Use of Chemically Enhanced Primary Treatment in Puerto Rico

by

Adrianne Hyldahl and Elisha Hopson

Submitted to the Department of Civil and Environmental Engineering
May 11,2001
In Partial Fulfillment of the Requirements for the Degree of Master of Engineering in
Civil and Environmental Engineering

Abstract

The use of chemically enhanced primary treatment (CEPT) is studied at the plant-scale at two sites (Vega Baja and Fajardo) in Puerto Rico. The two wastewater treatment plants (WWTPs), which are currently operating over their design capacity on a yearly basis, consist of primary settling tanks followed by fixed-film trickling filters. Previous studies, and local preference, mandated the use of aluminum chlorohydrate as the coagulant in both plants.

The chemical used at the Vega Baja WWTP had a dose of either 20 or 40 mg/l, and was applied for 9 hours during the day. The chemicals applied at the Fajardo WWTP were not the same for the duration of the experiment. It was initially dosed with aluminum chlorohydrate (Al content of 12.4%) at 43.5 mg/l for 14 hours. A different aluminum chlorohydrate solution (Al content of 11.6%) was utilized at the same dosage, but its application lasted for 17 hours.

In both WWTPs the primary clarifier and trickling filter received benefit from the use of CEPT. In both cases the primary clarifier and trickling filter was operating at a removal percentage higher than expected with conventional primary clarification. An interesting relationship was seen between the primary clarifier and the trickling filter. As expected, when the primary clarifier increased its removal of BOD, the trickling filter removed less BOD. When the primary clarifier increased its removal of TSS and Total P, the trickling filter was able to remove more of each.

At Vega Baja, after the use of chemically enhanced primary treatment the BOD removal in the primary clarifier doubled to 65%, while TSS removal increased by a factor of four to 47%. Overall the effluent BOD concentration with CEPT was 12.5 mg/L, which is above the local compliance regulation limit of 5 mg/L for BOD, but is still a significant improvement. TSS in the effluent was 12 mg/L, which is well below their local compliance regulation limit of 30 mg/L for TSS.

At Fajardo, with the use of CEPT, the effluent concentrations were reduced to an average 14 mg/L for BOD and 16 mg/L for TSS, both below Fajardo's local compliance permit limits. At Fajardo two different coagulant solutions were tested, one of which provided better treatment at a reduced cost. These results indicate that CEPT can help the plants on this Puerto Rico meet their effluent standards

Thesis Supervisor: Donald R.F. Harleman
Title: Ford Professor of Environmental Engineering, Emeritus

Acknowledgements

To Professor Harleman and Susan Murcott, for their guidance and tutelage.

To Frederic Chagnon, for his help in Puerto Rico and his guidance and perspective after the trip.

To AAA, for allowing us the opportunity to do the project in Puerto Rico, monetary compensation, and all their help during our time there.

To Hector de Jesus, for helping arrange the project and get it approved.

To Jonathan Hasson, for arranging the contract with MIT.

To Hector Cepeda, for being there whenever we needed him.

To the UROP students, Luis Otero and Marlene de Varona, for their help, advice, and research report.

To the operators of the Vega Baja WWTP, for their help and aid.

To the operators of the Fajardo WWTP, for the same reason.

To Juan Medina and Carlos Ortiz at Gulbrandsen Chemicals, for help and service above and beyond their duty.

To Cesar Acevedo at Aquakem, for the same reason.

To the people from the AAA main lab in Caguas, providing us with the tools to sample, for analyzing our data, and doing it with a smile.

Table of Contents

List of Figures

List of Tables

Chapter 1- Introduction

Wastewater treatment in Puerto Rico is currently undergoing a period of rapid change. Much of the infrastructure is outdated and overloaded, and because of this many of the smaller plants are not meeting their effluent guidelines. Normally a massive construction effort would be required to replace the older plants. However in this case a cost-effective retrofitting option is available. The goal of this project is to evaluate that option for use in Puerto Rico.

1.1 General Overview

The project took place on the island of Puerto Rico, a commonwealth government associated with the United States. Puerto Rico measures 100 miles by 35 miles with an area of 3,464 square miles. The topography varies from flatlands to mountainous central highlands. Its moderate, tropical-marine climate is ensured year-round by trade winds. The population is about 3.9 million people, most of who are US citizens. Today, island residents live in substantial middle-class circumstances, characterized by modern urban services and amenities (Puerto Rico Chamber of Commerce 2000).

One of the most prized services is wastewater treatment. This project involved two of the exisiting wastewater treatment plants. The location of the WWTPs is shown below in Figure 1.

Figure 1: Map of Puerto Rico (Lonely Planet 2000)

The WWTPs are located in Vega Baja and Fajardo. Vega Baja is about 27 kilometers (km) from San Juan, and Fajardo is approximately 50 km from San Juan. Both WWTPs are located on the northeastern side of the island, and their effluents eventually empty into the Atlantic Ocean. The northern coast of Puerto Rico is heavily populated and has a high influx of tourists from November to March. Thus, the WWTPs' effluent quality is important in order to maintain the coastal beauty and public health.

1.2 Background Information on Puerto Rico's Wastewater Treatment Plants

1.2.1 Project Background

The Puerto Rican government hired the Compania de Aguas de Puerto Rico (CAPR), a Vivendi company, to operate the 30 wastewater treatment plants in Puerto Rico. CAPR is in charge of operating and improving the WWTPs. Last year most of these WWTPs got injunctions against them. EPA, which was responsible for getting the injunctions in court, wouldn't lift the injunctions until the WWTPs could prove that their effluents were meeting the required limits. These limits are usually an effluent value of 30 mg/L TSS and BOD.

CAPR and the Puerto Rico Aqueduct and Sewer Authority (PRASA) created a compliance plan for these WWTPs in order to meet these requirements. They formed a Polymer Addition Task Force as part of this plan. The Task Force included CAPR Technical experts, CAPR and PRASA regional managers and operators, MIT students, and chemical suppliers. Each team had a different objective in the task force. It was in this respect that this project developed. CAPR had MIT students M. Varona and L. Otero come in during the summer as part of MIT's Undergraduate Research Opportunities Program (UROP). The UROP students' main goal was to perform bench scale and full scale polymer testing. The students' tasks also included providing data accumulation and evaluation, and writing reports. The scope of work begun by the students was ultimately too large to be finished in a summer, which is where the current research came into the picture. By continuing from where the UROP students' final report (Otero and de Varona 2000) left off, the project goal of ultimately improving the performance of these WWTPs so they meet their limit requirements and get the injunctions lifted would be easily met. This would permit new development to attach to these WWTPs, and hopefully allow for future development around these WWTPs while safeguarding the environment.

1.2.2 Vega Baja and Fajardo Wastewater Treatment Plants

The two WWTPs chosen for this project were Vega Baja and Fajardo. These WWTPs were not only part of the background testing (Otero and de Varona 2000), but they are also very similar WWTPs in terms of their design. Both WWTPs have a trickling filter and a separate and parallel activated sludge train. In our studies, we have focused on the combination of chemically enhanced primary treatment (CEPT) followed by trickling filters. We have not changed or analyzed the parallel biological treatment system.

Trickling filters involve spraying the sewage over a bed of rocks or other media. As the water trickles through the rocks, a biofilm forms that removes organic carbon from the water. Occasionally the biofilm detaches from the rocks, so a settling tank is placed at the end of the trickling filter system (Metcalf & Eddy 1991). Vega Baja has two of these trickling filters that are operated in parallel; the flow from the primary clarifier is divided between the two trickling filters. Fajardo has a conventional trickling filter and a "biotower", which is simply a very tall trickling filter. These are in series; the water from the primary clarifier first flows through the trickling filter and then through the biotower (Otero and de Varona 2000).

The activated sludge trains in both of these WWTPs are one or two very compact package plants consisting of an aeration tank, a clarifier and usually an aerobic digester. In the aeration tank, air is bubbled into the tank to encourage microbial activity for the conversion of organic carbon to carbon dioxide. The settling tank allows for the removal of biomass, or sludge, created in the aeration tank, and the anaerobic digester consumes some of the sludge producing methane (Metcalf & Eddy 1991).

The Vega Baja Wastewater Treatment Plant is designed to handle 2.2 million gallons per day (MGD), and at the time of this study was handling an average flow of 1.6 MGD. The limits imposed by the injunction on this wastewater treatment plant are 30 mg/L of TSS and 5 mg/L of BOD. The Fajardo WWTP is designed to handle a flow of 4 MGD, and was handling an average flow of 2.2 MGD during testing. The injunction against the Fajardo Wastewater Treatment Plant specifies that it must achieve a TSS limit of 30 mg/L and a BOD limit of 28 mg/L (Otero and de Varona 2000).

1.3 Introduction to Chemically Enhanced Primary Treatment

1.3.1 Theories of Chemically Enhanced Primary Treatment

Traditional wastewater treatment plants use gravitational settling to remove many contaminants from the wastewater. This process usually removes 60% of the total suspended solids (TSS), 30% of the biochemical oxygen demand (BOD), and 30% of the nitrogen and phosphorus from the wastewater. Primary clarification is typically the first step in a series of treatment processes. Unfortunately in today's growing society where wastewater treatment plants are handling more wastewater that originally anticipated and environmental regulations are becoming more stringent, gravitational settling alone does not provide the necessary removal. Chemically enhanced primary treatment (CEPT) is a viable way of improving gravitational settling (Harleman 2000).

CEPT involves the addition of a coagulant to a settling tank in a wastewater treatment plant. The coagulant is usually an aluminum or iron salt, and is used to encourage the aggregation of particles in the wastewater into larger particles. These composites have a larger diameter than the original particles and therefore settle more quickly. Many particles that would not settle on their own, because they are too small, are incorporated into the flocs and descend to the bottom of the tank. Because more of the particles settle out, CEPT has a higher removal efficiency: 85% for TSS, 60% for BOD, 85% for phosphorus, and 30% for nitrogen (Harleman). The addition of CEPT can greatly improve the efficiency of a gravitational settler in a wastewater treatment plant (Harleman and Murcott 1992).

1.3.2 Orange County, California: Retrofitting with CEPT

The Water District of Orange County, California operates two wastewater treatment plants, one of which has a trickling filter and an activated sludge plant, similar to the WWTPs studied in Puerto Rico. Since the 1980s, Orange County has been adding chemicals to its influent to aid in coagulation and flocculation; they call this process Advanced Primary Treatment (APT) however it is the same as CEPT. The results have been wonderful; they achieved low enough levels of Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) that they were granted a waiver from full secondary treatment (Hetherington et al 1999).

The design of Orange County Plant #1 has CEPT plus a trickling filter and CEPT plus an activated sludge pant. This WWTP is able to handle an average flow of 60 million gallons per day (MGD). All of the influent is pretreated, and goes through chemically enhanced primary clarification. The wastewater is then divided into three parallel trains at the splitter box. A little more than half of the flow goes to the activated sludge plant. Eighteen MGD goes to the trickling filter, and the remaining four MGD goes straight to the disinfection step. The effluents of these three trains are blended and then combined with the effluent from Plant #2, which also uses chemicals, and sent to the ocean outfall. The diagram of Plant #1 follows in figure 2 (County Sanitation 1993).

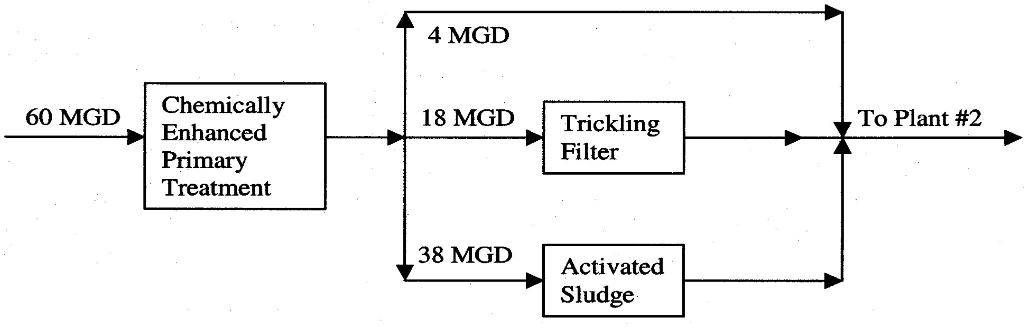


Figure 2: Orange County, CA Wastewater Treatment Plant

The use of chemicals at Orange County consists of Ferric Chloride (FeCl3) and a small amount of anionic polymer, to aid in flocculation of the coagulated material. The FeCl3 is currently added at the grit chamber splitter box, to ensure proper mixing. It was added prior to the grit chambers, but the addition at this point was starting to interfere with other parts of WWTP operation. The dose of FeCl3 is between 20 and 30 mg/L. The anionic polymer is added just before or directly to the primary clarifier in a dose from 0.15 to 0.25 mg/L. The chemicals are added for 8 to 10 hours during peak flow only. The amount of FeCl3 and polymer added to the system is monitored carefully; jar tests to determine the proper dose of each chemical are performed weekly (Hetherington et al 1999).

The results at Orange County have shown CEPT to be quite beneficial. The average removal of BOD, shown in figure 3, by CEPT is 42% and TSS, shown in figure 4, is removed up to 75%. The water is then treated with either the trickling filter or the activated sludge process. The average additional BOD removal in the trickling filter is 85% and the average TSS removal is 44%. The additional removal of BOD in the activated sludge process is 96%, and TSS is removed by an additional 93%. The average effluent concentrations are 36 mg/L BOD and 20 mg/L TSS; that is about an overall removal of 90% in both BOD and TSS.

