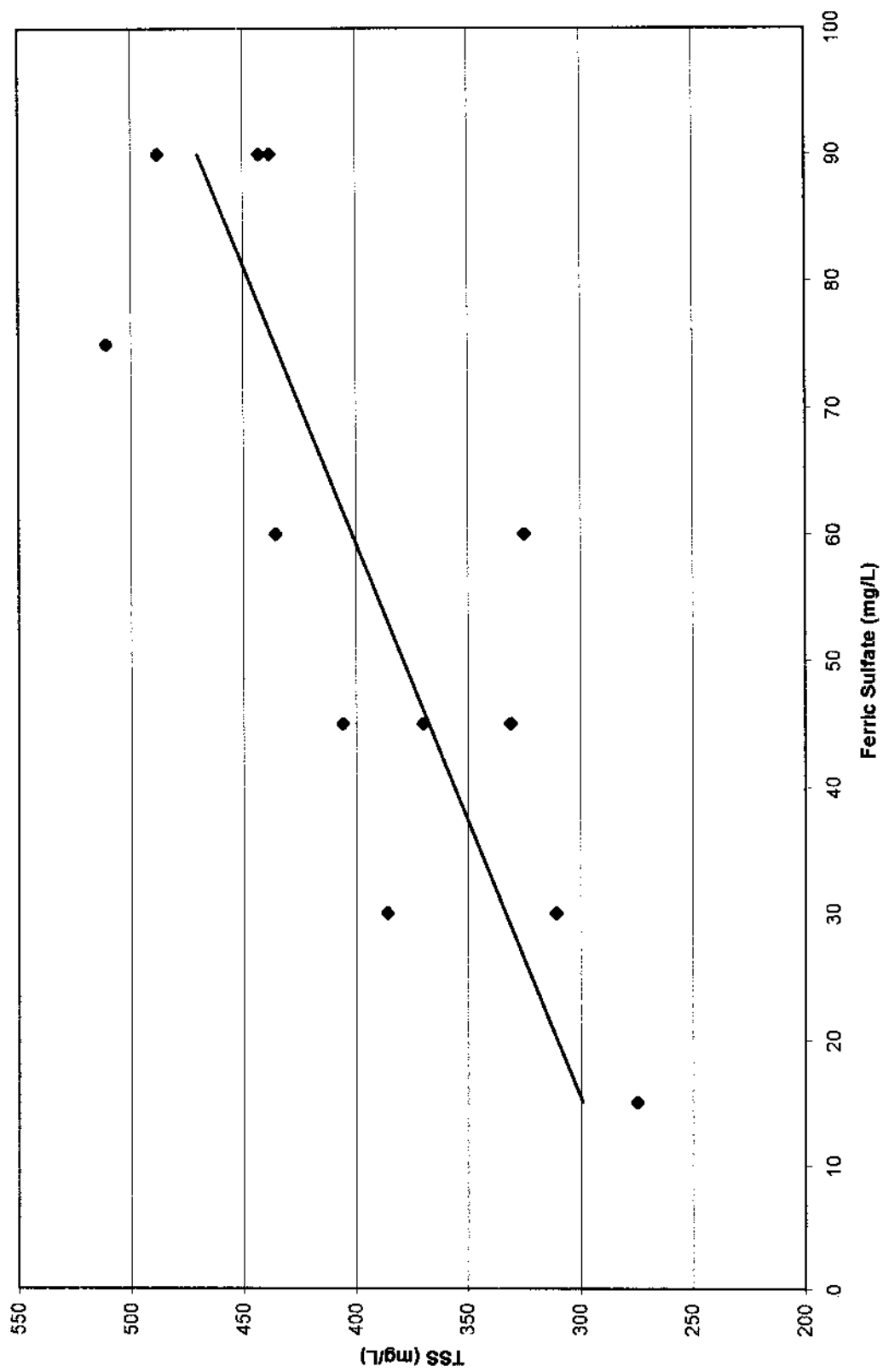


Figure 5: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Transitional Matrix Testing Phase - Matrix 1 - Polymer BPL 594

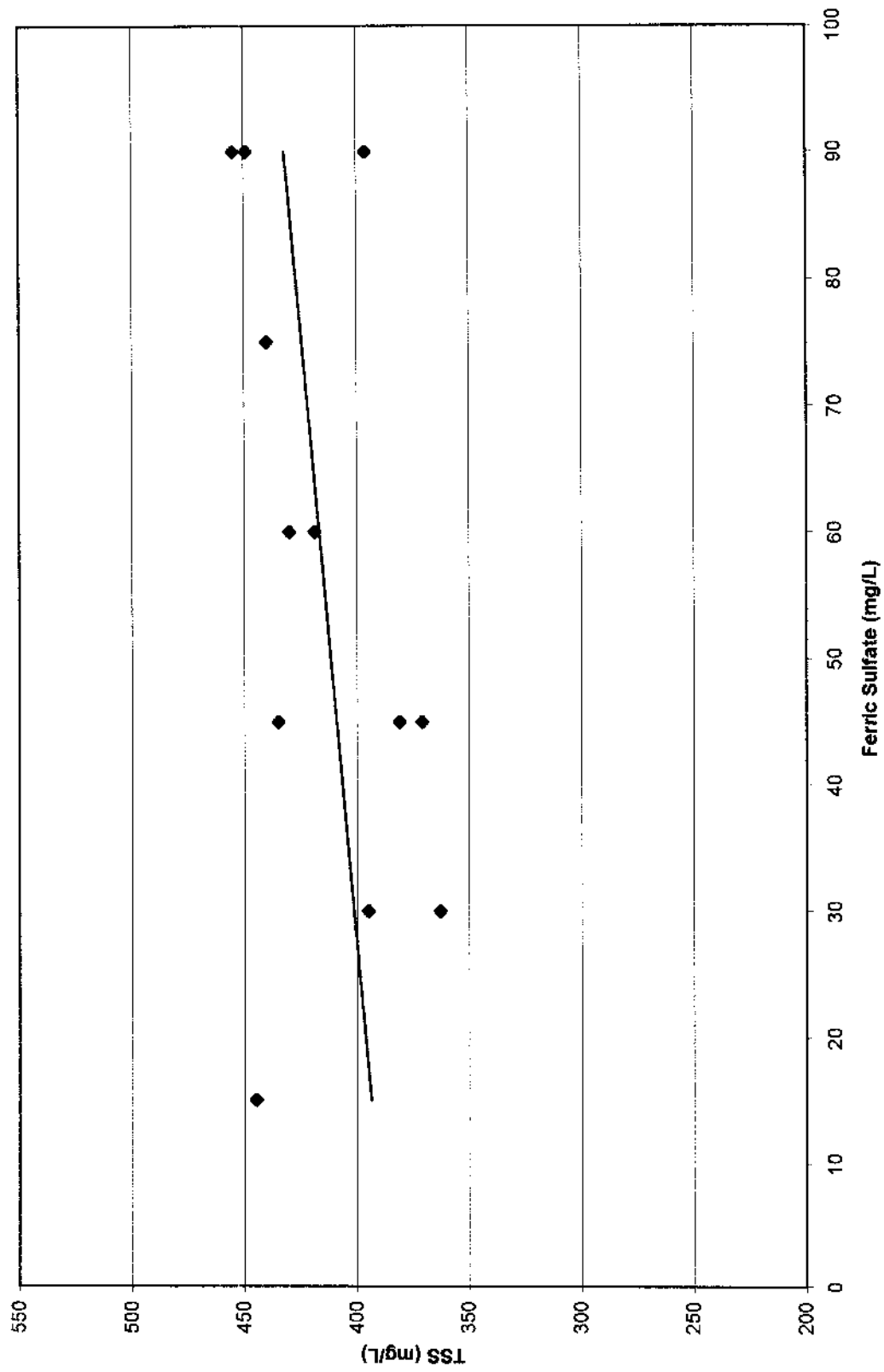


Figure 6: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Transitional Matrix Testing Phase - Matrix 1 - Polymer BPL 5504