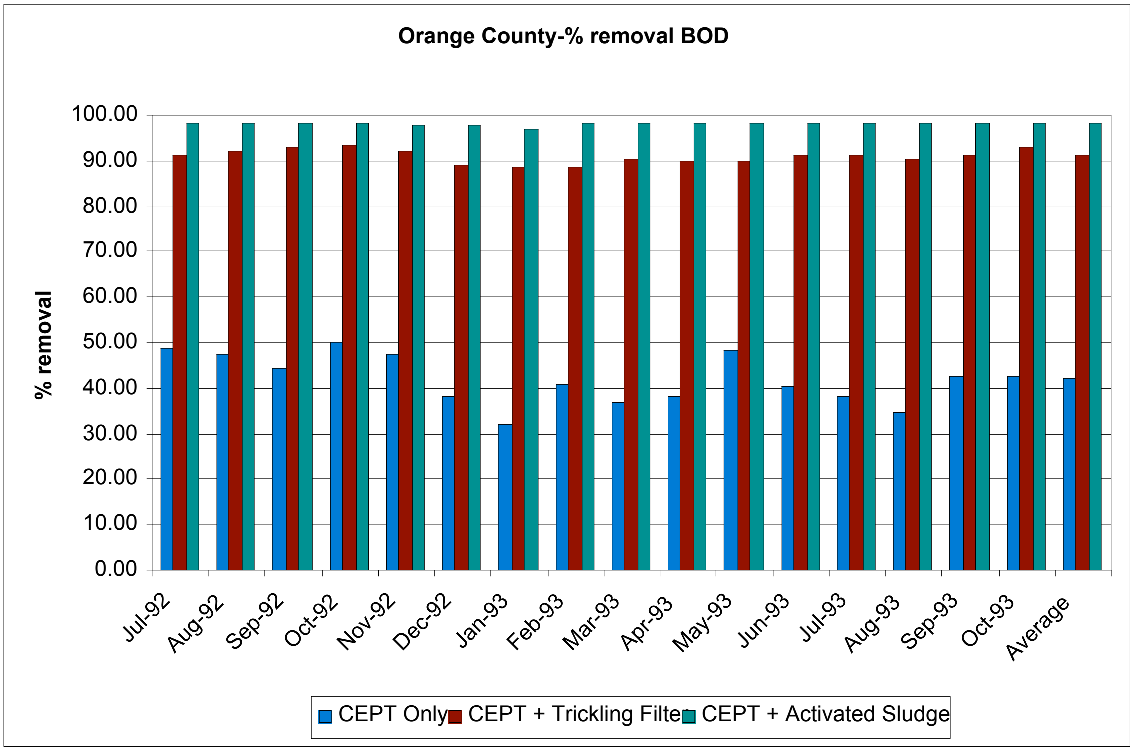


Figure 3: Orange County, CA- %BOD removal

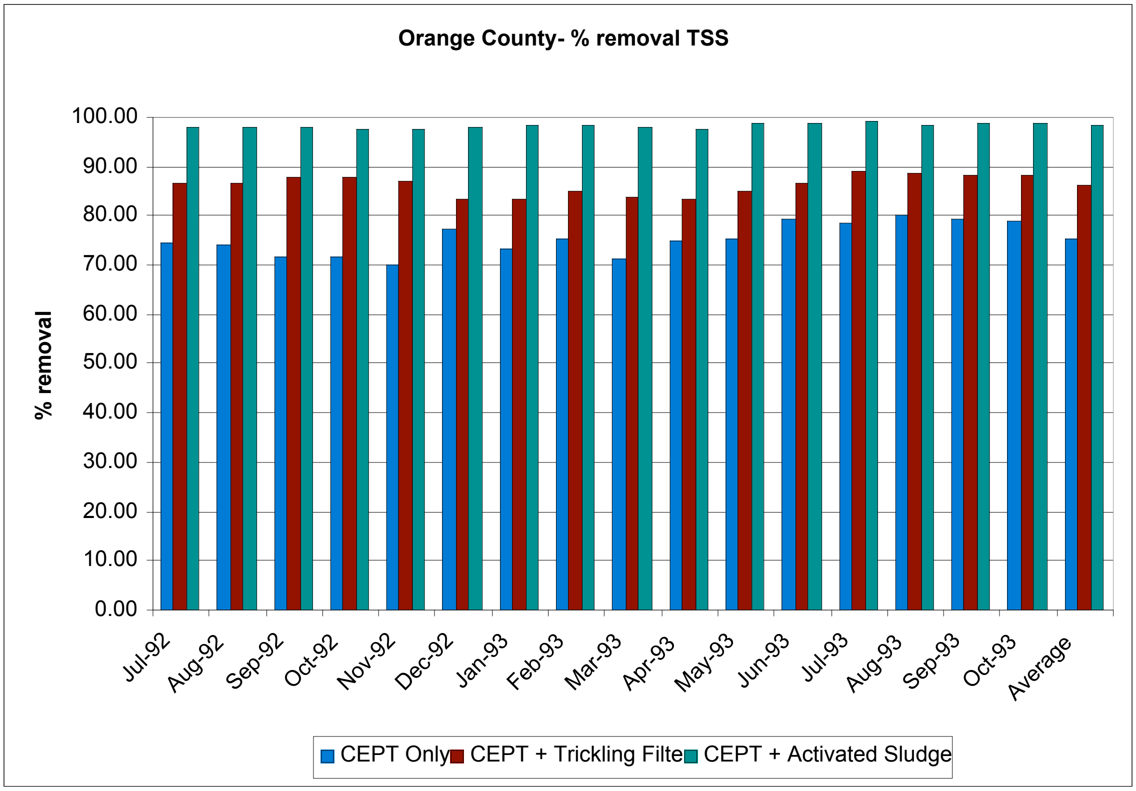


Figure 4: Orange County, CA- %TSS removal

Orange County has had some trouble with the implementation of Chemically Enhanced Primary Treatment, but over the years, they have found solutions to many of these problems. First of all, they found that if chlorine is added, for odor control, with the FeCl3, there is a problem with floating sludge. They solved this problem by simply adding the chlorine upstream of the ferric chloride. They also found that because the characteristics of the wastewater influent change periodically, they do not achieve optimum effluent quality. This was taken care of by periodically doing jar tests. These jar tests not only adjust the ferric chloride dose, but they also test the anionic polymer. If the polymer is found to not be performing well, the chemical vendor has an opportunity to submit a new polymer that would solve the problem. This allows for the chemical company to have the opportunity to remain as the supplier as well as for the WWTP to achieve optimum performance (Hetherington et al 1999).

Chemically Enhanced Primary Treatment has worked well in Orange County, California. They have reached low enough BOD and TSS effluent levels to meet their National Pollutant Discharge Elimination System permit and to receive a waiver from secondary treatment. CEPT has affected the performance of the trickling filter and activated sludge system. The trickling filter and activated sludge system are removing BOD and TSS as best as their design allows, maybe even a little better. The use of CEPT in Orange County allows the WWTP the option of not investing money into large capital projects and actually saves money in terms of sludge hauling. Advanced Primary Treatment is the cheapest, most effective way for the Orange County Wastewater Treatment Plant to meet its effluent requirements.

1.4 Otero and de Varona 2000 Results

The team's project is based in large part on prior work done on the plants in question. Prior results include analysis of the basic physical properties of the wastewater stream (COD, TSS, pH, temperature, turbidity, and residual chlorine), jar tests to recommend chemical selection and dosing, and on two of the five plants full-scale tests (Otero and de Varona 2000). This team chose two of the untested plants with similar treatment systems for the project. At both plants aluminum chlorohydrate was the recommended chemical. The results of the chemical selection jar tests can be found in appendix B, while analysis of the dosage jar tests is below.

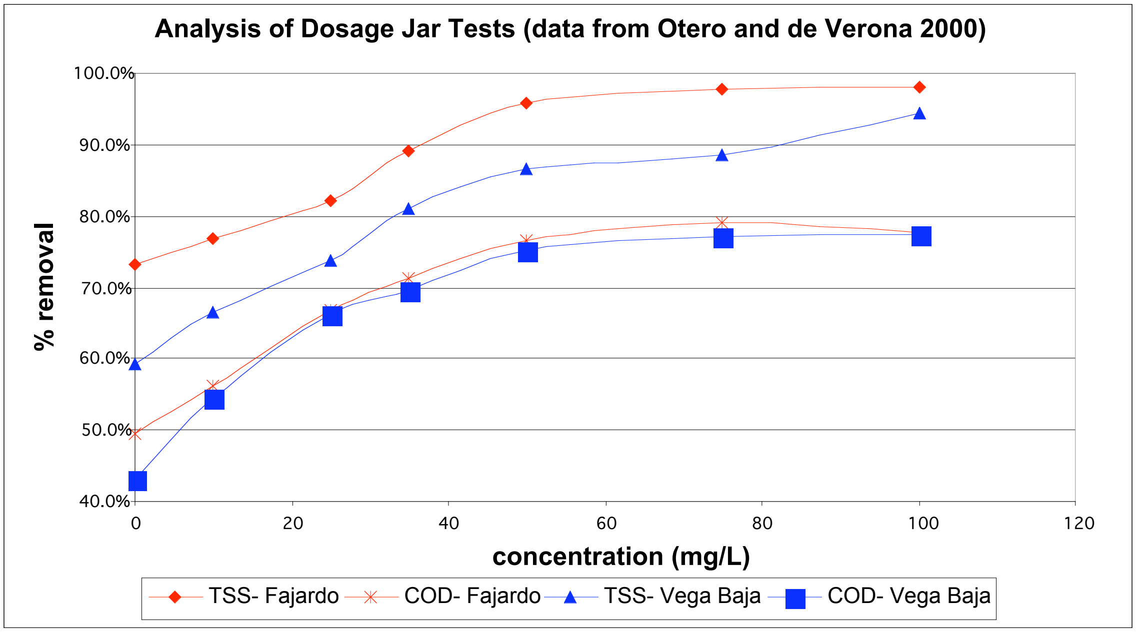


Figure 5: Dosage Curve

In choosing a dosage for a plant the goal is to choose the dosage at which the returns in percent removal drop significantly. At both plants the maximum dosage that continues to provide a benefit in increased treatment is in the 40-60 mg/L range. Accordingly the team planned to dose both plants at a value of 40 mg/L.

Chapter 2: Methods

2.1 Vega Baja

The Vega Baja Wastewater Treatment Plant is a system with two different parallel systems. The primary is on the primary clarifier/trickling filter series, but there is also an activated sludge package plant that was assumed to be working properly. After the primary clarifier, there are two parallel trickling filters and secondary clarifiers (Otero and de Varona 2000). The primary clarifier works by mechanical settling, removing a large number of the heavy particles. Trickling filters consist of a large spray arm that sprays the wastewater over a bed of rocks, or in some cases a porous plastic material similar to nested waffles. As the water trickles over the medium, a biofilm forms that removes organic carbon from the water. The medium for the trickling filters at Vega Baja is large gravel. As the biofilm grows, some of the biomass detaches from the rocks, so a secondary settling tank is placed at the end of the trickling filter system (Metcalf & Eddy 1991). A plant schematic is included at the end of this section.

The Vega Baja WWTP is designed to handle 2.2 MGD (Otero and de Varona 2000), and is currently handling an average flow of 1.6 MGD. In addition, at the time of this study, all of the pretreatment was out of service, and a filter press for the sludge was not being used. The effluent limits on this WWTP are 30 mg/L of TSS and 5 mg/L of BOD. The full-scale tests planned on the Vega Baja plant will investigate how CEPT can help this WWTP meet these standards.

Prior research indicates that for this system the addition of 40 mg/L of GC-850, an aluminum salt, would provide the most efficient removal with the least amount of floating solids (Otero and de Varona 2000). The group started with the recommended chemical and dosage in our full-scale tests. The GC-850 was added to the influent of the primary clarifier, and rapidly mixed in the influent pipe. The original testing plan was to run one background day without applying chemicals and then 5 days of constant chemical addition at 40 mg/L to allow the plant to adjust. Unfortunately, unforeseen circumstances prevented the initial plan from being implemented.

While working at Vega Baja there was one main problem, floating sludge in the primary clarifier. The best way to describe the condition is a film on the surface of the water varying from a thin layer to one that was about 2 inches thick. This film appeared to be made up of the sludge that is created in the primary clarifier. The first idea of the team was that the chemical dosage was too high, and it was cut in half to 20 mg/L. When this did not clear up the problem, the team turned to the plant operators for ideas. After speaking with the plant operators, it became evident that the sludge was accumulating

Figure 6: Floating sludge at Vega Baja

because it was not being removed fast enough. At Vega Baja the sludge pump, which moves sludge from the storage tank on the primary clarifier to the anaerobic digester, runs only during the day when the operators are present. The CEPT application produces more sludge than typical primary settling because more solids are removed, and unfortunately when that sludge wasn't removed during the night a large portion of it fermented and resuspended, floating to the top. After discovering this we applied chemicals only when the sludge pump was running. This seemed to clear up the problem.

At Vega Baja we placed portable composite samplers – machines that take several samples over the course of 24 hours to provide a mechanical daily average – at the entrance and exit of the primary clarifier, and at the exit of the trickling filter. We used the existing samplers at the entrance and exit of the plant as well. Each sampling point was tested for total suspended solids, BOD5, COD, total phosphorus, and total organic carbon.

All samples that were taken during the full-scale testing of both plants were analyzed at the regional lab in Cauguas. The samples were kept on ice until they reached the lab. Ice was also placed in the portable samplers to preserve the condition of the wastewater.

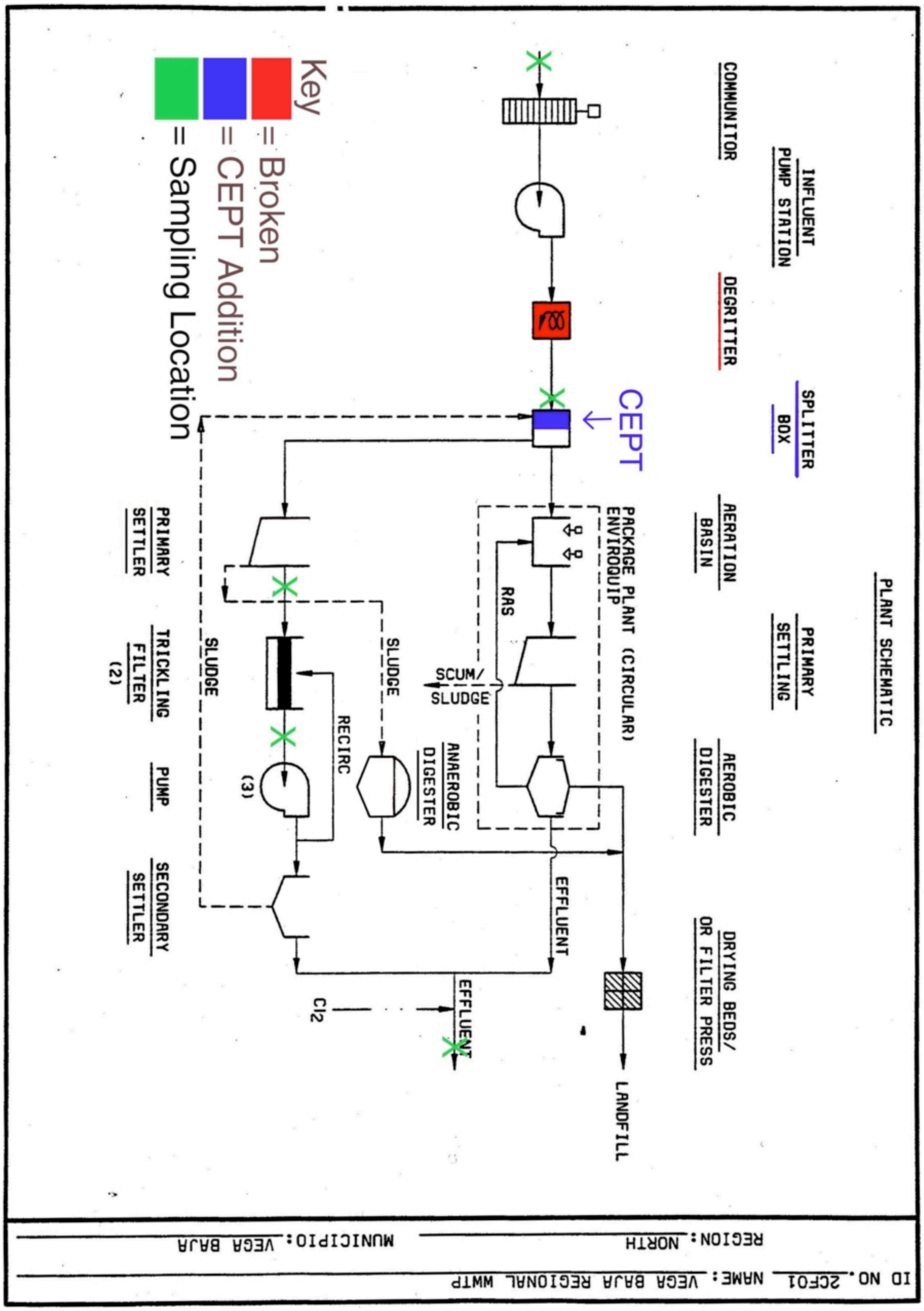


Figure 7: Vega Baja schematic (adapted from Otero and de Varona 2000)

2.2 Fajardo

The Fajardo Wastewater Treatment Plant is comprised of three parallel systems: an aeration plant, a package plant, and a trickling filter followed by a bio-tower (Otero and de Varona 2000). Both the package plant and aeration plant are assumed to be working efficiently, and independently meeting EPA standards. Our focus is on the primary clarifier/trickling filter chain.

The primary clarifier at Fajardo is very similar to the clarifier at Vega Baja, except that a chemical, an aluminum salt plus polymer at 45 mg/L, was already being added when we arrived. At Fajardo the trickling filter system is composed of a trickling filter, biotower, and secondary clarifier in series. The biotower in the Fajardo WWTP is basically a very large trickling filter.

In our study we added a chemical coagulant with a higher aluminum content and no polymer, to the entrance of the primary clarifier and then monitored the results. We placed portable composite samplers at the entrance to the primary clarifier, and at the entrance and exit of the trickling filter/biotower series. These sampling points are in addition to the permanent composite samplers at the entrance and exit of the plant. The sampling point at the plant exit draws from all three systems (package, primary, and aeration). Each sampling point was tested for total suspended solids, BOD5, COD, total phosphorus, and total organic carbon. A plant schematic is included at the end of this section.

The plant is designed to handle a flow of 4 MGD with the newly built package aeration plant (Otero and de Varona 2000). During the week the team was in Fajardo the total influent averaged 2.4 MGD, although over the past year the flow was as high as 9.5 MGD with monthly maximums typically around 4 MGD. During the testing the flow through the trickling filter was approximately 1 MGD. The effluent limits in Fajardo are the same as in Vega Baja for TSS (30 mg/L) but BOD is significantly higher than the Vega Baja limit at 30 mg/L (Otero and de Varona 2000).

In January there were several broken parts in the Fajardo WWTP. The trickling filter, pista grit, communitor and digester were all out of service. Although the lack of pretreatment is damaging to the life of the plant's equipment, a more immediate effect is caused by the non-functioning digester. Since there is a functioning anaerobic digester in the package plant the sludge from the primary clarifier is taken by truck from the clarifier to the package plant's digester. This led to the sludge storage tank on the primary clarifier being constantly full of sludge, and the sludge blanket in the clarifier consistently several feet deep in the center of the clarifier.

We based our chemical selection and dosing on preliminary studies of Fajardo and other WWTPs. The jar tests at Fajardo determined that the addition of approximately 40 mg/L of PAX-XL19, an aluminum based salt, would provide the most effective primary settling efficiency for the amount of chemical used (see Fig. 5).

Before our test at Fajardo 88 ml/minute of PAX-519 was being added constantly to the influent of the primary clarifier (this corresponds to a dosage at peak flow of approximately 45 mg/L). Originally we planned to halt the chemical dosage for at least a day before starting our tests, but the plant operators would not shut the chemical off for compliance reasons. Since the value was close to our recommended dose and seemed to be working effectively, we left the pump settings at 45 mg/L.

Our original schedule included 5 days of testing at a continuous dose of PAX-XL19. However problems arose with the trickling filter on our first and third day of dosing which caused the operators to stop the chemical addition. On the first day a whitish film appeared over the normal dark-green of the trickling filter. The cause of the whitish film is still unclear, since the chemical we added (aluminum chlorohydrate) was the same as the main component of the PAX-519 that was being added prior to our arrival. In order to prevent a possible overdose we lowered the chemical dose slightly to 44 mg/L and installed a timer on the pump for the chemicals. The timer stopped the addition of chemicals between 11:00 PM and 6:00 AM, during which low or no-flow conditions are present in the plant.

On the third day the majority of the trickling filter turned a dark brown color, and the chemical was again halted. Although we are confident that the problems on the third day were caused by the drying out of the filter during maintenance of the trickling arm the previous day, we were unable to convince the operators of the safety of the XL19, and they requested that we returned to the original 519. We did as they asked, and therefore our final days of sampling test the effectiveness of PAX-519 at the same dose of 44 mg/L.

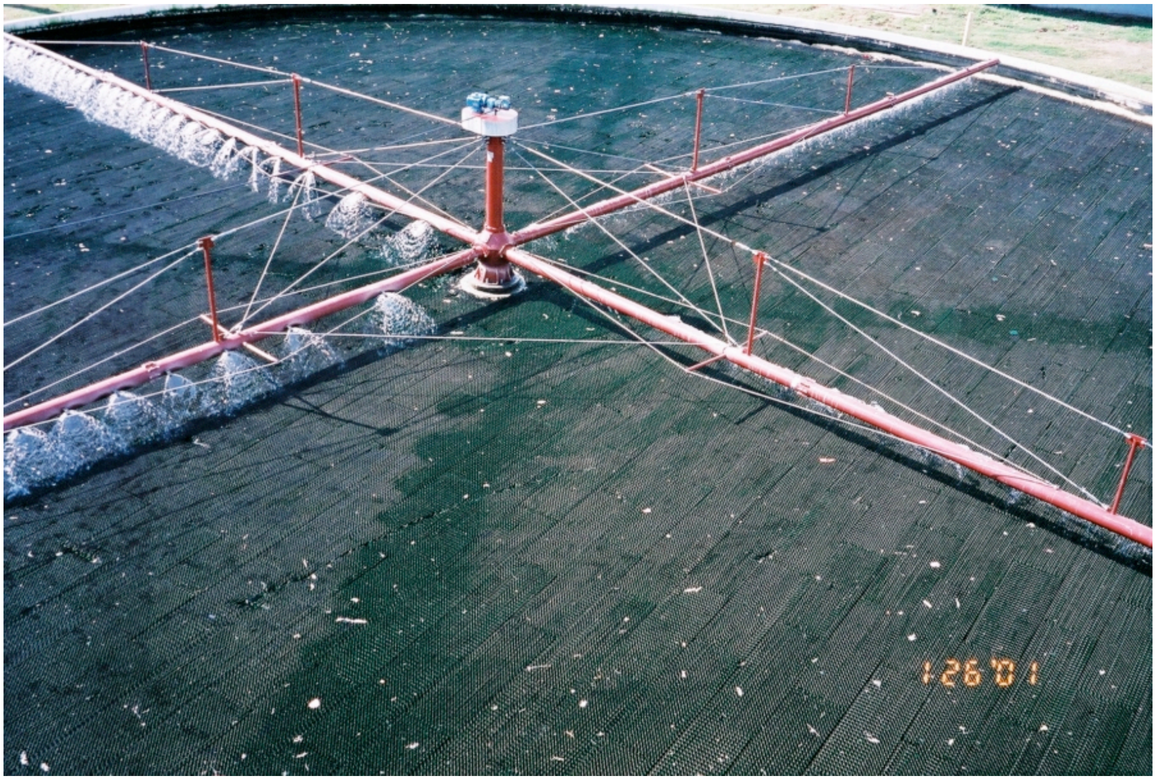


Figure 8: Dried out trickling filter at Fajardo – the dark lines are the normal color of the trickling filter and are where the arms were stopped for maintenance on the previous day.

All samples that were taken during the full-scale testing were analyzed at the regional lab in Cauguas. The samples were kept on ice until they reached the lab. Ice was also placed in the portable samplers to preserve the condition of the wastewater.

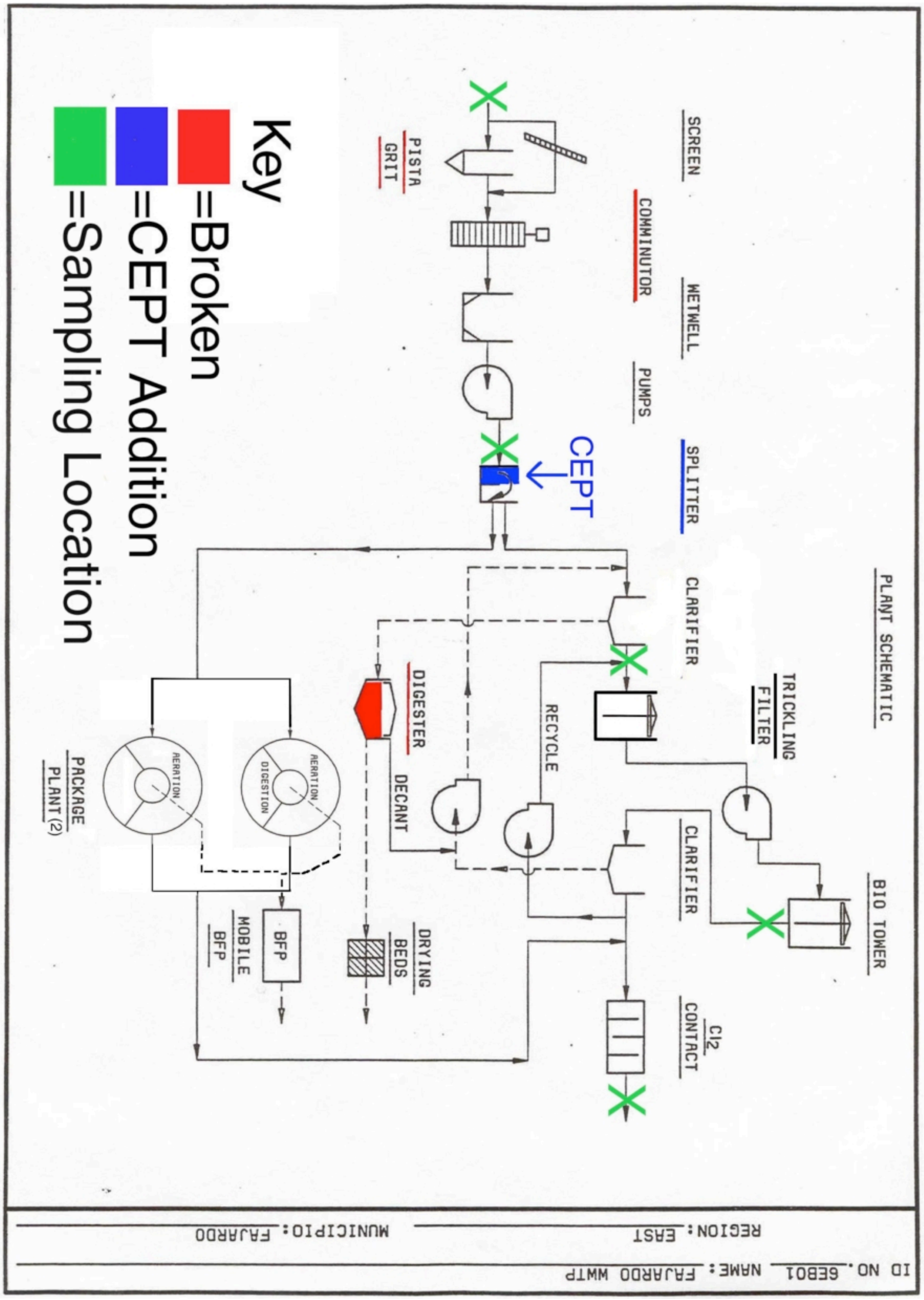


Figure 9: Fajardo Schematic (adapted from Otero and de Varona 2000)

Chapter 3- Effects of CEPT on Primary Clarifiers and Trickling Filters

3.1 Vega Baja

3.1.1 Biochemical Oxygen Demand

Data on Biochemical Oxygen Demand (BOD) was collected on three days during the testing at Vega Baja. On January 19, there was no chemical added to the system, providing a baseline for comparison. January 20 was a short day with a relatively low dose of chemical; the chemical was added at 20 mg/L for five hours. January 18th was a more typical day. The dosage was still relatively low, only 20 mg/L, but the addition time was nine hours, which is closer to how long the chemical would be added under normal operating conditions.

When examining the data for the primary clarifier, shown in figure 10, it is evident that the chemical must be run for a longer time to achieve removals that CEPT typically gives. The no chemical data shows that the primary clarifier is achieving removal of 34%, which is typical of a conventional primary clarifier. When the chemical is added at 20 mg/L for 5 hours, the percent removal increases to about 50%, and when it is added for 9 hours the percent removal jumps to 65%. The numbers for 20 mg/L of GC-850 at 9 hours, 65%, is what one would expect from CEPT being applied to a primary clarifier.

The trickling filter's removal efficiency, also shown in figure 10, seems to vary inversely with the effectiveness of the primary clarifier. When no chemicals were being added, the trickling filter was removing about 65% of the BOD, but when chemicals were added for 9 hours at 20 mg/L, the trickling filter only removed 30 % of the BOD. The combined removals of BOD for all three days are about 77%. This makes sense because the trickling filters are designed to remove BOD, and when the primary clarifier performs well, the trickling filter does not have to work as hard.

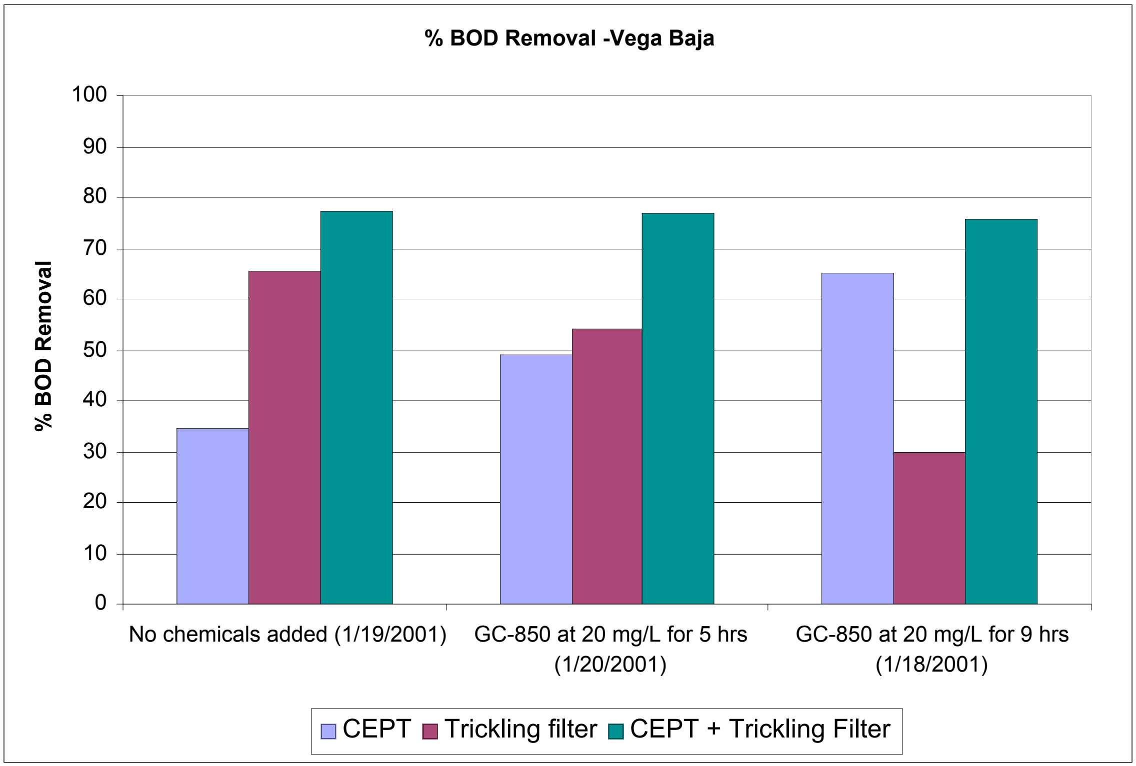


Figure 10: Vega Baja- % BOD removal

The combined removals of the primary clarifier and the trickling filter from figure 10 do not seem to change with the addition of chemicals. Prior to the 19th of January, the trickling filter has not been cleaned. It is likely that the data for the trickling filter could be skewed. On this day the chemical was added for the longest time, and the primary clarifier performed the best. The trickling filter's removal efficiency was low on that day because it need to be cleaned, so the measured combined removal of the CEPT and trickling filter is actually lower than would normally be expected.