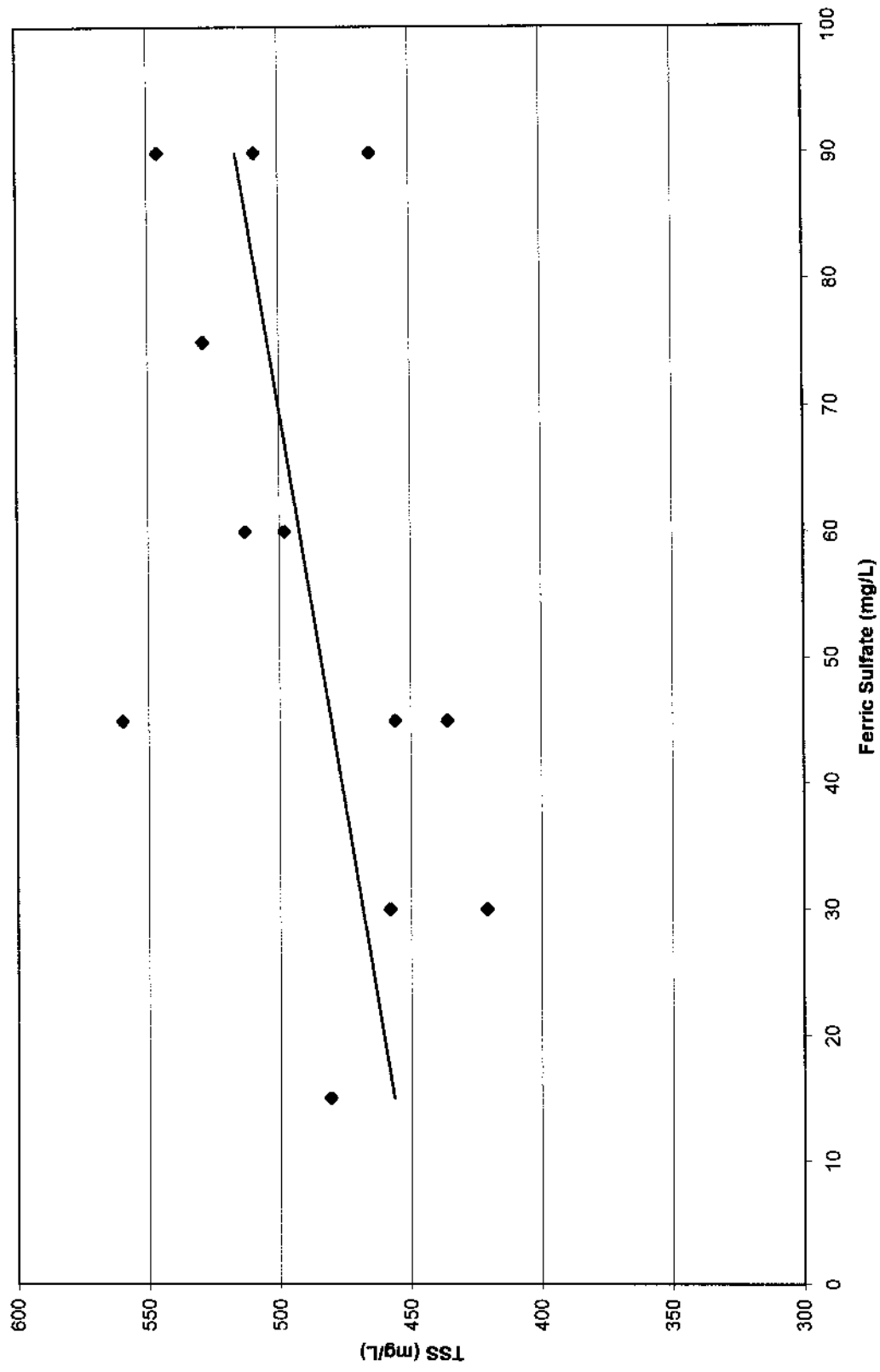


Figure 7: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Transitional Matrix Testing Phase - Matrix 2 - Polymer CA 9760

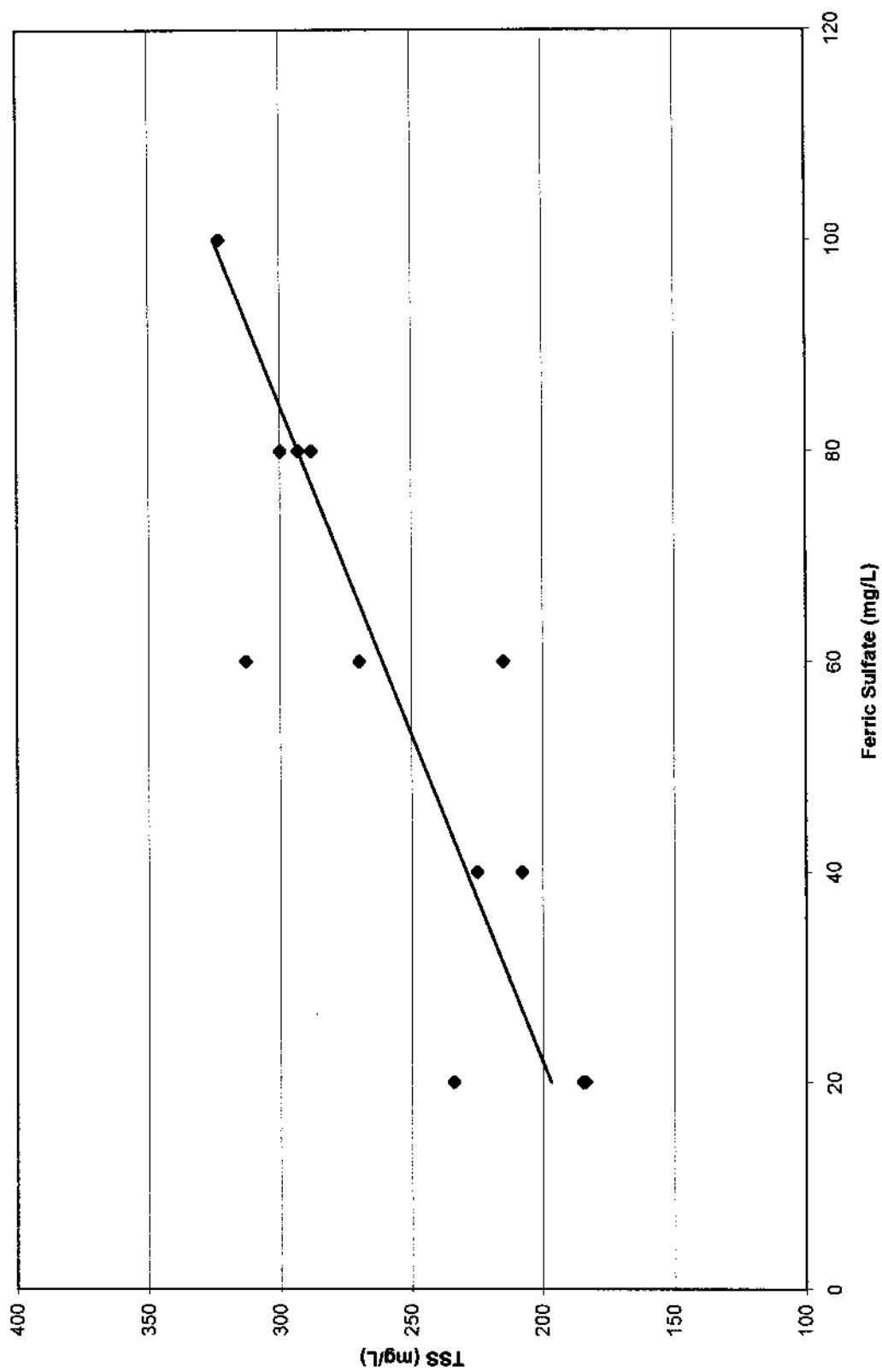


Figure 8: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Transitional Matrix Testing Phase - Matrix 2 - Polymer BPL 594