3.1.2 Total Suspended Solids

In terms of Total Suspended Solids (TSS), there are six significant days. The 15th and 19th of January represent days where no chemical was added to the system. A dose of 40 mg/L of GC-850 was added on January 16th and 17th, but the time was different for those days. On the 17th, the chemical ran for only 5 hours, while on the 16th the chemical ran for 20 hours. On January 18th and 20th the chemical was run at a lower dosage, only 20 mg/L. Again there was a time difference in these days. The 20th was a short day (only 5 hours), while the 18th was a typical day with 9 hours of chemical addition.

Figure 11 shows the effects of CEPT on the primary clarifier and trickling filter for TSS removal. On the day of no chemical addition, low values for the removal of TSS in the primary clarifier are achieved. Only 7% of the TSS is removed in the primary clarifier, and 33% additional TSS is removed in the trickling filter. Conventional primary clarification typically achieves 60% removal of TSS, and a working trickling filter can remove up to 30% of the TSS.

When examining January 20th and 17th, a comparison between low dose (20 mg/L) and a normal dose (40 mg/L) can be made. On the normal dose day, January 17th, the removal of TSS was 60%, but only 38% of the TSS was removed on the low dose day. On both of these days, the time was only 5 hours, shorter than would be implemented for typical dosing in Vega Baja. It can be seen that a higher dose gives a much higher removal of TSS in the primary clarifier.

On these days the trickling filter had opposite results. When more of the TSS was removed, the trickling filter only removed 22% additional TSS, while on the lower dose day, the trickling filter removed 65% additional TSS. One reason for the decreases removal of TSS in Vega Baja could be due to the fact that the filter was flushed on January 18th. The dirty trickling filter on the 17th would not remove as much TSS from the system, thus lowering the percent removal.

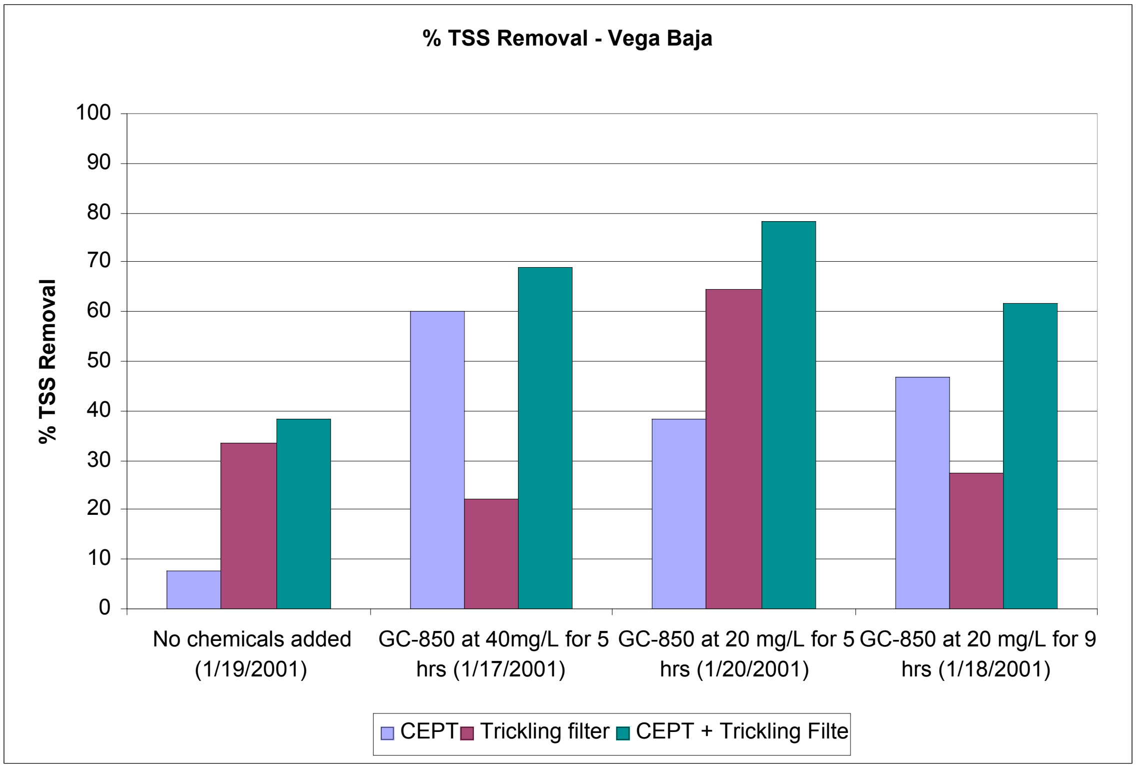


Figure 11: Vega Baja- %TSS Removal

On January 18th the chemical addition was only at 20 mg/L, but the time of addition was typical for Vega Baja operation. The primary clarifier removed 47% of the TSS; this value is much higher than was seen when no chemicals were added. When comparing January 20th and 18th, it is evident that a longer chemical addition time is necessary. When the chemical is added for 9 hours a removal of 47% in the primary clarifier is evident. The trickling filter was able to remove an additional 27% of TSS for the longer time period, but increased to 65% when the time was only 5 hours. Again the pattern of an increased removal of TSS in the primary clarifier leading to a lower removal by the trickling filter emerges.

When examining the removals of the combined primary clarifier and trickling filter, the best removal was when GC-850 was added for 5 hours at 20 mg/L. However, it should be noted that this day had the benefit of the clean trickling filter. In general the combined percent removals show that the use of CEPT increases the performance of the primary clarifier and trickling filter by at least 20%.

3.1.3 Total Phosphorus

The data for phosphorus removal at Vega Baja is not valid. The samples were collected in the beginning to the middle of January, but were not analyzed until the middle of February. While the samples were preserved and refrigerated according to EPA guidelines, the resulting numbers were not reasonable. For this reason, the data for phosphorus removal at Vega Baja was deemed invalid.

3.1.4 Summary

The use of CEPT at Vega Baja seems to improve the plant's ability to remove BOS and TSS from the wastewater. Tables 1 and 2 summarize the results at this WWTP.

The primary clarifier appears to see the most benefit from the addition of GC-850. While the TSS removal is not as high as expected with CEPT, there is a vast improvement when chemicals are added to the primary clarifier. In Orange County, California, the average removal of TSS is higher than is seen at Vega Baja, but Orange County has been using CEPT for many years and has adjusted the chemical dosage to achieve optimum results (Hetherington et al 1999). The low removal of TSS at Vega Baja could be due to the problems with sludge removal and floating sludge. If the sludge were resuspending because it is not being removed quickly enough, this would increase the TSS in the water. The BOD shows great improvement as well, the numbers that are seen are typical of CEPT and are even better than those seen at Orange County.

Primary Clarifier	**Conventional** (Metcalf & Eddy 1991)	**Typical CEPT** (Harleman 2000)	**Orange County, CA** (County Sanitation 1993)	**Vega Baja, No Chemicals**	**Vega Baja, 20 mg/L 9 hours**
BOD	30%	55%-65%	42%	34%	65%
TSS	60%	75%-85%	75%	8%	47%
Total P	30%	55%-85%	N/D	N/D	N/D

Table 1: Comparison of Conventional, CEPT and Vega Baja Removals for Primary Clarifiers

The trickling filters at Vega Baja do not appear to receive any benefit from the use of CEPT. In terms of the BOD there is a great decrease in the amount removed by the trickling filter. The use of CEPT does not seem to affect the trickling filter's ability to remove TSS; only a few percent decrease is seen.

Trickling Filter	**Conventional** (Metcalf & Eddy 1991)	**Orange County, CA** (County Sanitation 1993)	**Vega Baja, No Chemicals**	**Vega Baja, 20 mg/L 9 hours**
BOD	60%-80%	85%	66%	30%
TSS	30%	44%	33%	28%
Total P	none	N/D	N/D	N/D

Table 2: Comparison of Conventional and Vega Baja Removals for Trickling Filters

The trickling filters are Orange county are removing much more BOD and TSS than the Vega Baja plant. This could be because the trickling filters at Vega Baja are not in good condition. There was an obvious problem with flies, and the larvae are feeding on the biofilm of the trickling filter. With some maintenance, the values for removal of BOD and TSS at Vega Baja should increase.

3.2 Fajardo

3.2.1 Biochemical Oxygen Demand

In terms of Biochemical Oxygen Demand (BOD), there are five significant days. The first three days had PAX-XL19 added to the plant with an average concentration of 43.5 mg/L, while the last two days had PAX-519 added at a concentration of 43.5 mg/L. The main difference between the days was the duration of chemical addition. Figure 12 summarizes the BOD data.

When comparing the 24th and 23rd of January, the time difference is most evident. With a four-hour increase in chemical addition time, 14% more BOD was removed from the primary clarifier. The trickling filter series dropped in its removal of BOD, by 14% with a time increase.

The highest percent removal seen, when PAX-XL19 was added for 14 hours, is 44%. This number is much less than expected for CEPT when applied to the primary clarifier. In fact all of the numbers are well below what is expected for the addition of CEPT.

Overall the trickling filter series for Fajardo removes the amount of BOD that is typically expected. Only two of the days show removals that are below typical. It is important to note that these are the days when the highest removal of BOD is seen in the primary clarifier. A pattern of decreased removal of BOD by the trickling filter with increasing removal in the primary clarifier can be seen.

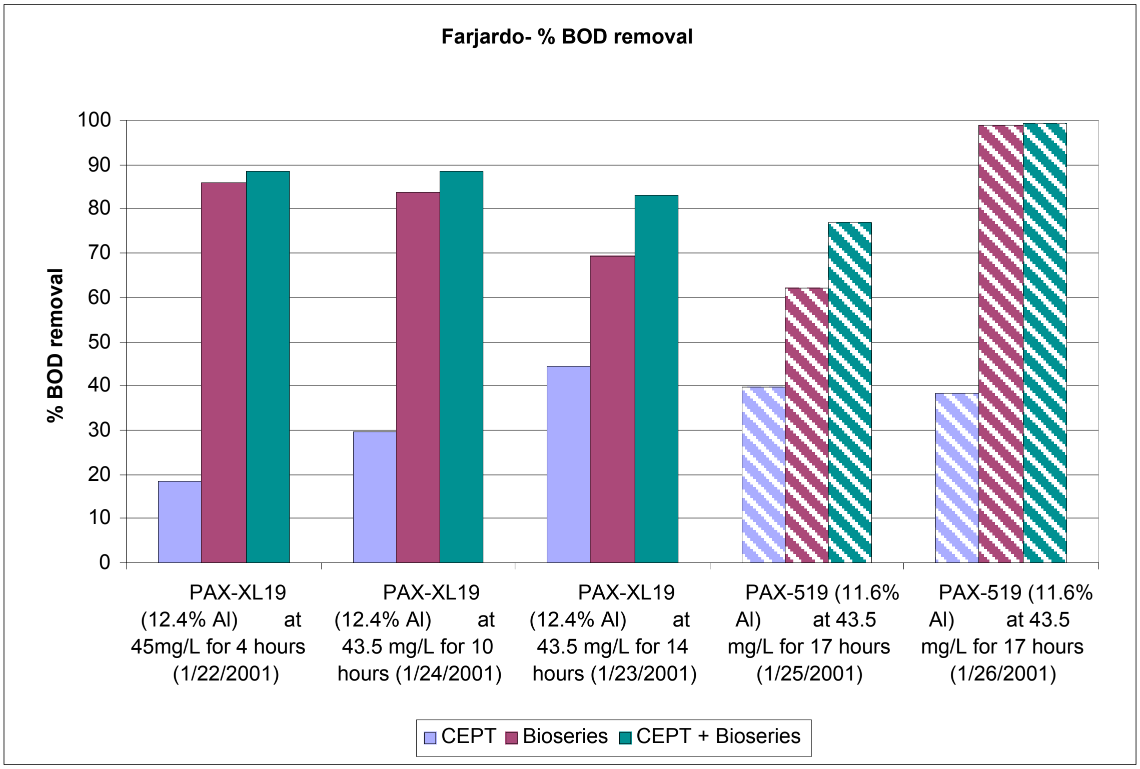


Figure 12: Fajardo %BOD Removals

Looking at the overall removals of the CEPT and bioseries, on average the PAX-XL19 performed as well if not better than the PAX-519. The gain in the trickling filter performance on the 26th of January is what seems to make the PAX-519 perform better that day.

3.2.2 Total Suspended Solids

For total suspended solids, all five days of the testing give significant results. Again the first three days had PAX-XL19 added and the final two days had PAX-519 added. When comparing the 23rd and 24th of January, it can be seen that an increased time of addition does not provide significant additional removal of TSS from the primary clarifier; the difference is only about 4%. Figure 13 summarizes the removals that were seen for TSS when chemicals were applied to the trickling filter train.

The highest percent removal in the primary clarifier is seen when PAX-XL19 was added for only 4 hours, but at a strength of 45 mg/L. This result is unexpected, and in light of the BOD data, it is probably not beneficial to cut the time and increase the dose. If we exclude this point, the best results for TSS removal in the primary clarifier, 68%, are seen with PAX-XL19.

Although the percent removals in the primary clarifier are promising, they are below what is expected with CEPT. Typically a removal of 75% or better can be achieved with CEPT. The best removals seen during this test are only around 68%.

The trickling filter data does not seem to follow the pattern of decreasing removal with increasing primary clarifier removals. In fact the opposite appears to be true; the increased removal of TSS in the primary clarifier allows the trickling filter to remove more TSS. The data is highly variable though; values range from 36% to 85%. A typical trickling filter can remove about 30% of the TSS from its influent. The reasons for the trickling filter's inability to remove TSS could be that the organics in TSS form are unavailable for the biota in the trickling filters to use.

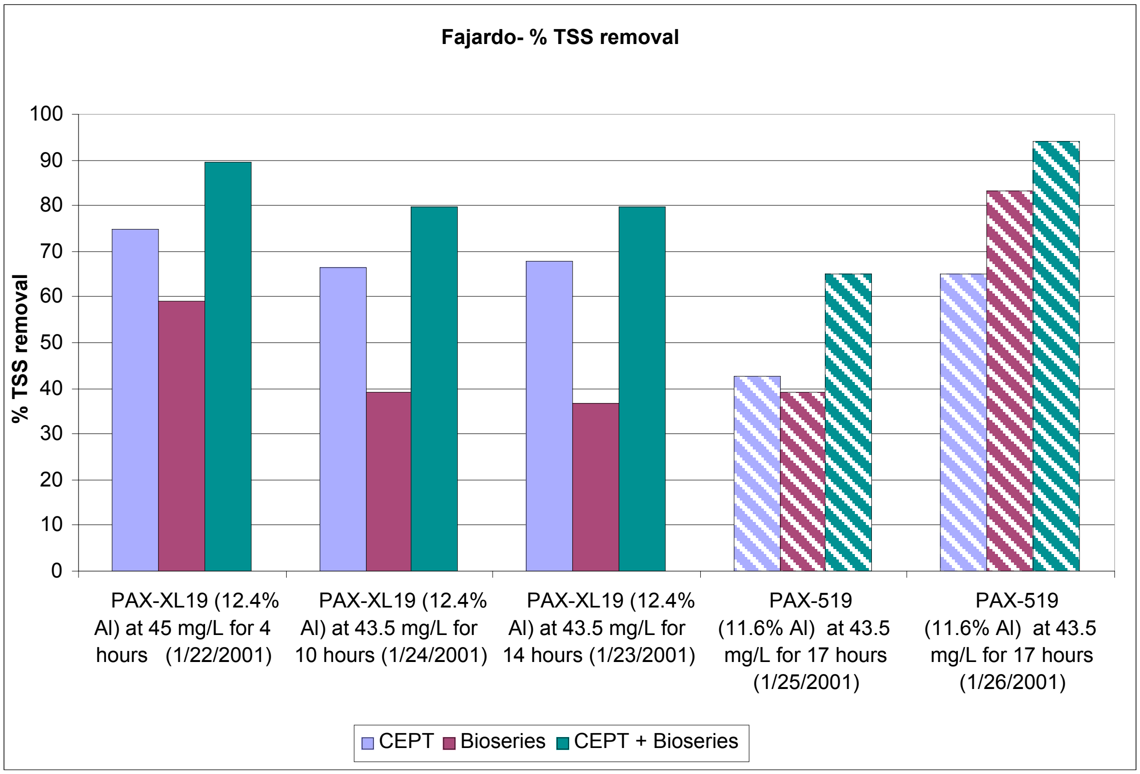


Figure 13: Fajardo %TSS Removal

The combined removals of the CEPT and bioseries again show that the use of PAX-XL19 removes TSS as well if not better than the PAX-519. The only reason that the PAX-529 would appear to perform better is the gain it receives from a good performance by the trickling filter. This is the same scenario that occurred with the BOD removals.

3.2.3 Total Phosphorus

For Total Phosphorus (Total P), there are five significant days. The first three days were the addition of PAX-XL19 at concentrations of about 43.5 mg/L, and the final two days were the addition of PAX-529 at 43.5 mg/L. The days of the experiment were quite similar, only variations in time or chemical used are different between the days. Figure 14 shows the data that was collected for phosphorus removals in the primary clarifier using chemicals and the trickling filter.

When examining the days when PAX-XL19 was added, it seems to show that Total P removal in the primary clarifier decreases with an increased time of addition. The variation of these removals is about 14%. The best removal, when PAX-XL19 was added for four hours at a slightly higher dosage, is 62%. This value is within the expected range for CEPT applied to a primary clarifier. The other two days of PAX-XL19 have removals are close to the observed values for Total P removals from CEPT. The days when PAX-519 was added showed a percent removal in the primary clarifier that is well below the observed values for CEPT.

The values for Total P removal in the trickling filters are quite low, but it should be noted that trickling filters are not expected to remove much phosphorus. One curious observation is that the Total P data for the trickling filter does not seem to follow the pattern that is seen with BOD. The effectiveness of the trickling filter to remove phosphorus is increased with increasing primary clarifier Total P removal.

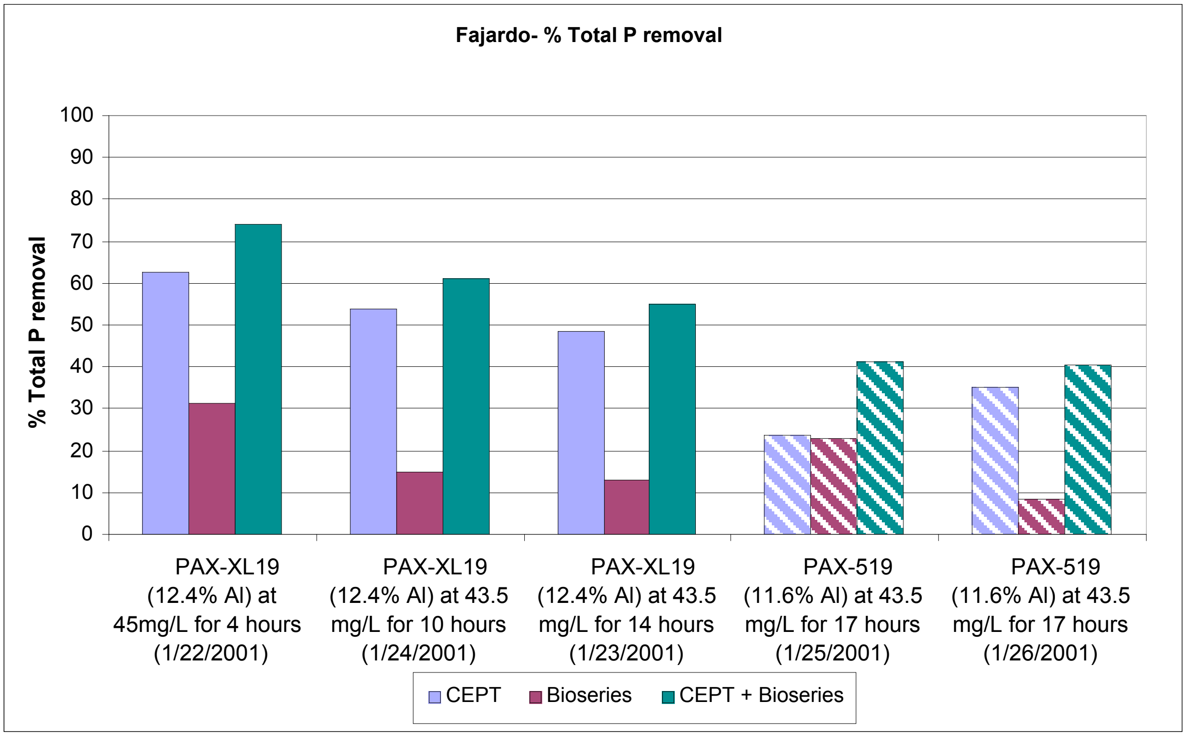


Figure 14: Fajardo- %Total P removal

When examining the combined removals for CEPT and the bioseries, it is evident that the PAX-XL19 works much better than the PAX-519. The only curious trend is the decrease in Total P removal with an increase in the time that the chemical is applied.

3.2.4 PAX-XL19 v. PAX-519

To examine the effectiveness of PAX-XL19 and PAX 519, the day when PAX-XL19 was added for 14 hours is compared to the average values for the days when PAX-519 was added for 17 hours. In terms of the performance of the chemicals in the primary clarifier, PAX-XL19 always works better than PAX-519. The difference in BOD is only a few percent, but both TSS and Total P vary by at least 14%. When examining the data for the overall performance of plant under the two chemicals, the results are very similar. The main difference is in the Total P removal, and in this case the PAX-XL19 clearly removes more of the phosphorus. One reason for the difference in performance is the aluminum content of the two chemicals. Since the metal is what promotes coagulation, a lower metal content would give lower removals. With this in mind, a higher dosage of PAX-519 should give results similar to those of PAX-XL19. Since a higher dosage in all probability costs more, the better chemical to use at Fajardo is PAX-XL19.

	Primary Clarifier, PAX-XL19	**Primary Clarifier, PAX-519**
BOD	44%	40%
TSS	68%	54%
Total P	48%	29%

Table 3: Comparison of PAX-XL19 and PAX-519

3.2.5 Summary

The use of Chemically Enhanced Primary Treatment would be beneficial to the Fajardo Wastewater Treatment Plant. The use of chemicals in the primary clarifier brings the percent removals to well above the conventional removal in a primary clarifier. In the primary clarifier, the use of PAX-XL19 gives results close to what would be expected with CEPT, and the values are similar to what Orange County California is achieving (County Sanitation 1993). The numbers for PAX-519 are not as close, and in general are only around conventional values for no chemicals.

Primary Clarifier	**Conventional** (Metcalf & Eddy 1991)	**Typical CEPT** (Harleman 2000)	**Orange County, CA** (County Sanitation 1993)	**PAX-XL19**	**PAX-519**
BOD	30%	55%-65%	42%	44%	39%
TSS	60%	75%-85%	75%	68%	54%
Total P	30%	55%-85%	N/D	48%	29%

Table 4: Comparison of Conventional, CEPT, PAX-XL19 and PAX-519 Removals for Primary Clarifiers

The trickling filters at Fajardo seem to performing well. The chemicals do not lower the removal of BOD out of conventional design range. The TSS removed is quite high, even higher than Orange County. A point to notice is the PAX-XL19 has a smaller removal than the PAX-519. This is most likely because there is less to remove in the PAX-XL19 case, since the removals in the primary clarifier are much higher.

Trickling Filter	**Conventional** (Metcalf & Eddy 1991)	**Orange County, CA** (County Sanitation 1993)	**PAX-XL19**	**PAX-519**
BOD	60%-80%	85%	70%	80%
TSS	33%	44%	37%	61%
Total P	none	N/D	13%	16%

Table 5: Comparison of Conventional, PAX-XL19 and PAX-519 Removals for Trickling Filter Series

3.3 Conclusion

The use of CEPT does not appear to hinder the operation of either the primary clarifier or the trickling filter. For the primary clarifier, it appears that the use of CEPT increases the removals of total suspended solids, biochemical oxygen demand, and total phosphorus. For Fajardo the use of CEPT ensured the performance of the primary clarifier was above the conventional removals. This was not the case at Vega Baja, but the use of CEPT increased the performance from 8% removal to 47%. At both plants, the removals of TSS with CEPT in the primary clarifier are below typical values seen. In terms of BOD, the use of CEPT in the primary clarifier ensures that the removal of BOD is above what is expected with conventional primary clarification. At Vega Baja, it worked so well that the removal seen, 65%, is about as high as CEPT typically gives. In Fajardo the BOD removal did not achieve the levels typically seen with CEPT, but the numbers seen are similar to Orange County, CA, which is a WWTP with a similar design(County Sanitation 1993). Total phosphorus values in the primary clarifier are not as good as expected with CEPT, but the use of CEPT guarantees that the primary clarifier removes more Total P than is expected with conventional primary clarification

The effects of CEPT on the trickling filter are related to the performance of the primary clarifier. At both WWTPs studied, the trickling filter appeared to remove more BOD when the primary clarifier less BOD. This is logical because the trickling filter uses the organics in the water to grow and survive, thus lowering the BOD. It was also seen at both plants that the increased removal of TSS in the primary clarifier allows the trickling filter to remove more TSS. The same pattern emerged for Total P at Fajardo.

The effects of CEPT on the primary clarifier and the trickling filter are positive. The trickling filter rarely performed below conventional design. This was true for the primary clarifier as well, unless it was performing poorly in the first place. In fact both pieces of equipment usually performed better than conventional design with the use of CEPT. Using CEPT in a plant with a primary clarifier followed by a trickling filter will not hinder the performance of the plant and will usually enhance it.

Chapter 4 - Compliance

4.1 Results and Analysis

4.1.1 Vega Baja

The benefits of CEPT at Vega Baja can be seen when examining the influent and effluent values of the wastewater treatment plant, which are shown in figures 14 and 15. It is important to note that the effluent values in this section are taken from the effluent for the entire plant, i.e. both the primary clarifier – trickling filter train and the package activated sludge plant (Fig. 7). For the following analysis it is safe to assume that the package plant operates at a constant removal rate, as it is unaffected by the chemical addition. Without chemicals the plant is able to bring the effluent BOD concentration down from 186 to 27.4 mg/L, which is an 85% removal. When chemicals are added, for

9 hours, the effluent BOD concentration drops from 143 to 12.5 mg/L; this is a 91% removal. The EPA limit for BOD in the effluent of the plant is 5 mg/L, which was not achieved during the testing. It seems though that a higher dose (30 to 40 mg/L) running for 9 hours should bring the effluent value of BOD very close if not under the strict EPA limit of 5 mg/L.

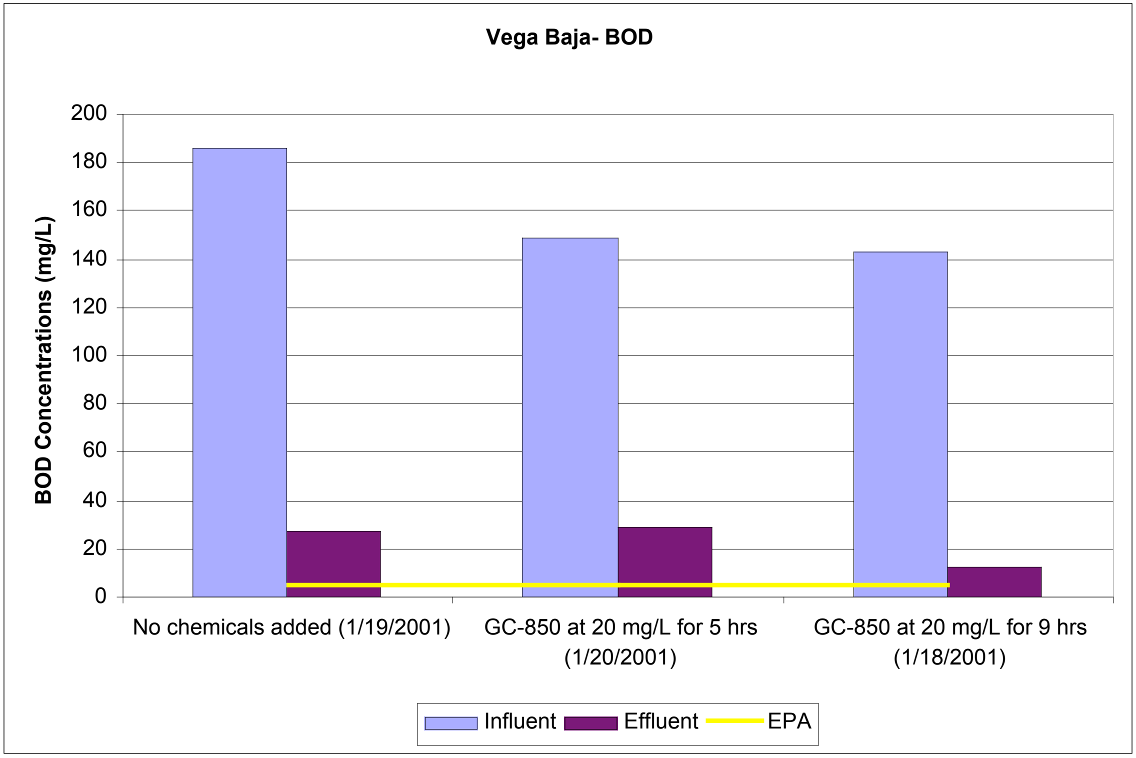


Figure 14: BOD Influent and Effluent Values for Vega Baja

When examining the influent and effluent values for TSS at Vega Baja, it is clear that the plant is in compliance with the EPA limitations of 30 mg/L. On the day when no chemicals are added, the TSS is lower than some of the days when CEPT is added. This is not what was expected, and its cause is unclear. Perhaps it is a byproduct the resuspended sludge, or perhaps the cleaning of the trickling filter affected the removal efficiency. There is a slight positive effect on the days when 20 mg/L of GC-850 was added: the plant was able to remove 90% of the TSS, and on the no chemical day, 86% of the TSS was removed. However, this small difference is statistically insignificant.