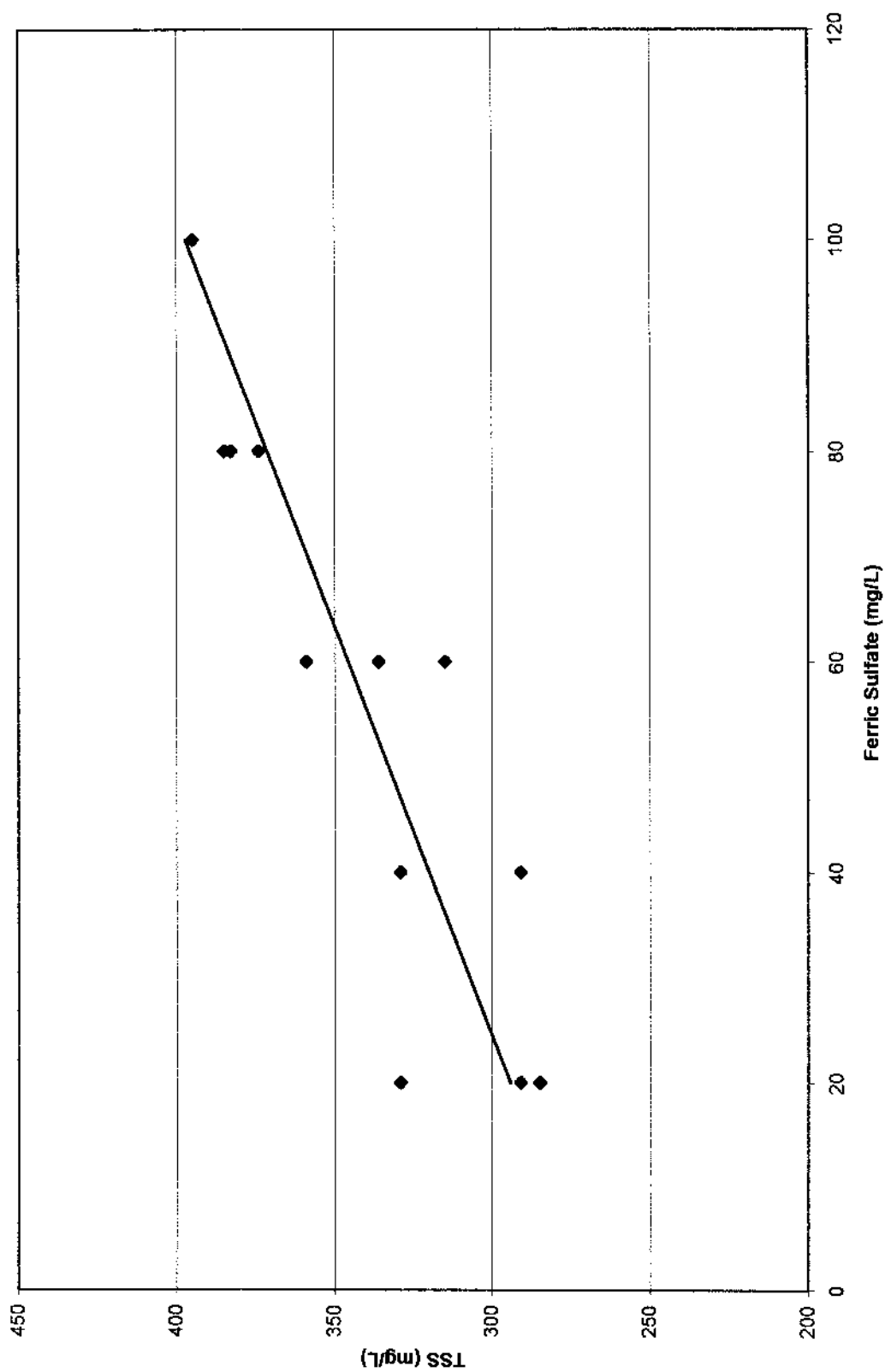


Figure 9: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Transitional Matrix Testing Phase - Matrix 2 - Polymer BPL 5504

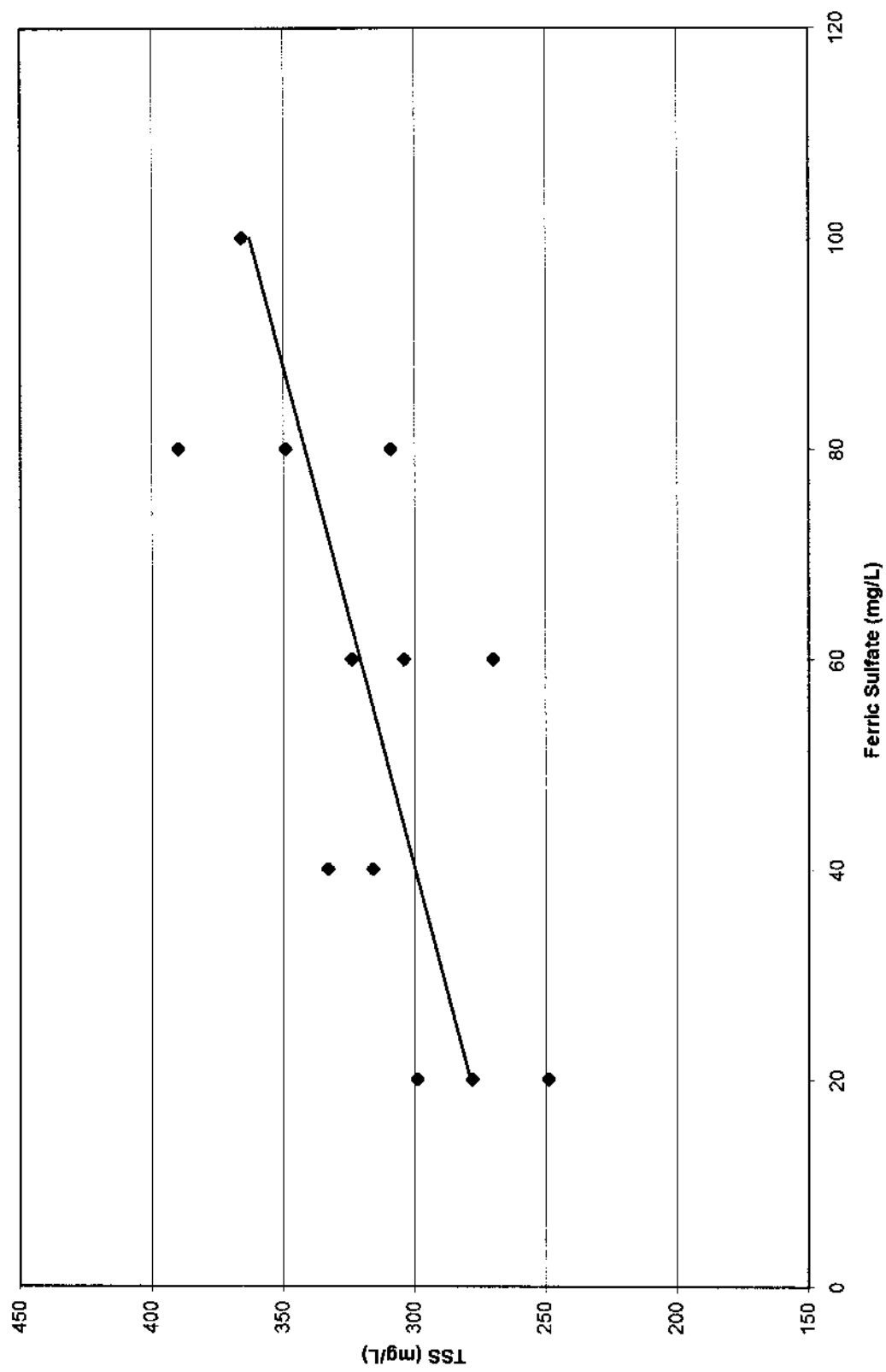


Figure 10: Treated Wastewater Turbidity vs. TSS - Transitional Matrix Testing Phase - Matrices 1 and 2 - Polymer CA 9760

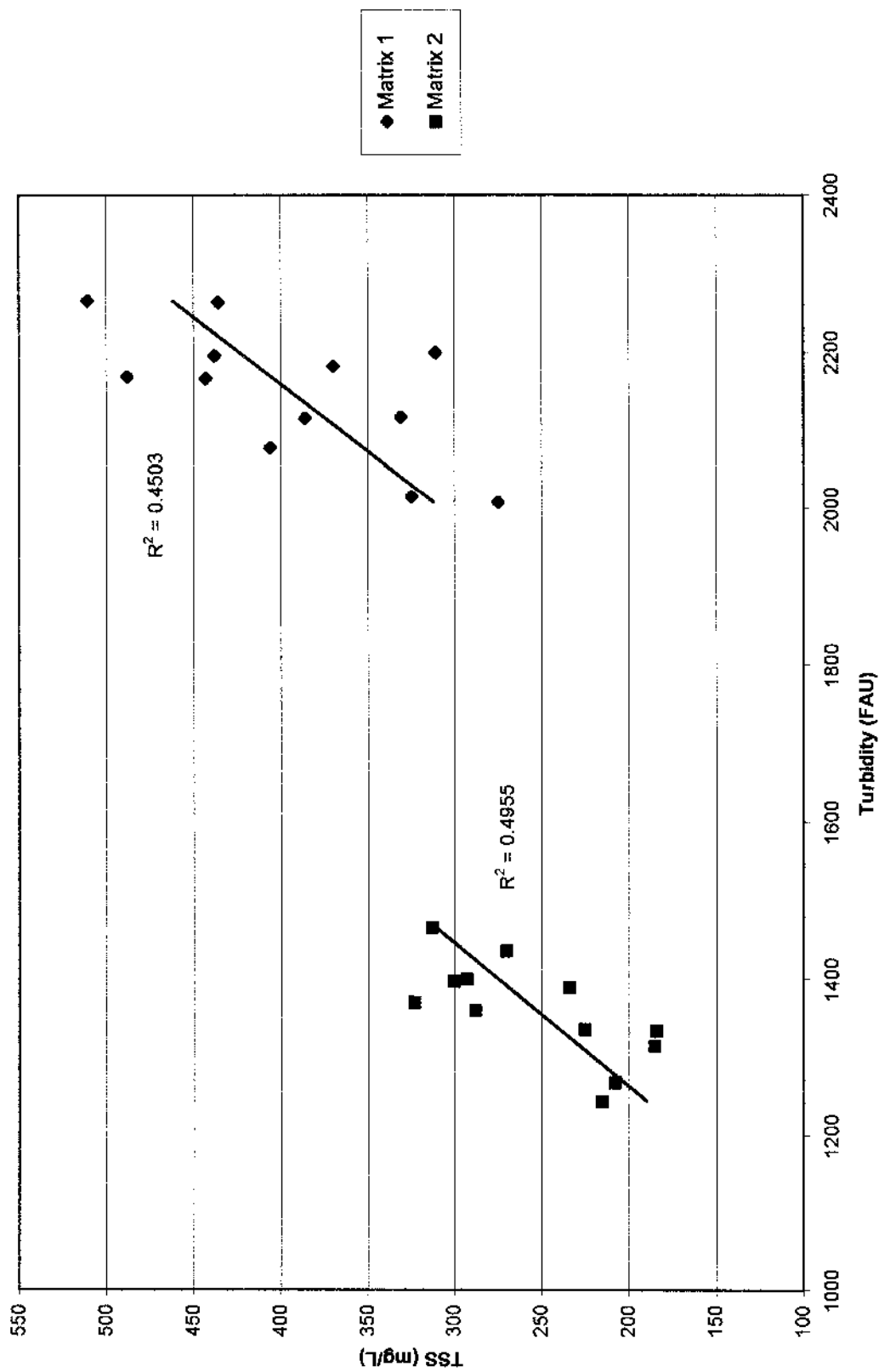


Figure 11: Treated Wastewater Turbidity vs. TSS - Transitional Matrix Testing Phase - Matrices 1 and 2 - Polymer BPL 594

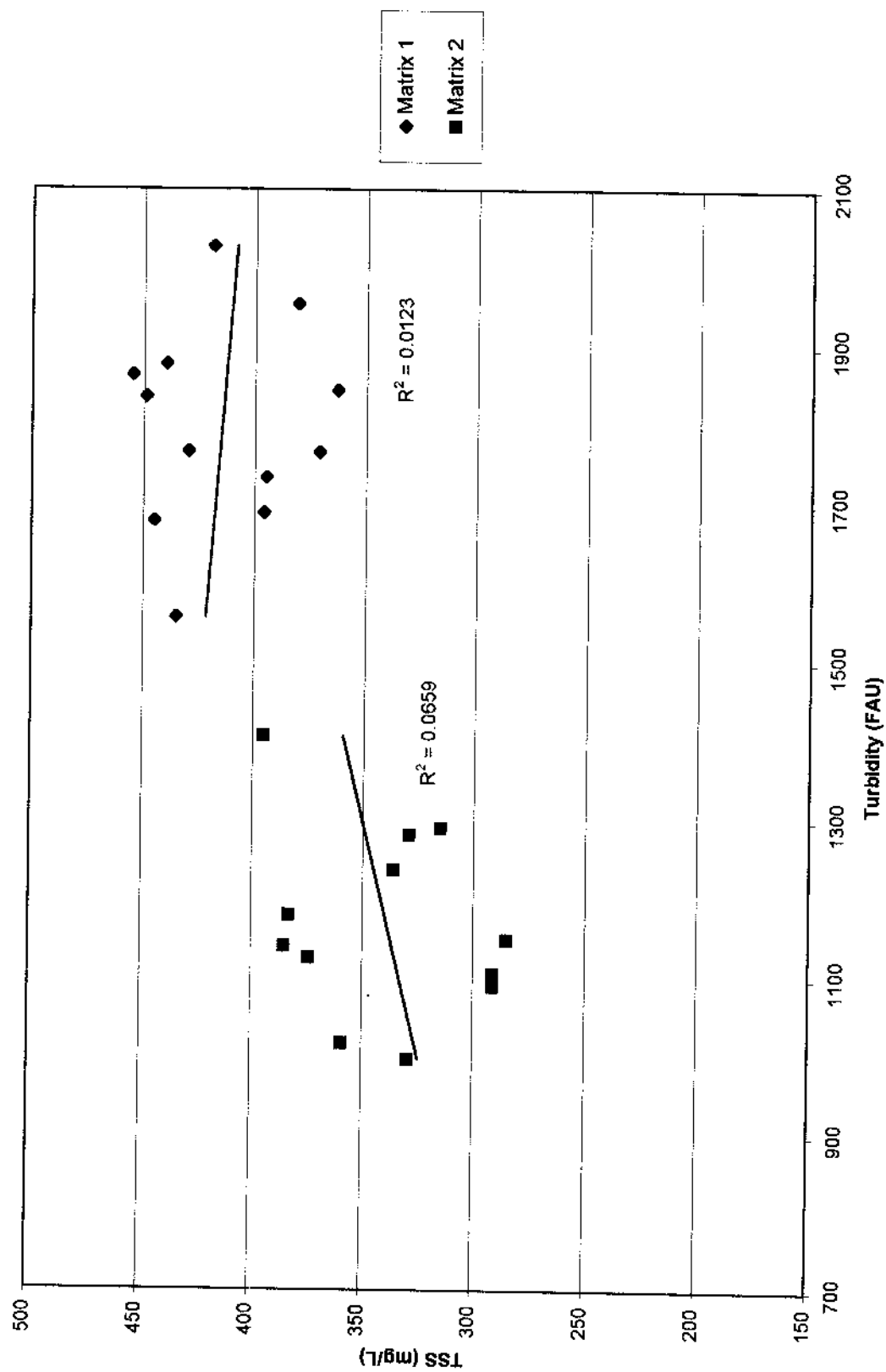


Figure 12: Treated Wastewater Turbidity vs. TSS - Transitional Matrix Testing Phase - Matrices 1 and 2 - Polymer BPL 5504

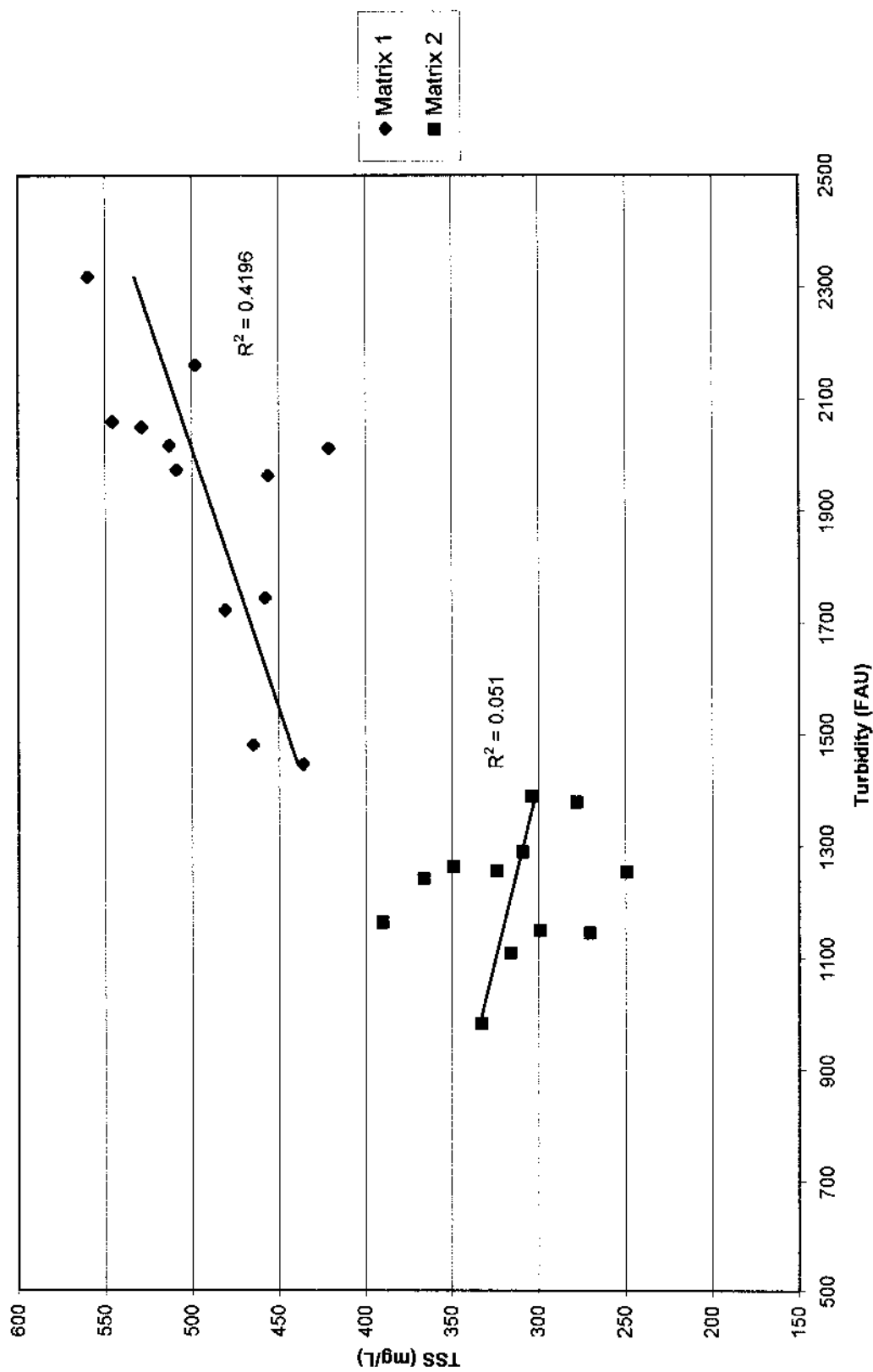


Figure 13: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Phase II - Test 1 - Sample II-1