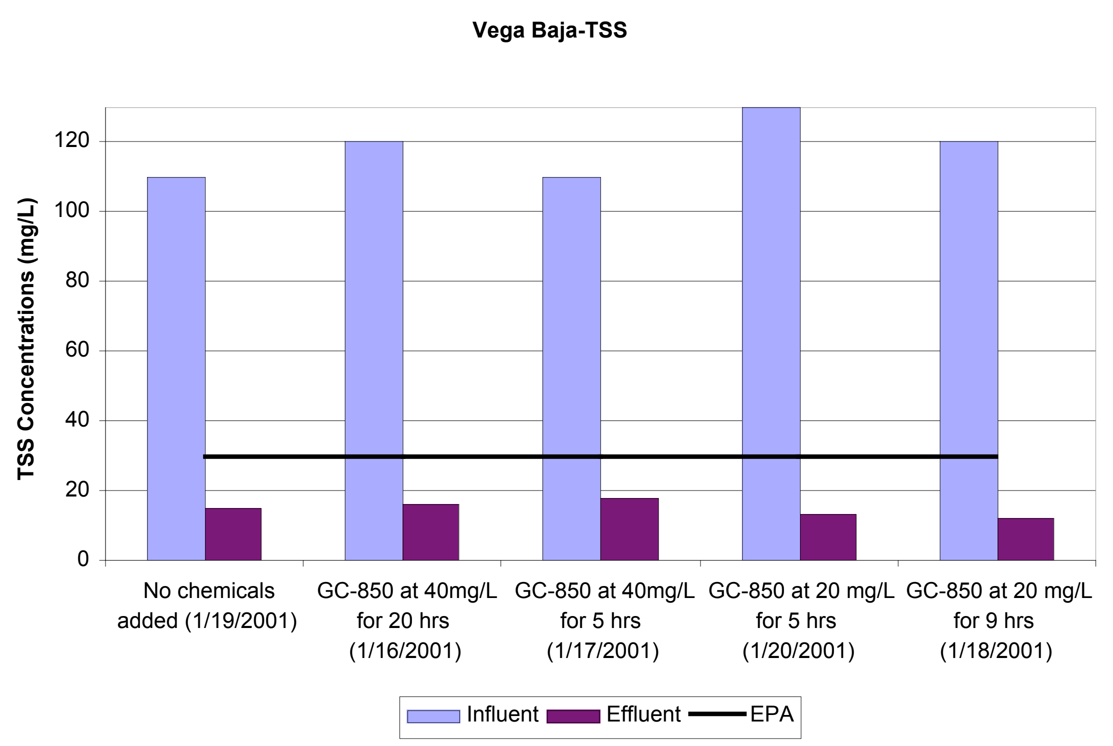


Figure 15: TSS Influent and Effluent Values for Vega Baja

Overall the use of CEPT at Vega Baja seems to be a success. The effluent values are very close to if not under the EPA guidelines set. It is probable that a dose of 40 mg/L running for 9 hours each day could lead to removals that meet the 5 mg/L BOD standard, but this should be investigated further.

4.1.2 Fajardo

When examining the influent and effluent values, it is seen that the effluent values of BOD, shown in figure 16, are all well bellow the EPA limit of 28 mg/L. The lowest effluent value is 10 mg/L when PAX-XL19 is added for 14 hours, but the highest percent removals, around 96% are seen from both PAX-XL19 and PAX-519.

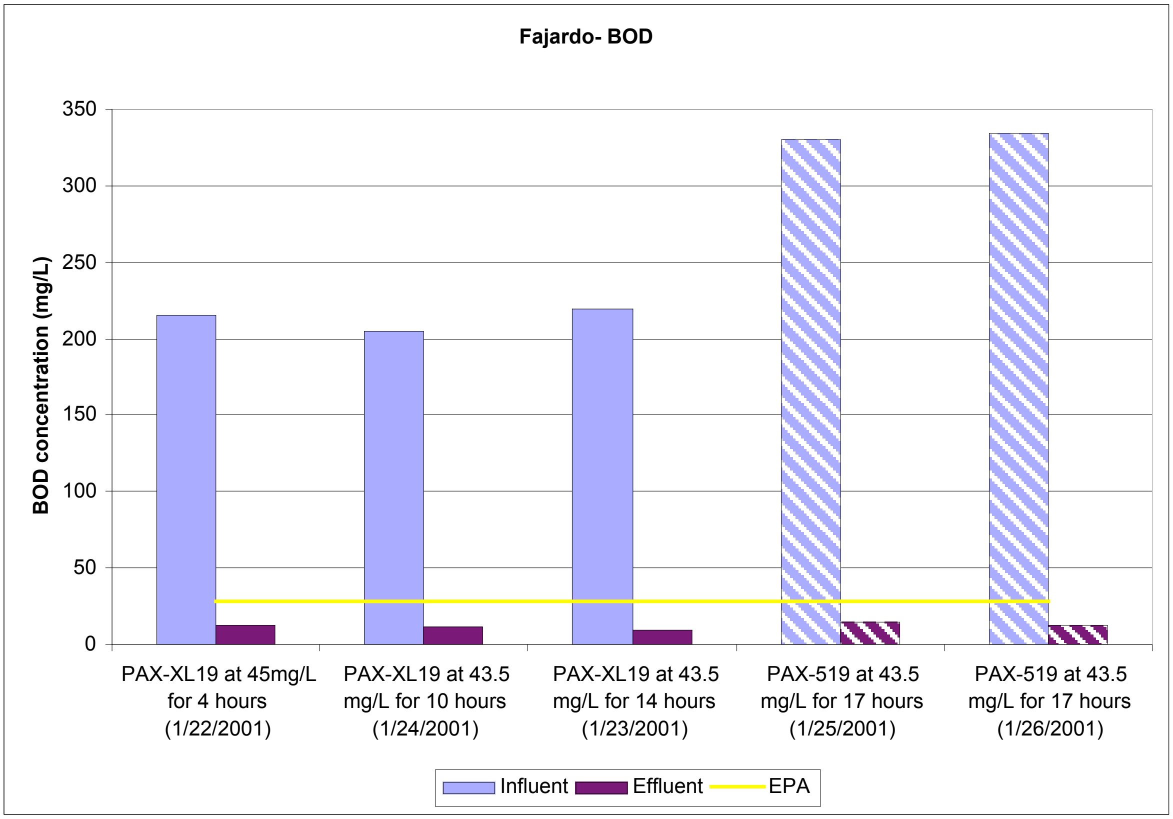


Figure 16: BOD Influent and Effluent Values for Fajardo

In examining the influent and effluent values for Fajardo's TSS removal, which are shown in figure 17, it can be seen that all effluent levels are below the EPA limit of 30 mg/L. Overall the percent removal of the plant for TSS is around 95% when any chemical is used for more than 14 hours. Fajardo has not had a big problem in the past meeting the TSS standards set by the EPA; it was only out of compliance 2 months in 2000.

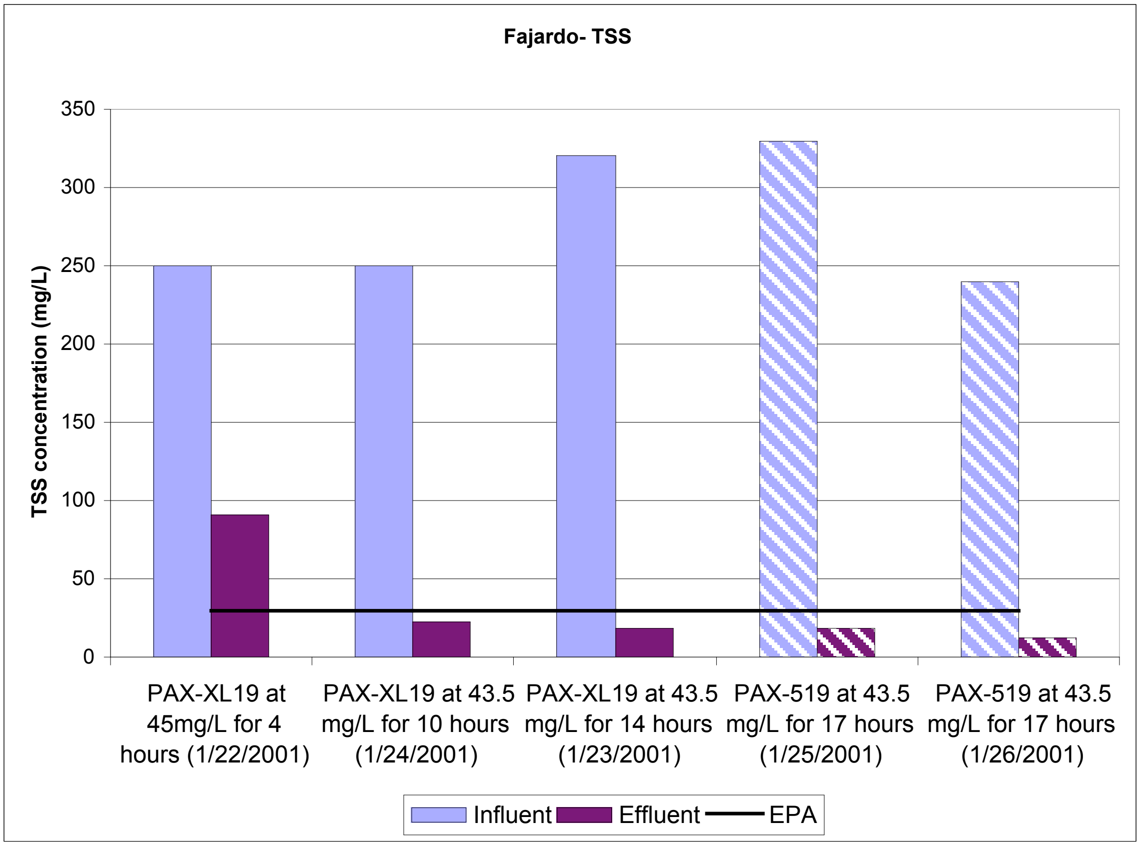


Figure 17: TSS Influent and Effluent Values for Fajardo

When examining the influent and effluent values for Total P at Fajardo (Figure 18), it is clear that all values are well below the EPA limit of 7.5 mg/L. Not only are all of the effluent values well below this limit, but often the influent values are below the EPA limit as well. Fajardo did not seem to have a problem meeting the EPA limit in 2000; it was never out of compliance. In terms of percent removals, the biggest is seen with PAX-519, but that is the only day when the influent value was above the EPA limit for the effluent. Overall the highest removal rate was achieved with PAX-XL19.

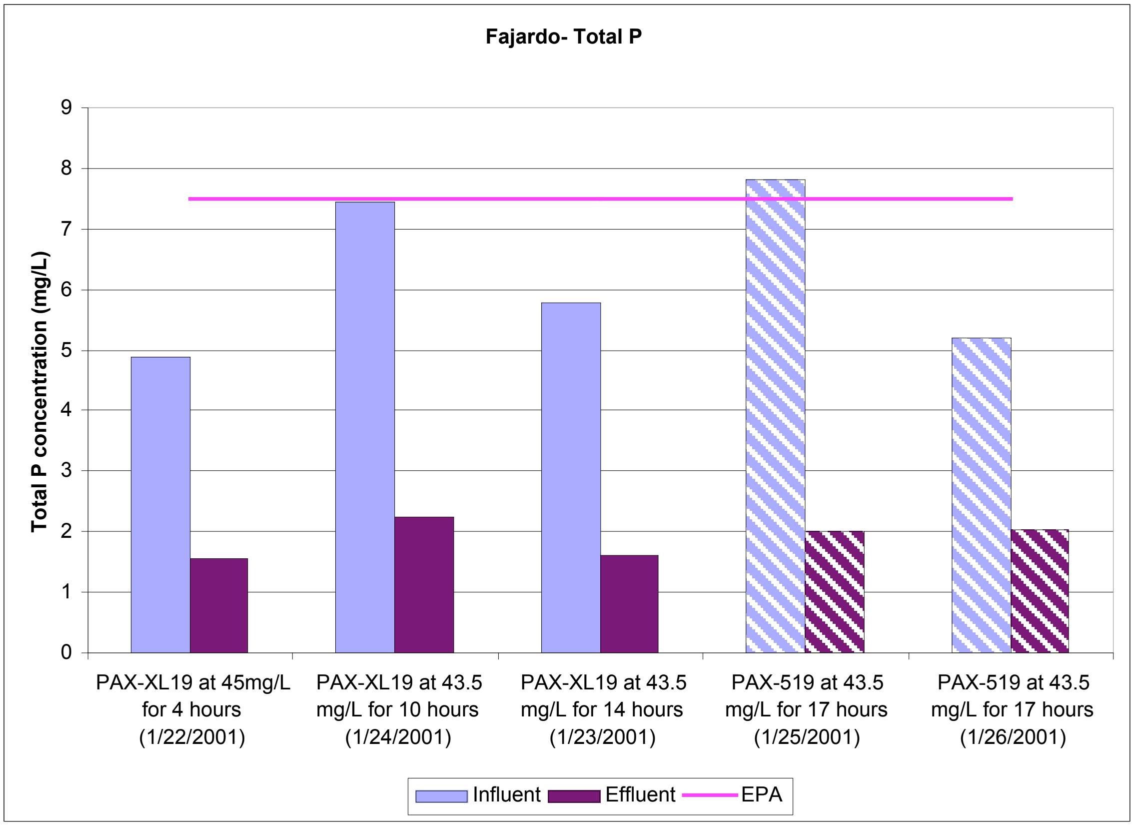


Figure 18: Total P Influent and Effluent Values for Fajardo

4.2 Cost Analysis

4.2.1 Vega Baja

The cost of GC-850, the suggested chemical to be used in Vega Baja Wastewater Treatment Plant is $0.35 per pound. If the chemical were dosed at 20 mg/L for 9 hours per day, the cost for one day of operation would be $22. This same dosage and time of dosage would only cost about $8,000 per year. If the dose were increased to 40 mg/L, the cost would increase to $44 per day or $16,000 per year. This is a small price to pay for the results seen in this experiment.

4.2.2 Fajardo

The cost of PAX-XL19, the chemical recommended for use at the Fajardo Wastewater Treatment Plant (Otero and de Varona 2000), costs $0.33 per pound. At the recommended dosage of about 40 mg/L the cost for one year of chemical addition is approximately $30,000. Not only does this chemical perform better, it also costs less. The PAX-519 costs $0.45 per pound or roughly $40,000 per year.

Even though PAX-519 was performing adequately, PAX-XL19 can achieve compliance at a lower cost. Given its lower expense and better performance, especially in terms of total P reduction, PAX-XL19 is clearly the better chemical for Fajardo.

4.3 Recommendations

4.3.1 Vega Baja

Testing at Vega Baja showed that the use of Chemically Enhanced Primary Treatment would be beneficial to the wastewater treatment plant in reducing the total suspended solids and biochemical oxygen demand in the effluent. The chemical that is recommended is the aluminum chlorohydrate compound GC-850, and it should be added to the splitter box to insure proper mixing. The dosage of this chemical needs to be investigated a bit further. The chemical was used at a dose of 20 mg/L, but the effluent concentration of BOD was not below 5 mg/L, which is required by the WWTP's NPDES permit. The chemical was tested at this low dose because there was a problem with floating sludge. It is the opinion of this team that the floating sludge was caused by the sludge not being removed at all times while the chemical was running. Also, if the chemical is only added from 7:30 am to 3:30 pm, the dosage could be increased to 40 mg/L, the original dose the team tried.

It is possible that Vega Baja could benefit from applying CEPT to both the trickling filter chain and the activated sludge chain. In Orange County, California this is the current practice. They were able to improve the performance of their activated sludge processes as well as their trickling filter series. By doing this, Orange County was able to achieve BOD effluent values under 5 mg/L (County Sanitation 1993), which is the requirement for Vega Baja. If all of the flow is diverted to the primary clarifier, and the flow is then split between the activated sludge pant and the trickling filters, it could bring the entire WWTP into compliance with its NPDES permit, including the very low BOD effluent concentration requirement. That the clarifier could handle the flow of the entire plant is feasible; experience with CEPT in California indicates that the primary clarifier could handle two to three times the flow with increased removal rates if implemented properly.

The team also recommends that jar tests be performed with composite samples of water from the WWTP. While Otero and de Varona performed jar tests in their initial testing, they used grab samples because composite samplers were not available (Otero and de Varona 2000). Composite samples provide a better representation of the wastewater stream of a plant over the course of a whole day. Also, another aluminum-based chemical was recommended by the chemical manufacturer and should be tested. This chemical is supposed to "settle better" than the GC-850 and the company recommends it for wastewater treatment (Medina 2001). Jar tests should also be performed to find the optimal dosage of the final chemical chosen.