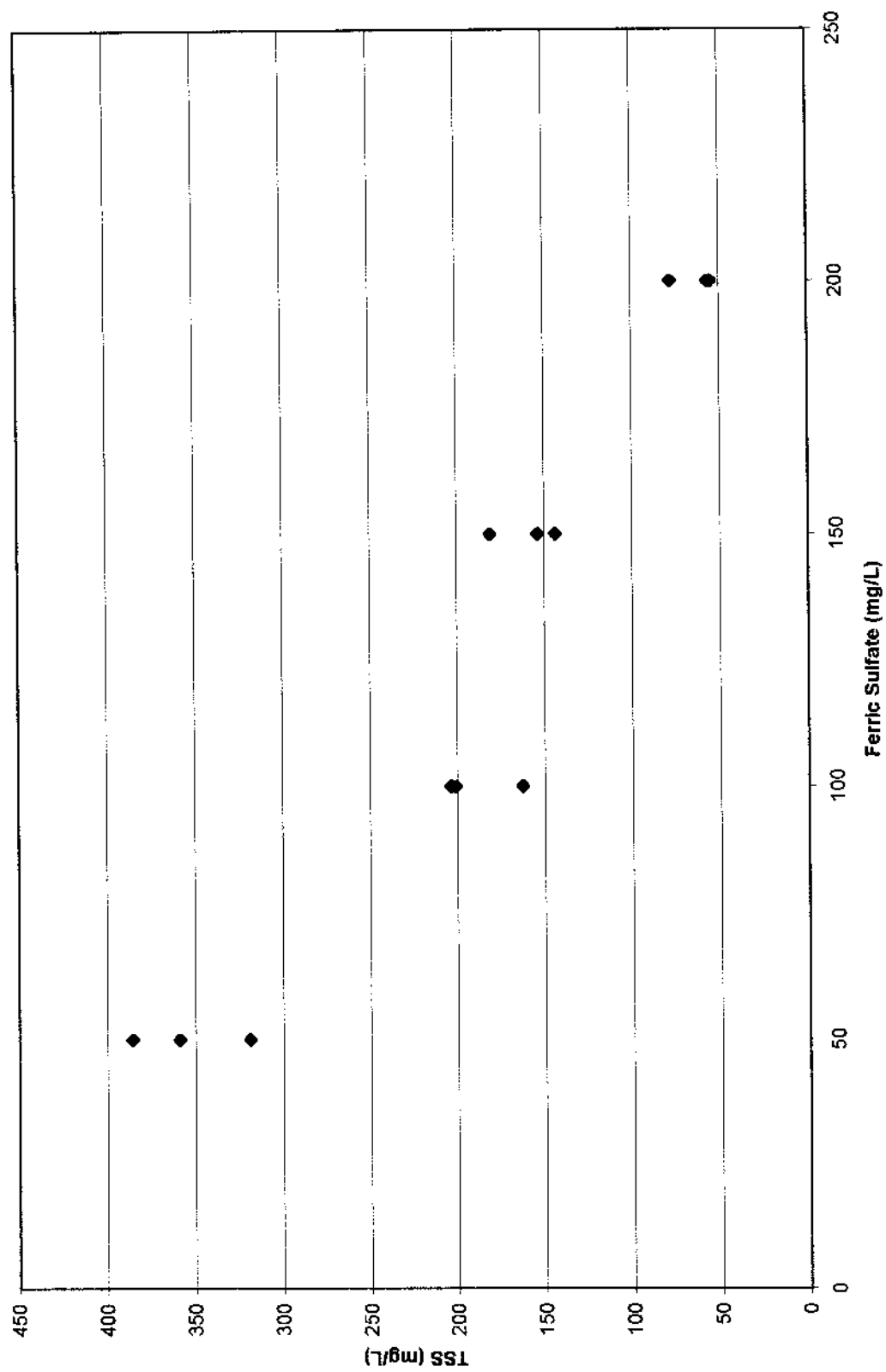


Figure 14: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Phase II - Test 2 - Sample II-2

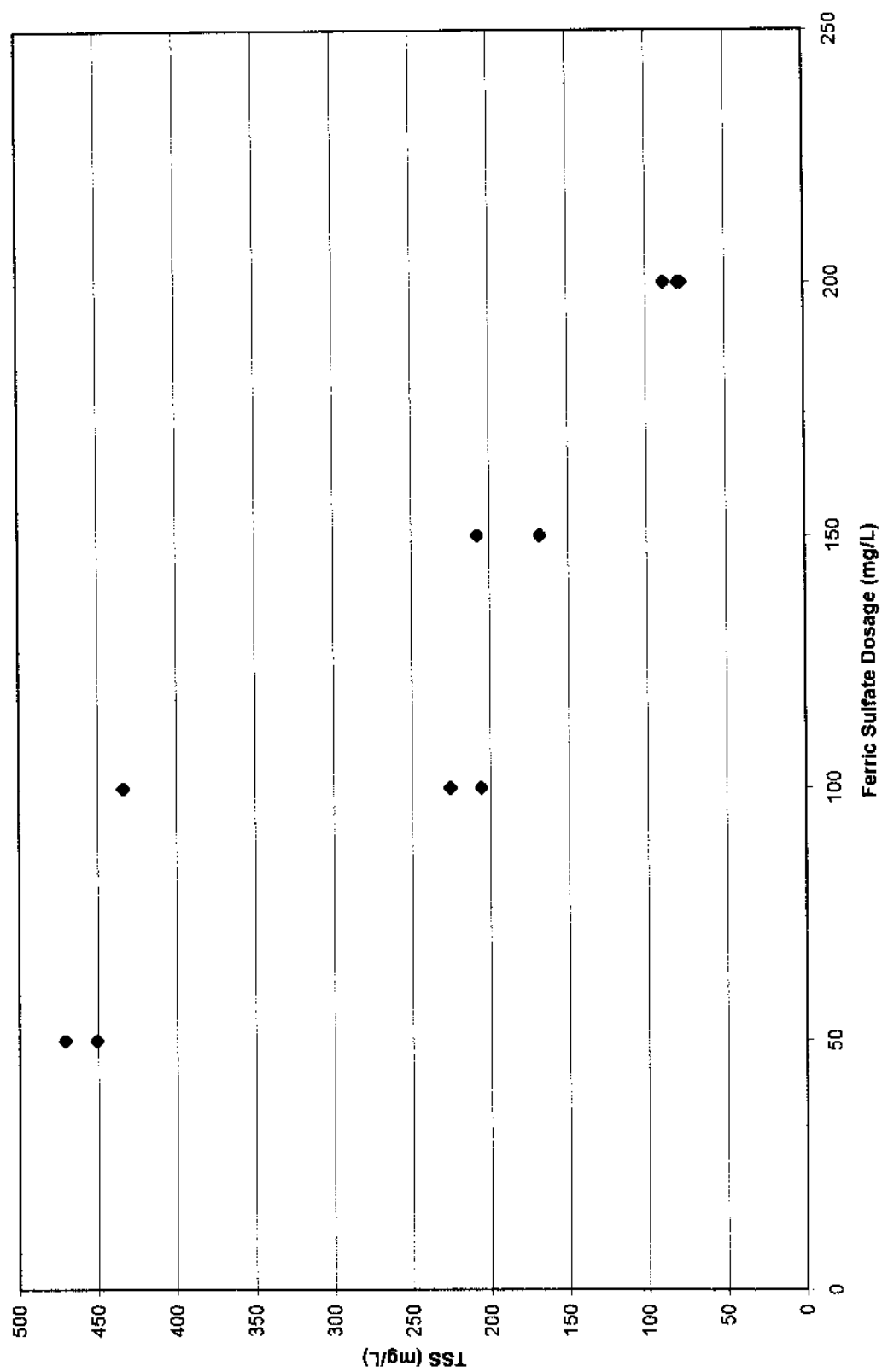


Figure 15: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Phase II - Test 3 - Sample II-3

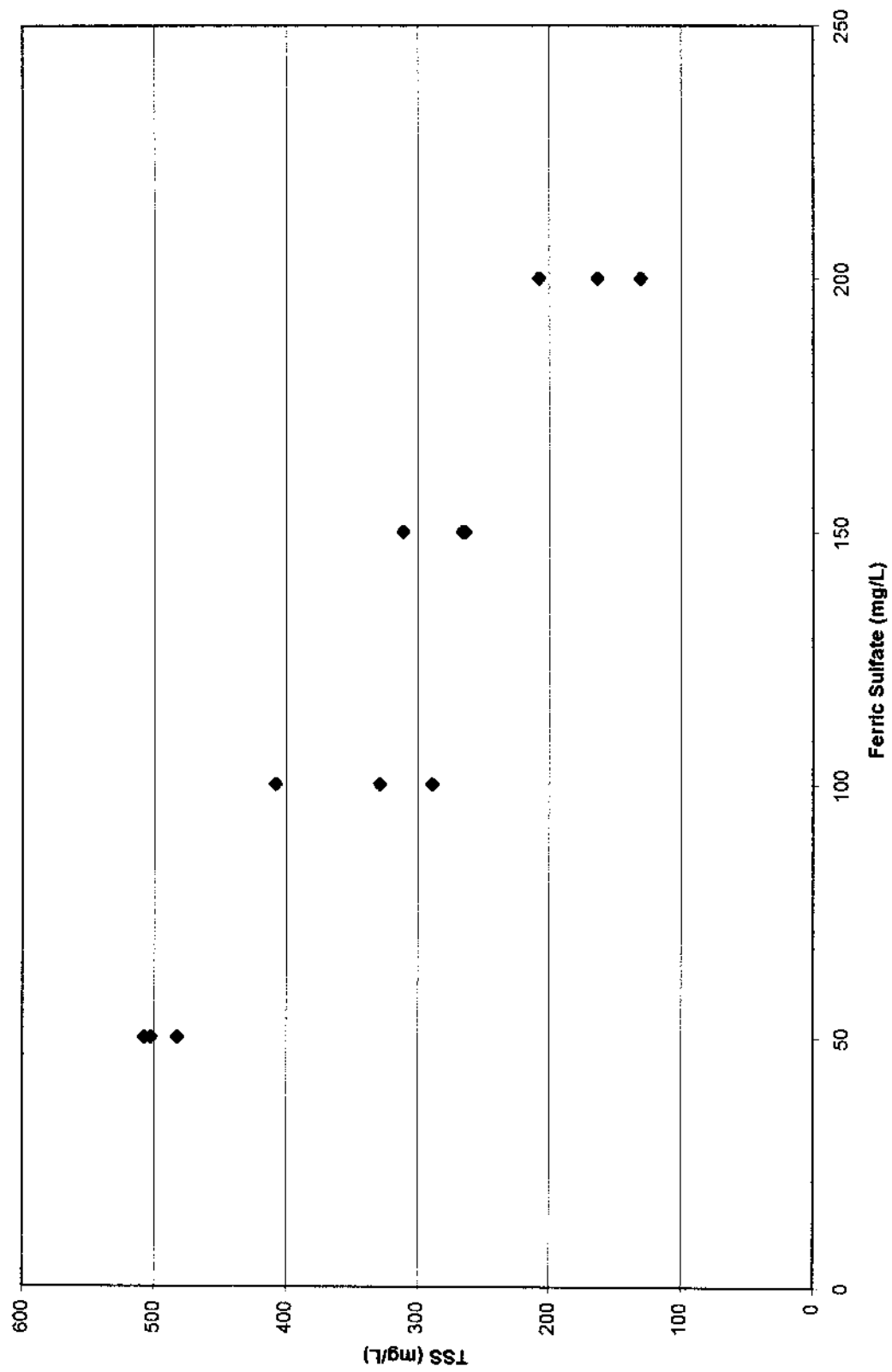


Figure 16: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Phase II - Test 4 - Sample II-4

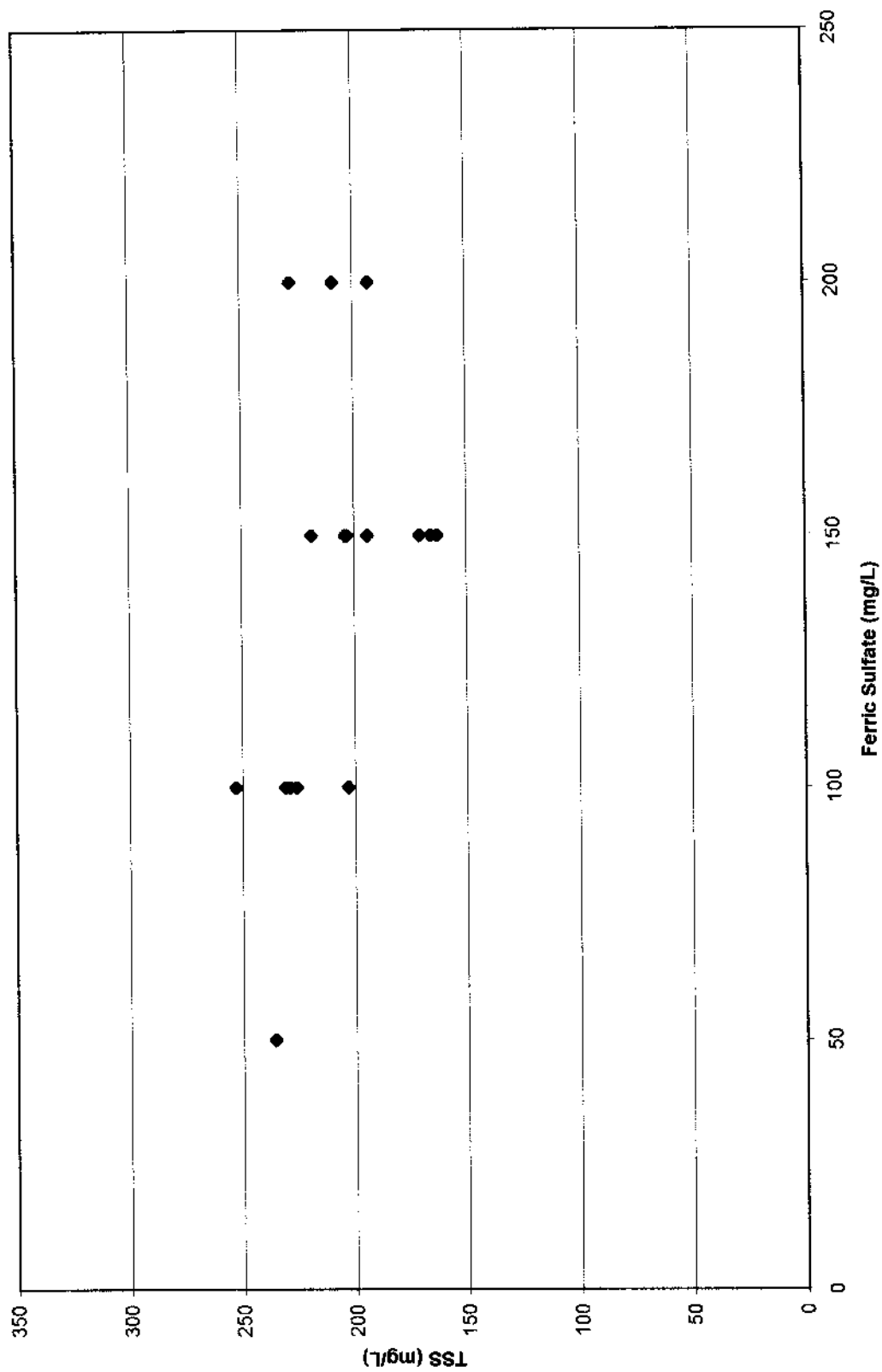


Figure 17: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Phase II - Test 5 - Sample II-5