After jar tests have been completed or while they are being performed, it is recommended that the samples be analyzed for total phosphorus as well as total suspended solids, biochemical oxygen demand, and the appearance of floating sludge or how quickly the particles settle. CEPT has been shown to be beneficial in removing up to 85% of the Total Phosphorus in wastewater, and should be effective here for

Phosphorus removal. In choosing the proper chemical for Vega Baja all three of these parameters should be considered.

In terms of equipment and maintenance, there are a few things that need to be fixed or implemented. Much of the pretreatment at Vega Baja was broken; the WWTP operators were working on fixing the problems. It is also recommended that the WWTP invest in roofs for the sludge drying beds. Roofs would keep the rain from rewetting the sludge, thus allowing the sludge to be held in the drying beds for a shorter time. If this link in the sludge chain is changed, the WWTP should be able to handle any extra sludge from CEPT. Another recommendation is for the plant operators to use the filter press for sludge processing. This would remove some of the water from the sludge. Again this would mean that the sludge would spend less time in the drying beds.

Another recommendation is that the sludge pump be fixed so that it can run constantly. This would allow a continuous chemical addition, which would lead to higher removal rates. Until the pump can be fixed, a timer should be installed with the chemical pump. A time can be set to turn on at 7:30 am and off at 3:30 pm; the plant operators wouldn’t have to turn the chemical on and off everyday. Finally the team recommends that a flow meter/chemical pump combination be installed. The chemical/chemical pump combination would be used to adjust the amount of chemical being added to the waste stream based on the flow. This assures that the proper dose is being applied no matter the flow.

The other recommendation that the team has is to provide CEPT specific training for the plant operators. This is necessary because the plant operators will be the people who see the effects of CEPT on the WWTP and should be prepared to fix any problems that may occur. In Vega Baja the plant operators did not want to see any film or scum on the surface of the primary clarifier. With CEPT they must accept a small amount and know how to handle large amounts. The plant operators knew how to handle the large amounts of scum by breaking it up with water and turning off the chemical. The plant operators also need to know how to tell if the CEPT dose is being effective. A quick test of either TSS or COD, which can be done with a testing kit, in the effluent would let the operators know if the dose was working well. These tests do not necessarily have to be performed daily, but should be performed weekly. This allows the plant operators to have some control over the dosing of the chemical into the WWTP that they operate.

4.3.2 Fajardo

At the Fajardo WWTP, two different aluminum chlorohydrate chemicals were tested, PAX-XL19 and PAX-519. It is the opinion of this team that the WWTP use PAX-XL19. Not only is it cheaper, but the results also show that it also performed better than PAX-519. PAX-XL19 should be applied to the WWTP at a dose of 44 mg/L from 6:30 am to 11:30 pm. The point of application should be in the splitter box where the water flows toward the primary clarifier.

Most of the pretreatment at Fajardo as well as the anaerobic digester was broken and needs to be repaired as soon as possible. Currently all primary sludge produced is being pumped into the anaerobic digester of a package plant. Because the use of CEPT increases the amount of primary sludge, a functioning anaerobic digester for the primary clarifier would prevent overloading the anaerobic digester in the package plant. It also would allow the sludge to be removed from the primary clarifier more rapidly.

While the team was working at Fajardo, the biota on the trickling filter died. This happened when the plant operators stopped the arms to perform maintenance on the motor. The day was very hot and the arms were stopped for a couple of hours. If possible the plant operators need to minimize the time that the arms are stopped. For trickling filters to work properly the WWTP’s waste stream be applied continually to keep the biological growth alive. If it is not possible to stop the arms for shorter times, the maintenance on the motor should not be done during the hottest part of the day or on extremely warm days.

Another recommendation is to install a flow meter/chemical pump combination at the point of chemical dosing. The flow at Fajardo is very variable. There were times when we were at the WWTP at 10 or 11 am and there was no flow in the splitter box. If a constant rate of chemical dosing is applied, the primary clarifier could be receiving far too much chemical at some points, and too little at others. The flow meter would measure the flow and the chemical pump would adjust to keep a constant dose of 44 mg/L. If the flow meter/chemical pump equipment is installed, the proper dose of chemical would always be applied.

The plant operators at Fajardo were more open to applying CEPT at their WWTP. A small amount of floating scum on the top of the primary clarifier did not bother them. This could have been because chemicals had been used at this WWTP before we arrived. Still they were not completely used to the idea of using chemicals and the problems that could happen. The plant operators were quick to blame the chemical for any problems with the trickling filter. When the trickling filter died because the arms were stopped for maintenance on the motor, the plant operators were sure that the chemical had killed the trickling filter. When the plant operators thought that the chemical was the problem, they quickly turned off the chemical and samplers. They need to not assign blame to the chemical without examining other possibilities. This would come with a little training on what kind of problems are likely to happen with the chemical and experience with using the chemical.

Jar tests should also be done at Fajardo periodically to make sure that the chemicals are working properly and at the proper dose. Kits that test the influent and effluent for TSS or COD would be an easy way for the plant operators to monitor the daily performance of the chemicals. Jar tests performed on a weekly or monthly basis would insure the dose is proper for the conditions of the influent.

4.3.3 How to pick a chemical and test it

Chemically Enhanced Primary Treatment is a technique that could be applied to many of Puerto Rico's poorly performing WWTPs. It would save in large capital investments to add additional "package plants" or build other treatment alternatives at the WWTP. For this reason the team decided to include a procedure on how to choose a chemical for wastewater treatment and how to implement it on a full-scale basis. The following section is adapted from Harleman and Murcott 1992.

4.3.3a How to choose a chemical

Choosing a chemical is typically done with jar tests, which consist of using one-liter jars and mixers. The test should use composite samples of wastewater taken from the entrance to the primary clarifier, or wherever the chemical is to be applied. The wastewater samples should be taken at several times throughout the day to account for any changes in the influent. The wastewater should be well mixed and divided among the 6 jars.

The next step is to choose the mixing intensity for the testing. This depends on where the chemical is to be added. If the location is the aerated grit chambers, the mixing intensity should range from 80 to 100 rpm. If the pumps are the selected location, a mixing intensity of 100 to the maximum the mixer can handle is appropriate. A mixing intensity of 40 to 60 rpm should be used if the chemical is to be added in piping with elbows and 20 to 40 rpm if it is added to piping with no elbows. Finally, if the chemical is to be added to the influent channel into the sedimentation tanks, the mixing intensity should be 20 rpm.

The first part of the jar testing should just be used to eliminate chemicals that obviously do not work for the wastewater. This can be done with visual indicators such as clarity, rate of floc formation and settling, size of floc, and amount of floating solids. Once this is done a more detailed test with each chemical that appears to work will be performed. The details of how long to mix during the testing follows.

As soon as the chemicals are added, the initial mixing should begin. The mixing should continue at the maximum intensity of the mixer for 30 seconds to insure proper mixing. The mixing intensity should then be reduced to the appropriate rate, and the jars should be allowed to mix for 2 minutes. If the use of a polymer is desired, it should be added at this point, and the mixing intensity should be increased to the maximum of the mixer for ten seconds to allow for proper mixing of the polymer. If there is no polymer this step can be skipped. Next the mixing intensity should be decreased so that it is 80% of the original value and the water should mix at this slow speed for an additional three minutes. Finally the mixer should be turned off and the jar should be left alone for five minutes.

Once chemicals have been eliminated, a more detailed analysis of each chemical can be done. The jars need to be labeled depending on the concentration of the chemical being tested. The first jar should be the control, with no chemical being added. The next five jars should have increasing concentrations of the chemical. For initial jar tests, the chemical concentration should be incremented by 20 mg/L, ranging from 20 mg/L to 100 mg/L. The chemicals should be diluted before addition so the final concentration is as labeled on the jar. The mixing should follow the same procedure as for the initial screening of chemicals.

After these steps are completed, analysis can be performed on the final supernatant. Visual parameters such as clarity, rate of floc formation and settling, size of floc, and amount of floating solids can be used to eliminate certain chemicals and dosages. Actual tests of turbidity, TSS, COD, and orthophosphate can provide definition between concentrations of the same chemical or two chemicals that appear to work similarly. Using COD is recommended because it is a much quicker test than BOD, and the percent removals of COD are about the same as for BOD. If it is desired, the jar tests can be repeated with smaller increments in the concentration once a rough estimate of the concentration is known.

4.3.3b Full-Scale Testing

Once the laboratory optimal concentration is determined, the full-scale testing can begin. The chemical should be added at the desired concentration with a chemical pump, usually supplied by the chemical manufacturer. The chemical should be applied for at least a few days to allow the system to adjust to the chemical. While this process is going on, composite samplers should be placed at least before the chemical addition and after the primary clarifier. The wastewater taken from these samplers should be tested for TSS, COD or any other parameter desired. This will allow a quick picture of if the chemical is working as well as predicted and if the dose needs to be changed. It is recommended to test the influent and effluent of the WWTP for these same parameters to see if the overall reduction with CEPT is satisfactory. If the CEPT is working as desired, but the WWTP effluent is not satisfactory, composite samplers may be set up to see if there are problems with other parts of the WWTP. If after a few days, the effluent levels are not acceptable, the chemical dose should be adjusted.

Chapter 5 - Further Studies

5.1 Seawater Addition

One developing technology that may be of interest in Puerto Rico is the use of seawater and seawater derivatives in wastewater treatment. The effect was discovered when unusually high tides caused seawater to flow into the influent of the VEAS WWTP in Norway. The higher quality effluent was discovered, and ever since the plant has been actively adding 2-3% seawater to the waste stream. In lab tests this addition of seawater at a constant iron dose produced the maximum phosphorus removal. No extra sludge or corrosion was produced by this addition (Sagberg et al 1990). This technique is especially effective when used in combination with CEPT, and has been shown to work with both ferric chloride and aluminum chloride coagulants. Seawater addition could be especially useful in Puerto Rico as a large fraction of the island's sewage is treated in six large CEPT-only plants (average flows between 8 and 45 MGD) with ocean outfalls. There are several benefits of adding seawater to sewage in the treatment process, most importantly increased phosporus removal. Other benefits include the reduction of heavy metals. Mechanistically these benefits are the product of seawater's magnesium ions, which lead to coagulation of various species. One study used seawater liquid bittern, a form of seawater with magnesium ions concentrated by a series of evaporation pans, to achieve greater than 90% removals for cadmium, chromium, lead, mercury, nickel, and zinc, and between 70 and 90% removals for arsenic, copper, and nickel (Ayoub et al 2001). While these are preliminary lab results, they look promising for future techniques that could be applied to treatment plants with heavy metals in their influent. Another pilot plant study used 9-10% seawater in digester sludge dewatering liquor to achieve 70% P-removal and recover struvite granules which could be used as fertilizer (Matsumiya et al 2000). Again this is only a pilot test, but the possible rewards of producing a utilizable fertilizer while treating wastewater are worth looking into.

The use of seawater in wastewater treatment processes seems particularly valuable to Puerto Rico since many of the plants are located on the coast and have easy access to seawater. Depending on a particular plant's location, seawater may also be cheaper than the additional chemical dosing required to achieve similar removal methods. One example of this on a large scale is Hong Kong. In Hong Kong toilets flush with seawater since freshwater is scarce leading to a sewage seawater concentration of roughly 20%. CEPT treatment in Hong Kong removed 75% BOD, 85% TSS, and 35% P with a relatively low dose of 10 mg/L ferric chloride (Harleman 2001). Although the concentration of seawater in the influent is higher in Hong Kong than might be practical in Puerto Rico, the possible benefits in removal efficiencies deserve further study.

5.2 Ferric Chloride vs. Aluminum Salts

In reading Otero and de Varona's report on their work in Puerto Rico, all of the chemicals recommended were aluminum salts. Because iron salts are traditionally used in wastewater treatment, the question came up of why aluminum salts were suggested for use in Puerto Rico. Apparently the plant operators in Puerto Rico were unwilling to try iron salts because they were of afraid of corrosive effects (Otero and de Varona 2000). This led to the question why do many of the wastewater treatment plants in the United States use iron salts if iron salts really do cause these problems. The answer is simple; iron salts give better removals as well as being cheaper even with the problems of corrosion.

Murcott (Murcott and Harleman 1992) surveyed several wastewater treatment plants in the United States for several factors including if the WWTP uses chemicals and what kind. Several WWTPs replied that they used Ferric Chloride or Alum at different dosages. Some of these WWTPs also reported the removals of BOD, TSS and Total P that they see between their influent and effluent. Examining this data showed one astonishing fact. The average percent removals between alum and ferric chloride for BOD and TSS are virtually identical, when these chemicals are added at doses typically seen in a WWTP. The average BOD removal was around 60% and the average TSS removal was around 75% for both alum and ferric chloride. The big difference was in the ability of the chemical to remove Total P; this is shown in figure 19. The WWTPs that used alum, at a dose typically seen in a WWTP, were only able to remove, on average, 62% of the Total P, while the WWTPs that used ferric chloride, at an average dose typical of WWTPs, were able to remove and average of 73% (Murcott and Harleman 1992). It seems that iron has a better chance at removing phosphorus from the wastewater than aluminum.

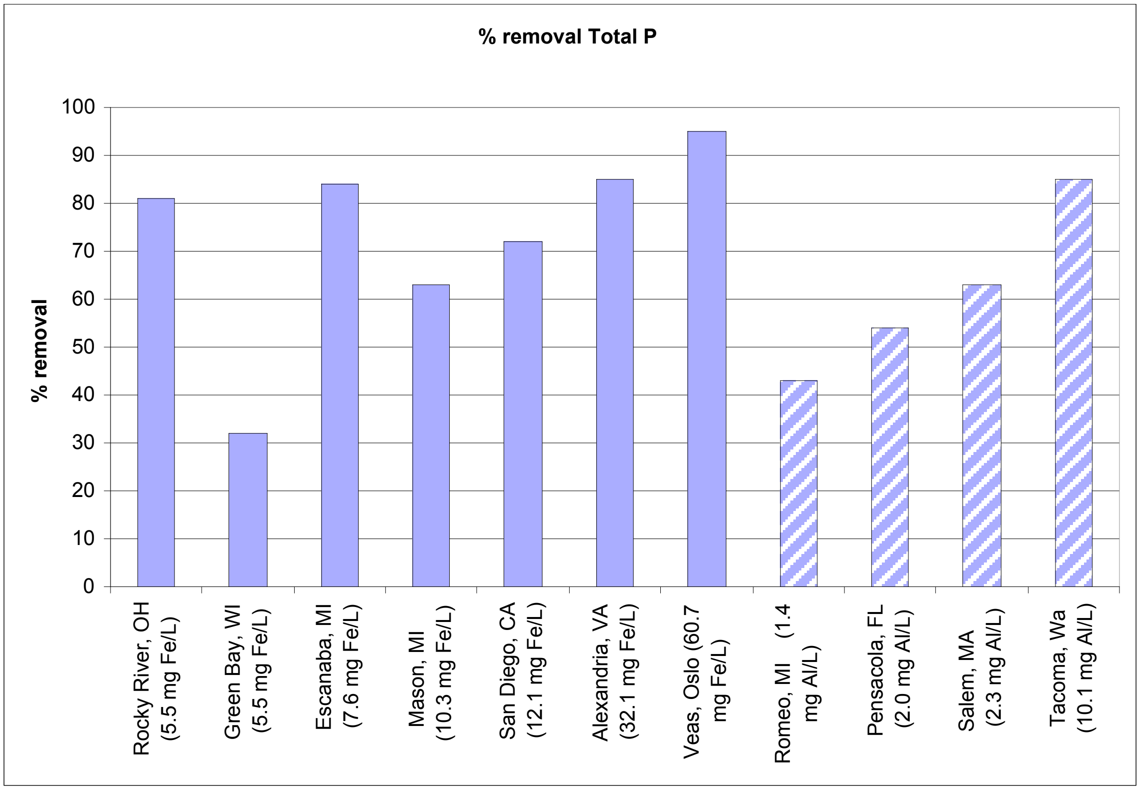


Figure 19: Total P Removal Based on Amount of Iron or Aluminum Used

Because the ferric chloride appears to remove phosphorus better than aluminum salts, this topic needed to be investigated further. First of all a search for any data on the amount of iron and aluminum required for certain removals of Total P was conducted. What was found was that on a mole-to-mole basis a higher amount of iron is needed to remove the same amount of Total P from the wastewater.