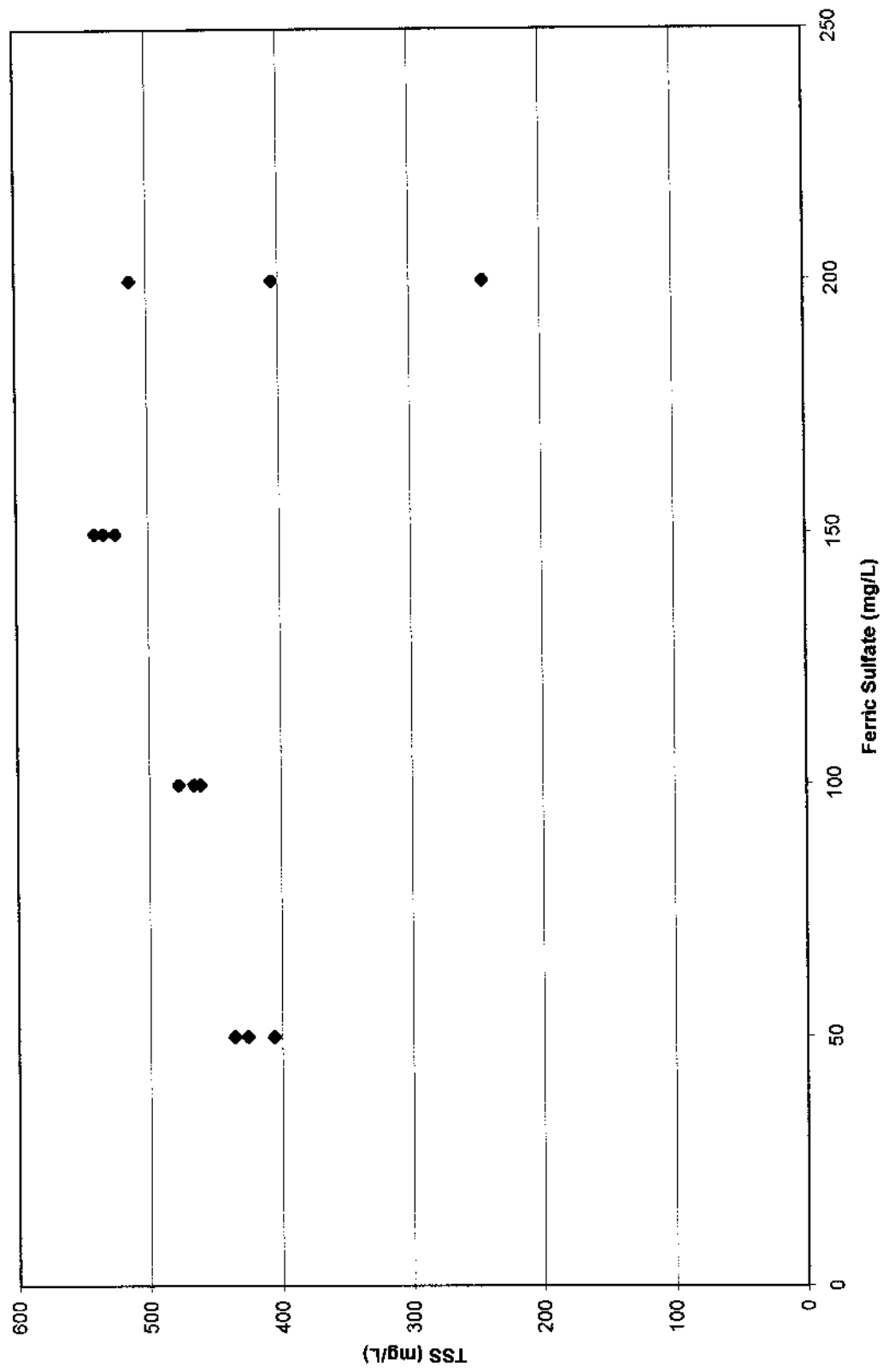


Figure 18: Treated Wastewater Turbidity vs. TSS - Phase III - Tests 1-3 - Polymer CA 9760 - Samples III 1-3

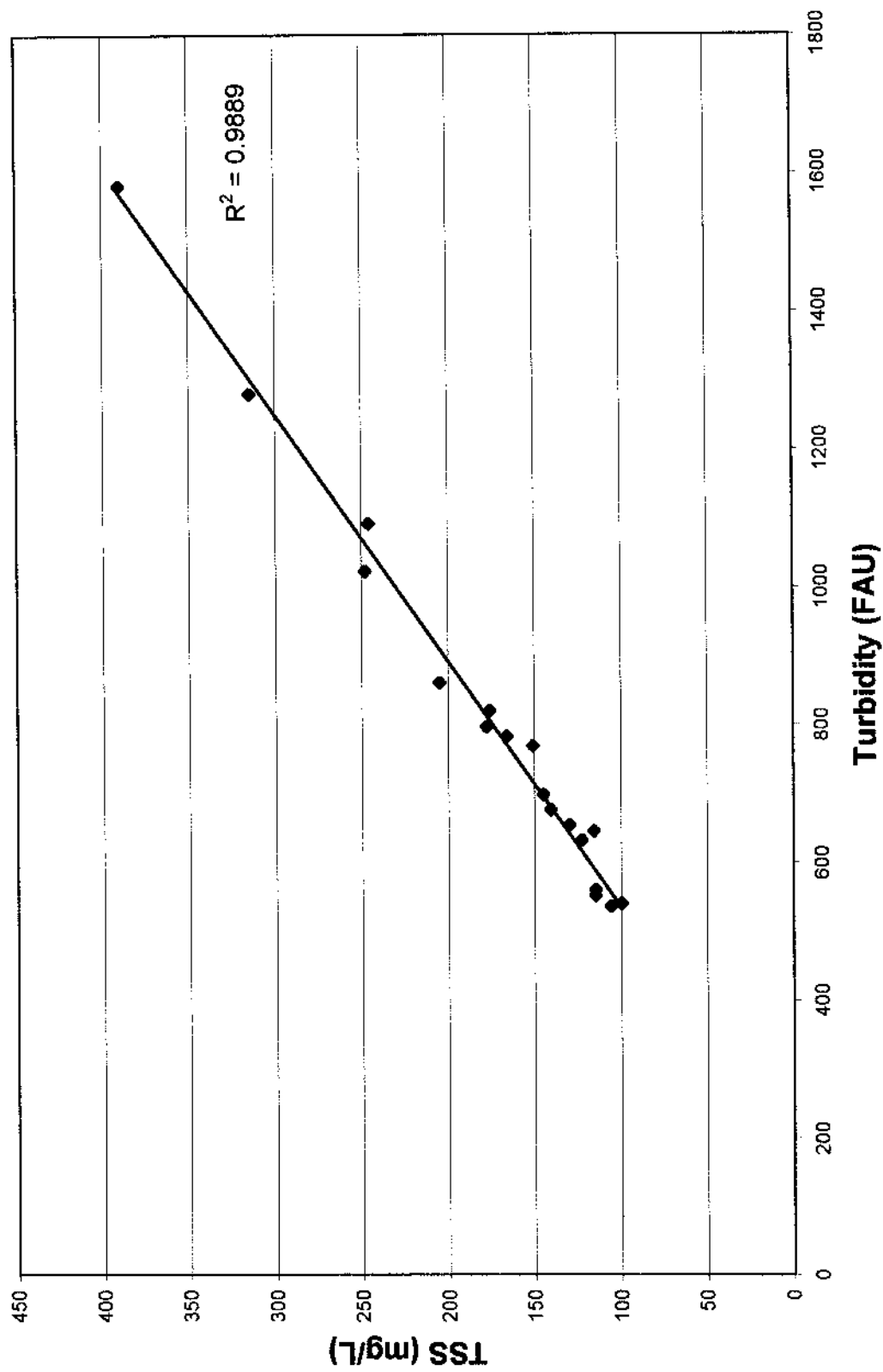


Figure 19: Treated Wastewater Turbidity vs. TSS - Phase III - Tests 1-3 - Polymer BPL 594 - Samples III 1-3

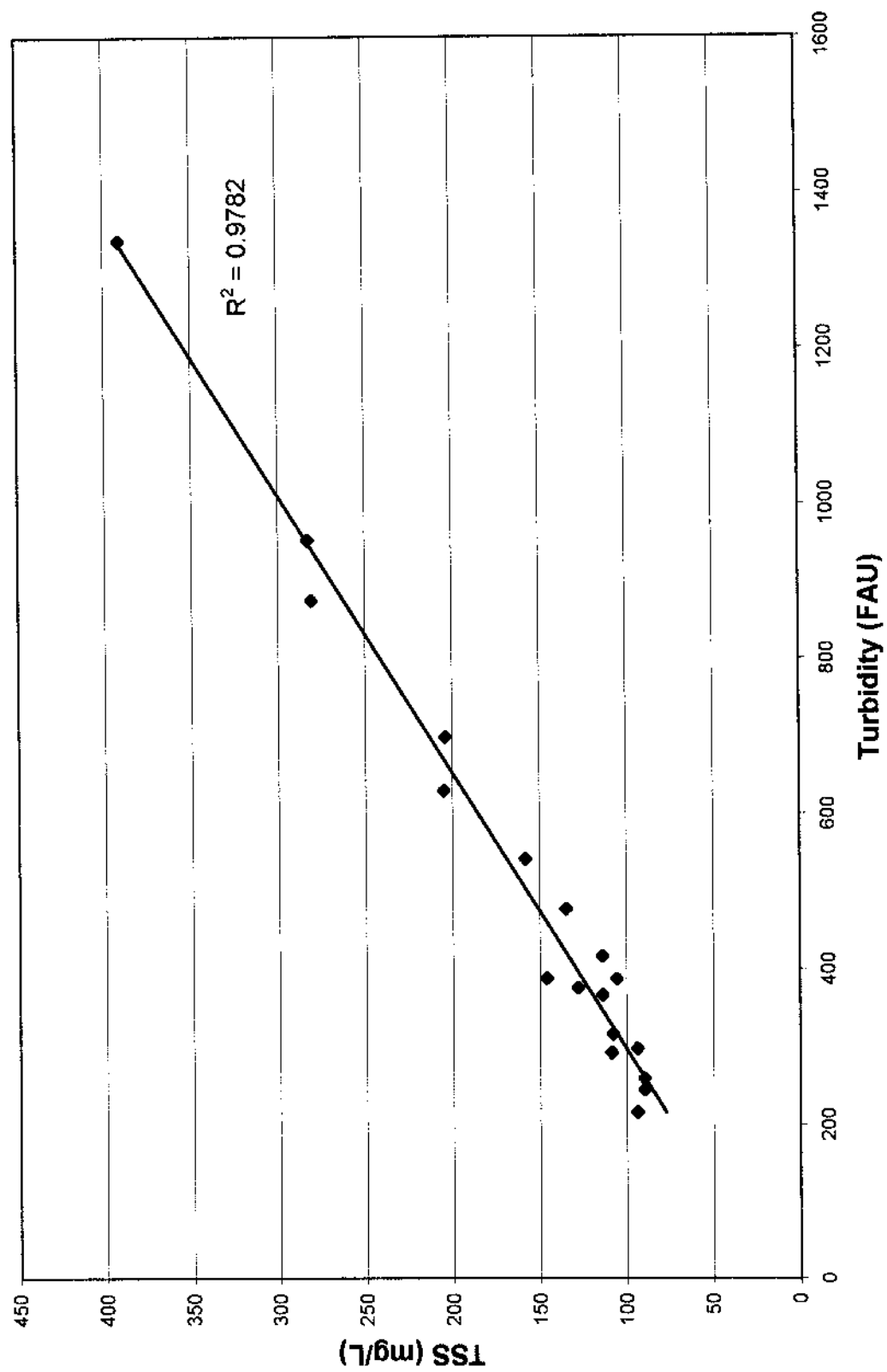


Figure 20: Treated Wastewater Turbidity vs. TSS - Phase III - Tests 1-3 - Polymer BPL 5504 - Samples III 1-3

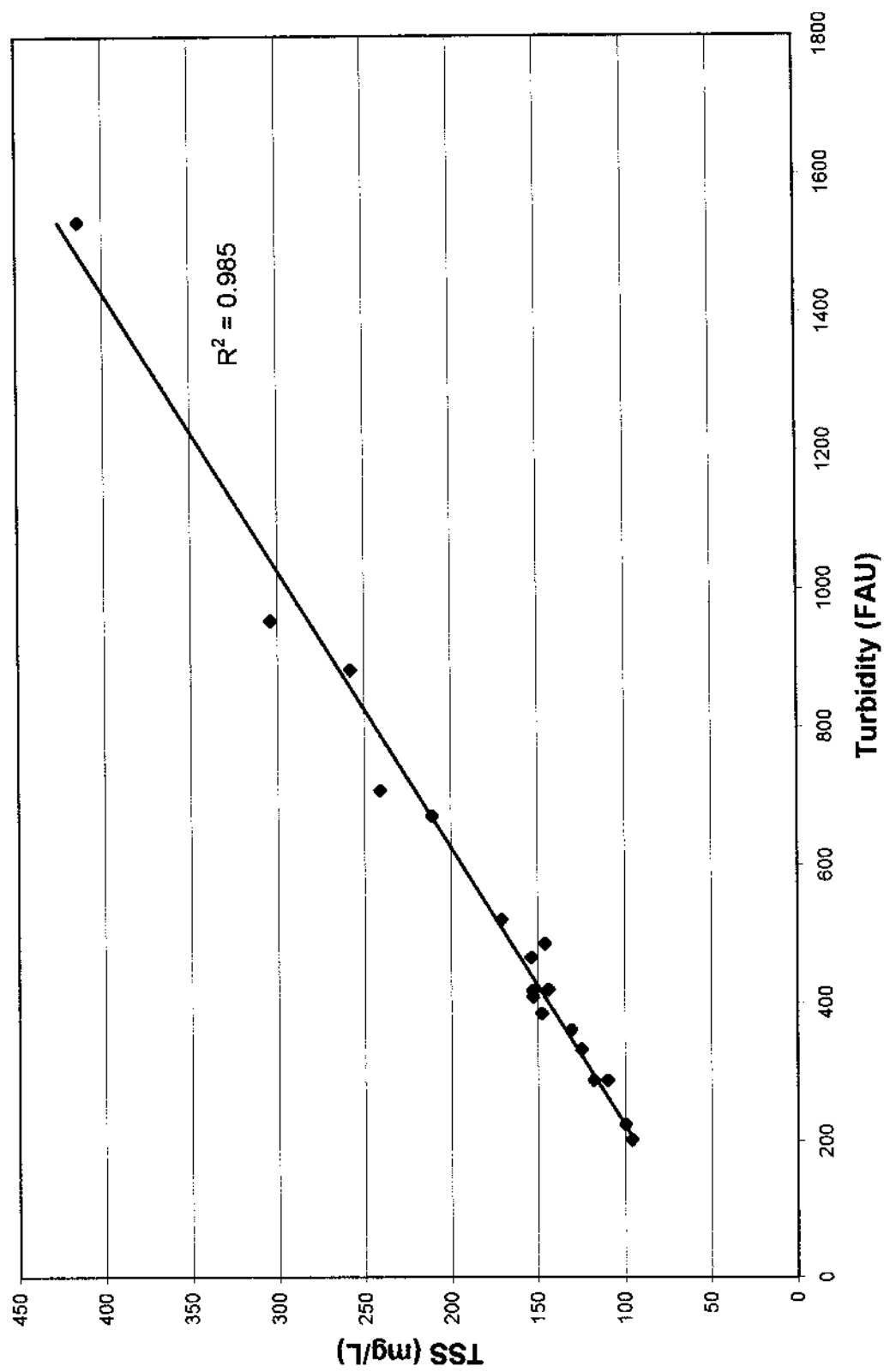
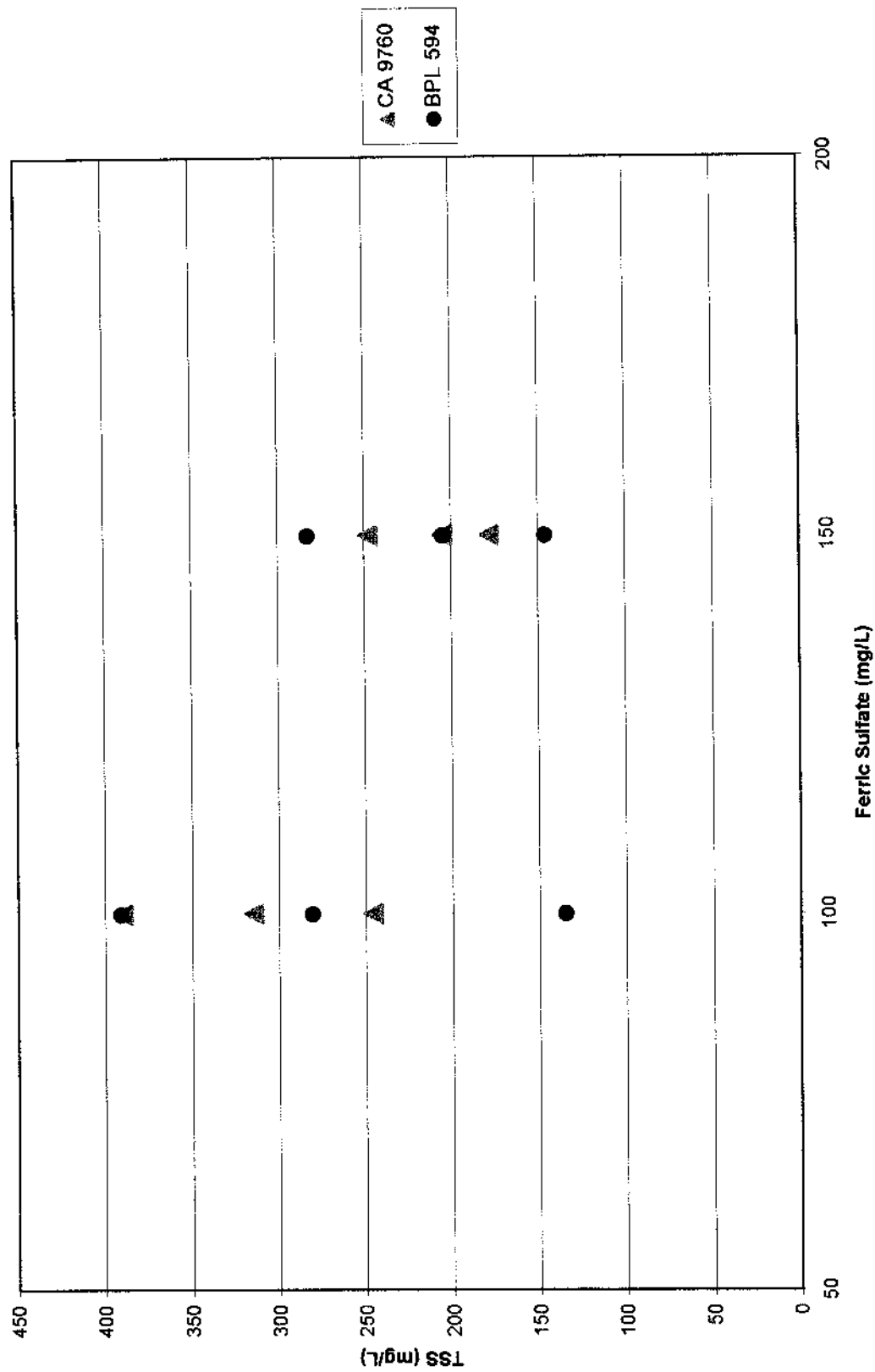


Figure 21: Ferric Sulfate Dosage vs. Treated Wastewater TSS - Phase III - Test 1 - Polymers CA 9760 and BPL 594 - Sample III-1



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