% Phosphorus Reduction	Mole Ratio Al:P	Mole Ratio Fe:P
75	1.4	1.3
85	1.7	1.9
95	2.3	3

Table 6: Mole Ratio of Metal Required for an Increased Total P Reduction (EPA 1976)

This is especially true for higher removals of phosphorus, as shown in table 6. It is interesting to notice that as a higher percent removal is desired, the amount of iron and aluminum required increases. If one examines the equations that describe how phosphorus is removed by metal salts, it would appear that one mole of metal should remove one mole of phosphate. There are several factors that influence how well these reactions work including alkalinity and final pH of the effluent, competing anions and cations such as sulfate, flouride and sodium, quantity and nature of the total suspended solids, intensity of mixing and microorganisms or other colloidal particles present (EPA 1987).

In comparing WWTPs that remove the same amount of Total P from Murcott's work, the WWTPs that use alum use a smaller metal dose, but must use a much higher dose of chemical (Murcott and Harleman 1992). This is because the metal content of the alum solution is much less than what is in an aluminum chlorohydrate solution. Table 8 below shows two sets of plants with identical %Total P removals but different metal salts.

WWTPs with Same %Total P removal	%Total P removed	Metal Dose (mg Me/L)	Concentration (mg/L)
Mason, MI (FeCl3)	63	4.1	30
Salem, MA (Alum)	63	2.2	50
Alexandria, VA (FeCl3)	85	12.6	93
Tacoma, Wa (Alum)	85	9.9	225

Table 7: Plants with the Same %Total P Removed and Metal Dose Required

One reason that ferric chloride is used so extensively in wastewater treatment plants in the United States is that it is much cheaper than aluminum salts. Ferric Chloride usually costs around $0.14/lb, while aluminum salts can cost around $0.35/lb. Using Murcott's numbers for the metal dose need to remove 85% of the Total P, a cost analysis for Vega Baja and Fajardo is performed and the results are shown in Table 8.

Plant	Chemical	Metal Dose (mg/L)	Chemical Dose (mg/L)	Cost of Chemical ($/year)
Vega Baja[a]	GC-850	2.2	18	$30,000
	FeCl3	4.1	30	$16,000
Fajardo[b]	PAX-XL19	9.9	80	$57,000
	PAX-519	9.9	85	$83,000
	FeCl3	12.6	92	$30,000

Table 8: Cost Analysis for Various Metal Salts
a. Flow is 1 MGD, chemical run for 9 hours
b. Flow is 1 MGD, chemical run for 17 hours

For Vega Baja, the cost of reducing Total P by 85% from the influent value using GC-850, the WWTP would have to spend around $30,000 per year. For the same results with ferric chloride the cost would be around $16,000 per year. The cost of using ferric chloride is much lower, saving $14,000 dollars, and this difference could offset maintenance associated with corrosion in the WWTP. For Fajardo to reduce the Total P by 85%, the use of PAX-XL19 would cost around $57,000 per year, and the use of PAX-519 would be about $83,000 per year. In contrast the cost of ferric chloride would be a little over $30,000 per year. Using the ferric chloride would save the WWTP at least $27,000 a year. This savings would most likely cover some if not all of costs associated with corrosion from the ferric chloride.

Talking with Jesse Paguiero, the plant operator at the Point Loma Wastewater Treatment Plant, gave a perspective as to why his WWTP uses ferric chloride. Point Loma is a WWTP in California that just uses chemically enhanced primary treatment, not any other treatment like trickling filters or activated sludge, to meet its NPDES permit standards. The WWTP has been using ferric chloride at a dose of 25 mg/L for the last several years. When asked directly about the corrosion that ferric chloride causes, he said that they had also had problems. They had to line the sediment basins with a nylon coating and have replaced pipes with ones that are resistant to iron corrosion. He also said that if they continually test the amount of ferric chloride used to make sure they are not overdosing, the amount of corrosion is reduced. When asked why another chemical was not used, Mr. Paguiero said that they tested other chemicals and never found one that worked better, for the price including corrosion problems, than ferric chloride (Paguiero 2001).

Puerto Rico should consider using ferric chloride in its wastewater treatment WWTPs. The main benefit of switching to ferric chloride is in the reduction of total phosphorus (Total P); on average ferric chloride is able to remove 10% more Total P than alum in actual WWTPs when the chemicals are used at typical dosages. The other benefit of using ferric chloride is the cost of using chemicals in the WWTPs. If the dosages in Murcott's work are applicable, using ferric chloride would save Vega Baja $14,000 per year and would save Fajardo $27,000 per year. While ferric chloride has its problems with causing corrosion in the WWTPs, the reduced cost more than makes up for any of the costs associated with the corrosion. If Puerto Rico wants to reduce its effluent Total P level and costs, it should consider the use of ferric chloride in its WWTPs.

If Puerto Rico insists on using an aluminum salt to remove phosphorus from wastewater, it should consider switching to a different aluminum compound. Jar tests using polyaluminum chloride (PAC) and aluminum chlorohydrate, the chemical used in Puerto Rico, show that the PACs perform much better than either alum or aluminum chlorohydrate, but the aluminum chlorohydrate performs worse than both alum and PAC (EPA 1987).

References

1. Ayoub, G. M.; Semerjian, L.; Acra, A.; El Fadel, M.; and Koopman, B. "Heavy Metal Removal by Coagulation with Seawater Liquid Bittern" *Journal Of Environmental Engineering.* Vol 127, No. 3, March, 2001

2. County Sanitation Districts of Orange County, CA. "Operations and Maintenance Department Monthly Report" October 1993.

3. Harleman, D.R.F.H and Murcott, S.E., Upgrading and Multi-stage Developmet of Municipal Wastewater Treatment Plants: Applicablility of Chemically Enhanced Primary Treatment. World Bank Report, 1992

4. Harleman, D.R.F.H. Personal Communication, April 2001.

5. Harleman, D.R.F.H.; Personal Communication, October 19, 2000

6. Hetherington, Michelle, Pamson, Gregg, and Ooten, Robert , Advanced Primary Treatment Optimization and Cost Benefit Documented at Orange County Sanitation District, *Water Environment Federation*, 1999

7. Lonely Planet Book for Puerto Rico, http://travel.yahoo.com/t/caribbean/puerto_rico/, December 8, 2000

8. Matsumiya, Y.; Yamasita, T.; and Nawamura, Y. "Pilot Plant: Using Seawater for Struvite Recovery" *Scope Newsletter* No. 39 September, 2000.

9. Medina, Juan; Gulbrandsen Chemical Company; Personal Communication; January 2001.

10. Metcalf & Eddy, Inc.; *Wastewater Engineering*, 3rd Ed. Boston, Irwin McGraw-Hill: 1991.

11. Murcott, S. and Harleman, D.R.F.H. Appendices to "Performance and Innovation in Wastewater Treatment" Technical Note # 36, Ralph M. Parsons Laboratory, Massachusetts of Institute of Technology, 1992.

12. Otero, L. and de Varona, M. Personal Communication, October 2001.

13. Otero, Luis, and de Varona, Marlena, Bench Scale Polymer Application/Full Scale Polymer Testing Research Project, September 2000

14. Paguiero, Jesse; Orange County Sanitation Department; Personal Communication; March 8, 2001.

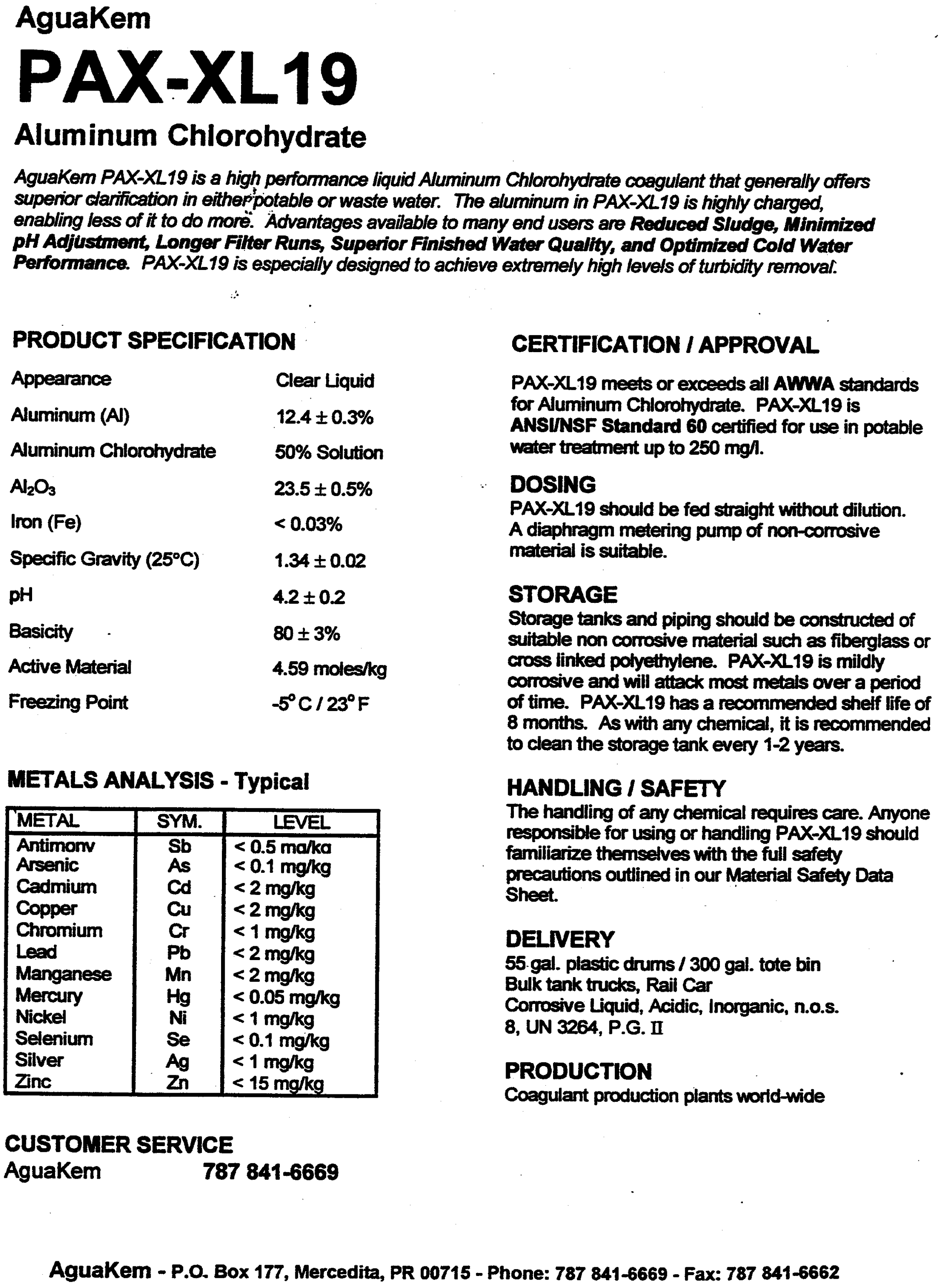
15. Puerto Rico Chamber of Commerce of South Florida , http://www.boricua.com/facts.htm, December 8, 2000

16. Sagberg, Paul; Saether, Ruth, and Berge, Astrid Baggerud. "Increasing the Surface Load at a Direct Precipitation Plant, VEAS, Norway" *Chemical Water and Wastewater Treatment*. Springer-Verlag 1990.

17. U.S. Environmental Protection Agency, *Process Design Manual for Phosphorus Removal*; Office of Technology Transfer; Washington, D.C. September 1987.

18. U.S. Environmental Protection Agency; *Process Design Manual for Phosphorus Removal*; Office of Technology Transfer; Washington, D.C. April 1976.

Appendix A – MSDS



AguaKem

PAX-XL19

Aluminum Chlorohydrate

AguaKem PAX-XL19 is a high performance liquid Aluminum Chlorohydrate coagulant that generally offers superior clarification in either potable or waste water. The aluminum in PAX-XL19 is highly charged, enabling less of it to do more. Advantages available to many end users are ***Reduced Sludge, Minimized pH Adjustment, Longer Filter Runs, Superior Finished Water Quality, and Optimized Cold Water Performance****. PAX-XL19 is especially designed to achieve extremely high levels of turbidity removal.*

PRODUCT SPECIFICATION

Appearance	Clear Liquid
Aluminum (Al)	12.4 ± 0.3%
Aluminum Chlorohydrate	50% Solution
Al_2O_3	23.5 ± 0.5%
Iron (Fe)	< 0.03%
Specific Gravity (25°C)	1.34 ± 0.02
pH	4.2 ± 0.2
Basicity	80 ± 3%
Active Material	4.59 moles/kg
Freezing Point	-5° C / 23° F

METALS ANALYSIS - Typical

METAL	SYM.	LEVEL
Antimony	Sb	< 0.5 mg/kg
Arsenic	As	< 0.1 mg/kg
Cadmium	Cd	< 2 mg/kg
Copper	Cu	< 2 mg/kg
Chromium	Cr	< 1 mg/kg
Lead	Pb	< 2 mg/kg
Manganese	Mn	< 2 mg/kg
Mercury	Hg	< 0.05 mg/kg
Nickel	Ni	< 1 mg/kg
Selenium	Se	< 0.1 mg/kg
Silver	Ag	< 1 mg/kg
Zinc	Zn	< 15 mg/kg

CUSTOMER SERVICE

AguaKem **787 841-6669**

CERTIFICATION / APPROVAL

PAX-XL19 meets or exceeds all **AWWA** standards for Aluminum Chlorohydrate. PAX-XL19 is **ANSI/NSF Standard 60** certified for use in potable water treatment up to 250 mg/l.

DOSING

PAX-XL19 should be fed straight without dilution. A diaphragm metering pump of non-corrosive material is suitable.

STORAGE

Storage tanks and piping should be constructed of suitable non corrosive material such as fiberglass or cross linked polyethylene. PAX-XL19 is mildly corrosive and will attack most metals over a period of time. PAX-XL19 has a recommended shelf life of 8 months. As with any chemical, it is recommended to clean the storage tank every 1-2 years.

HANDLING / SAFETY

The handling of any chemical requires care. Anyone responsible for using or handling PAX-XL19 should familiarize themselves with the full safety precautions outlined in our Material Safety Data Sheet.

DELIVERY

55 gal. plastic drums / 300 gal. tote bin
Bulk tank trucks, Rail Car
Corrosive Liquid, Acidic, Inorganic, n.o.s.
8, UN 3264, P.G. II

PRODUCTION

Coagulant production plants world-wide

AguaKem - P.O. Box 177, Mercedita, PR 00715 - Phone: 787 841-6669 - Fax: 787 841-6662

Appendix B – Chemical selection jar test results